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Insights in aging and public health: 2022

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Development and Validation of a New Simple Functional Score in the Older Chinese Population

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Background: Existing aging metrics incorporating cognitive and physical function are often not feasible for application in research and clinical practice. Therefore, this study aimed to develop and validate a new simple functional score based on self-reported cognitive and physical function in the older Chinese population.

Methods: The development sample included 3,929 older adults aged 60–95 years from the China Health and Retirement Longitudinal Study (CHARLS). The validation sample included 1,345 older adults aged 60–87 years from the Rugao Longitudinal Aging study (RLAS). Logistic regression models and receiver operating characteristic curves were used to examine the associations of the new functional score with all-cause mortality risk.

Results: Six items were selected to construct the new functional score in CHARLS. This functional score was associated with all-cause mortality risk, with an adjusted odds ratio of 1.10 (95% confidence interval = 1.07, 1.13). This functional score presented additional predictive utility beyond age and sex, as demonstrated by the significantly increased C-statistic, integrated discrimination improvement (IDI), and continuous net reclassification improvement (NRI) (all $P < 0.001$). Furthermore, this functional score was further validated in RLAS, such that adding the new functional score to a model of age and sex improved all-cause mortality risk discrimination (IDI = 0.036, $P < 0.001$; NRI = 0.485, $P < 0.001$). To facilitate the quick screening of the older population with deteriorations in cognitive and physical function, we introduced a publicly available online tool designed for this new functional score.

Conclusions: A new functional score based on six self-reported items was developed and validated in the older Chinese population, and was demonstrated to be a simple and practical tool to assess functional deterioration, showing good feasibility, and performance.

Keywords: aging, Chinese, cognitive function, mortality, physical function

INTRODUCTION

Aging is an irreversible and complex process of multi-system physiological dysregulation. To better assess the aging process, aging metrics incorporating biological or functional markers have been proposed. Functional metrics of aging usually comprise cognitive and physical function, reflecting individual health status in different domains of physiological function, and perform well in predicting downstream health outcomes including mortality (1, 2). Cognitive impairment ranges in severity from mild to severe due to the deteriorations in cognitive domains such as memory, learning, and/or executive function. Physical function refers to the capability to perform activities and is usually assessed by various subjective [e.g., basic activities of daily living [BADL] (3), instrumental activities of daily living [IADL] (4)] and objective [e.g., short physical performance battery [SPPB] (5), timed up and go test (6), grip strength (7), and gait speed (7)] tools. Physical frailty (PF) is a state of being vulnerable to stressor events due to the cumulative physiological declines in multiple systems (8, 9), contributing to the decline in physical function (10). PF usually affects mobility first, and further results in disability (8). Abundant evidence showed that the combined presence of cognitive impairment and PF contributes to a significantly increased risk of adverse outcomes (11–16).

There are at least three metrics that have incorporated cognitive and physical function in previous studies (17–19). The first one is cognitive frailty, which was defined as the coexistence of cognitive impairment and PF in non-dementia older populations, and proposed by an International Association of Gerontology and Geriatrics (IAGG) consensus group in 2013 (17). The second one is the frailty index (FI) that integrates cognitive and physical phenotypes into a single-dimensional index, reflecting cumulative health deficits (18). The third one is motoric cognitive risk syndrome (MCR), which was characterized by the concurrence of subjective cognitive complaints with slow gait speed in older adults without dementia and mobility disability, and proposed by Verghese et al. (19). Although these metrics are conceptually overlapping, they are different to some extent. More importantly, these metrics have some drawbacks. Measurements of both cognitive frailty and MCR require physical examination (e.g., measurement of gait speed), which is often not feasible in clinical practice. The FI comprises many items ($\geq$30 items) and requires extensive data collections, which hampers its application in research and practice. In addition, the cognitive function has equal weight as physical function in cognitive frailty, FI, and MCR. This might not be true in the real world. Given these limitations aforementioned, there is a need to develop a new simple metric with practical value by incorporating cognitive and physical function simultaneously.

Therefore, this study first aimed to develop a new simple functional score by integrating self-reported cognitive and physical function items and examine the predictive utility for all-cause mortality, in the China Health and Retirement Longitudinal Study (CHARLS). Additionally, we validated this new functional score in the Rugao Longitudinal Aging Study (RLAS), an independent dataset. To further facilitate the quick screening of the older population with deteriorations in cognitive and physical function, we introduced a publicly available online tool designed for this new functional score.

MATERIALS AND METHODS

Study Population

CHARLS is a nationally representative prospective cohort study of adults aged 45 years and above in China initiated in 2011/2012 and followed up every 2 years. As described elsewhere (20), the multistage probability proportional to size sampling strategy was adopted to identify participants through four stages according to their regions, urban or rural countries, and statistics on the gross domestic product. CHARLS has been approved by the Ethical Review Committee at Peking University and all participants provided written informed consent. The baseline survey (2011/2012) recruited 17,708 participants aged 45 years and older. Those who had disability in BADL ($N = 1{,}462$), or had the memory-related disease ($N = 103$), aged below 60 years ($N = 10{,}124$), or with missing data on demographic covariates ($N = 6$) and items for constructing aging metrics ($N = 2{,}084$) were excluded. Finally, 3,929 participants aged 60–95 years were included in this study.

RLAS is a community-based longitudinal study conducted in Rugao, Jiangsu Province, China (21). In 2014, RLAS recruited participants from 31 rural communities of Jiang'an Township, Rugao, according to 5-year age and sex strata. A total of 1,960 participants were recruited to complete questionnaires, physical examinations, and provided biological samples. The follow-up survey was conducted in 2016, 2017, and 2019 for repeated measurements of health status. Due to the data availability, we included 1,345 participants aged 60–87 years from the 2016 wave to validate the new functional score in this study. The Human Ethics Committee of the School of Life Science at Fudan University approved the RLAS. Written informed consent was obtained from all RLAS participants.

All-Cause Mortality

The death information in CHARLS was collected at the exit interview of each survey during follow-up. But the exact date of death was not available in the 2015 and 2018 waves. Therefore, we defined a binary variable to denote the occurrence of death within the 6-year follow-up since baseline.

The death information in RLAS was collected from the Funeral home of Rugao and Rugao Civil Affairs Bureau. The village or community doctors were responsible to investigate and validate the cause of death.

Covariates

Covariates in CHARLS including age, sex, residence, education, and disease count were collected at baseline. The residence was defined as urban or rural. Educational level was defined as illiterate, elementary school, middle school, high school, or college and higher than college. We counted the total number of chronic diseases (including hypertension, diabetes or high blood sugar, cancer or malignant tumor, chronic lung

disease, heart problems, stroke, kidney disease, stomach or other digestive diseases, arthritis or rheumatism, and asthma), and then classified disease count into 5 categories: 0 disease, 1 disease, 2 diseases, 3 diseases, and 4 or more diseases. Additionally, we measured depression by the 10-item Center for the Epidemiological Studies of Depression Short Form (CESD-10) (20). The summary score of CESD-10 ranges from 0 to 30, with higher scores indicating severer depressive symptoms during the last week.

Covariates in RLAS including age, sex, education, and diseases count were collected in the 2016 wave. Education level was defined as illiterate or literate (≥1-year education). We counted the total number of chronic diseases (including hypertension, diabetes, cancer or malignant tumor, chronic lung disease, heart problems, stroke, kidney disease, stomach or other digestive diseases, arthritis or rheumatism, and asthma), and then classified disease count into 5 categories as done in CHARLS.

Development of the New Functional Score

Building on the findings that cognitive frailty and FI performed relatively better in predicting all-cause mortality compared to another measure (22), we developed a new simple functional score that integrated cognitive frailty and FI. We ran a stepwise logistic regression model to identify candidate items from components of cognitive frailty and FI for predicting all-cause mortality. Then, the new score was calculated in four steps (23). First, we ran a multivariable logistic model that includes age, sex, education, and candidate items to estimate the effect of each item independent of potential confounders and other items. Second, we calculated the individual risk point for each item by dividing the corresponding regression coefficient with a single constant, which represents the regression coefficient for a 1-year increase in age with the risk of all-cause mortality. Third, we rounded the risk points to the nearest integers. Fourth, we calculated the composite score by summing the individual risk point for each candidate item of each participant. Considering that several self-reported diseases (e.g., chronic lung disease, heart disease) items were retained in the stepwise logistic regression models, we replaced them with one disease count variable. After carefully screening self-reported items for all-cause mortality prediction and their properties (e.g., reflect cognitive or physical function), we included one item for cognition and five items for physical function to develop the new functional score. Cognition was assessed by serial subtraction of 7 from 100 up to five times, with a score range from 0 to 5. Weight loss was defined as having a body mass index (BMI) of 18.5 kg/m^2 or less, or a self-reported weight loss of 5 kg or more in the past year. Chronic diseases included ten self-reported conditions as mentioned above. The total number of chronic diseases was calculated. We classified disease count into 5 categories: 0 disease, 1 disease, 2 diseases, 3 diseases, and 4 or more diseases. Limitations in running/jogging, walking, and climbing stairs were measured by asking participants whether they have difficulty in running/jogging 1 km, have limitations in walking 1 km, and have limitations in climbing several flights of stairs, respectively. The detailed scores for each item were presented in **Table 1**. The summary score (i.e., the new functional score) ranged from 0 to 20, with the higher score indicating worse function. The estimation of all-cause mortality risk for the functional score was presented in **Supplementary Table 1**.

TABLE 1 | Components of the new simple functional score in CHARLS.

Components	Construction		Person #1	
	Category	Risk points	Response	Points
Serial subtraction of 7 from 100	0	4	2	2
	1	3		
	[2, 3]	2		
	4	1		
	5	0		
Having a BMI of 18.5 kg/m^2 or less	No	0	No	0
	Yes	5		
Disease count	[0, 1]	0	2	1
	[2, 3]	1		
	≥4	2		
Limitations in running/jogging 1 km	No	0	Yes	3
	Yes	3		
Limitations in walking 1 km	No	0	No	0
	Yes	5		
Limitations in climbing several flights of stairs	No	0	Yes	1
	Yes	1		
	Total points	0–20	Total points	7
			Estimate of risk	0.063

CHARLS, China Health and Retirement Longitudinal Study; BMI, body mass index.

Statistical Analyses

All statistical analyses were performed using R version 3.6.3 (2020-02-29) and SAS version 9.4 (SAS Institute, Cary, NC). A P value of <0.05 (two-tailed) was considered statistically significant. We described characteristics of participants using mean ± standard deviation (SD) for continuous variables or number (percentages) for categorical variables.

We used 3 logistic regression models to examine associations of the new functional score with all-cause mortality risk in CHARLS. The odds ratios and corresponding 95% confidence intervals (CIs) were calculated. Model 1 was a crude model. Model 2 adjusted for age and sex. Model 3 additionally adjusted for residence and education. ROC curves were then used to evaluate the predictive utility of the new functional score for all-cause mortality risk. We calculated the delta C-statistic, integrated discrimination improvement (IDI) (24), and continuous net reclassification improvement (NRI) (24) in comparison to that of the basic model with age and sex. Delta C-statistic equals to x% means that the difference in predicted risks between the persons with and without the outcome increased by x% in the updated model. IDI equals to x% means that the difference in average predicted risks between the persons with and without the outcome increased by x% in the updated model. Continuous NRI equals to x% means that compared with persons without outcome, persons with outcome were almost x% more

likely to move up a category than down. With a given cut-off, NRI might be a better choice; otherwise, IDI may be preferred (24). Finally, we evaluated the associations of the new functional score with all-cause mortality in RLAS using the same analytic models above.

We performed several sensitivity analyses to test the robustness of our findings. First, to account for the influence of depression on the associations, we repeated the main analysis (i.e., testing the association of the new functional score with all-cause mortality risk) with additional adjustment for depression (assessed by CESD-10) based on Model 3 in CHARLS. Second, there were three existing metrics integrating cognitive and physical function in literature, and thus, we evaluated the predictive ability for all-cause mortality risk when adding the new functional score to a model including one existing metric (i.e., cognitive frailty, FI, or MCR), age, and sex in CHALRS.

RESULTS

The characteristics of the study participants in CHARLS are presented in **Table 2**. The mean age of the 3,929 participants in CHARLS was 67.4 ($SD = 6.3$) years. About 53.3% ($N = 2{,}102$) were males. The proportions of rural residence and illiteracy were 61.8% ($N = 2{,}427$) and 33.0% ($N = 1{,}296$), respectively. During 6 years of follow-up, 574 participants died (14.6%). In RLAS, the mean age of the 1,345 participants was 77.2 ($SD = 3.9$) years, and the proportion of males was 46.4% (**Supplementary Table 2**). During 3 years of follow-up, 135 participants died (10.0%).

Table 3 presents the associations of the new functional score with all-cause mortality in CHARLS. In the crude model, a 1-score increase in the functional score increased the risk of all-cause mortality by 13% ($OR = 1.13$, 95% $CI = 1.11, 1.16$). The ORs for all-cause mortality in the second, third, fourth, and fifth quartile of the new functional score were 1.75 (95% $CI = 1.27, 2.39$), 1.83 (95% $CI = 1.31, 2.57$), 2.44 (95% $CI = 1.79, 3.32$), and 4.72 (95% $CI = 3.48, 6.40$), respectively, compared with that in the first quartile. After adjusting for demographic covariates, these results did not change substantially (models 2 and 3 in **Table 3**).

As shown in **Figure 1**, the area under the curve (AUC) for all-cause mortality prediction by the new functional score was 0.639 in CHARLS. This new functional score added predictive utility to the basic model with age and sex only, with an AUC of 0.740, which was significantly higher than that of the basic model (i.e., 0.721). Additionally, the model including the new functional score had better discrimination and reclassification ability, as assessed by significantly increased delta C-statistic (i.e., 0.020), IDI (i.e., 0.025), and continuous NRI (i.e., 0.307).

In RLAS, an independent dataset, we found that the new functional score predicted all-cause mortality as well, with an AUC of 0.618 (standard error = 0.026) (**Figures 2A,B**). More importantly, we found that the new functional score added predictive utility to the basic model with age and sex only. The AUC for mortality prediction was higher for a model with the new functional score, age, and sex (i.e., 0.689), relative to that of the basic model (i.e., 0.649). Adding the new functional score contributed significant improvements for predicting all-cause mortality in terms of reclassification, evidenced by the significant increase in IDI and continuous NRI relative to that of the basic model (all $P < 0.05$, **Figure 2C**).

To help the public use of all-cause mortality prediction using the newly developed simple functional score, we provided an illustrative online tool (https://zipoa.shinyapps.io/mortalityprediction) based on parameters from CHARLS. In addition to the six self-reported items that we included in the new functional score, we also included age, sex, and education. We included age and sex as they are extremely important for health and are generally known to each person. We included

TABLE 2 | Summary characteristics of the study participants in CHARLS.

Characteristics	Total	Male	Female
N	3,929	2,102	1,827
Age, mean ± SD	67.4 ± 6.3	67.4 ± 6.1	67.4 ± 6.6
Male, *N* (%)	2,102 (53.5)	—	—
Residence, rural, *N* (%)	2,427 (61.8)	1,329 (63.2)	1,098 (60.1)
Education			
No schooling, *N* (%)	1,296 (33.0)	352 (16.8)	944 (51.7)
Primary school, *N* (%)	1,859 (47.3)	1,181 (56.2)	678 (37.1)
Middle school, *N* (%)	511 (13.0)	368 (17.5)	143 (7.8)
High school or more, *N* (%)	263 (6.7)	201 (9.6)	62 (3.4)
Marital status			
Currently married, *N* (%)	3,064 (78.0)	1,780 (84.7)	1,284 (70.3)
Others, *N* (%)	865 (22.0)	322 (15.3)	543 (29.7)
Smoking status[a]			
Non-smoker, *N* (%)	2,639 (67.2)	963 (45.8)	1,676 (91.7)
Smoker, *N* (%)	1,289 (32.8)	1,138 (54.2)	151 (8.3)
Alcohol consumption			
Non-drinker, *N* (%)	2,291 (58.4)	746 (35.5)	1,545 (84.6)
Drinker, *N* (%)	1,635 (41.7)	1,354 (64.5)	281 (15.4)
BMI (kg/m^2), mean ± SD	22.9 ± 3.9	22.4 ± 3.6	23.4 ± 4.1
BMI category			
Underweight, *N* (%)	397 (10.1)	209 (10.0)	188 (10.3)
Normal, *N* (%)	2,154 (55.0)	1,276 (60.9)	878 (48.1)
Overweight, *N* (%)	1,015 (25.9)	474 (22.6)	541 (29.6)
Obese, *N* (%)	354 (9.0)	136 (6.5)	218 (12.0)
Disease count[b]			
0, *N* (%)	1,116 (28.4)	633 (30.1)	483 (26.4)
1, *N* (%)	1,252 (31.9)	678 (32.3)	574 (31.4)
2, *N* (%)	885 (22.5)	437 (20.8)	448 (24.5)
3, *N* (%)	426 (10.8)	226 (10.8)	200 (11.0)
≥4, *N* (%)	250 (6.4)	128 (6.1)	122 (6.7)
CESD-10, mean ± *SD*	7.9 ± 5.9	7.1 ± 5.5	8.8 ± 6.2

CHARLS, China Health and Retirement Longitudinal Study; SD, standard deviation; BMI, body mass index; CESD-10, 10-item Center for the Epidemiological Studies of Depression Short Form.

[a] *Percentages may not sum to 100 because of rounding. There were 1 participant with missing data on smoking status, 3 participants with missing data on drinking status, 9 participants with missing data on BMI.*

[b] *In CHARLS, chronic diseases included hypertension, diabetes or high blood sugar, cancer or malignant tumor, chronic lung disease, heart problems, stroke, kidney disease, stomach or other digestive diseases, arthritis or rheumatism, and asthma.*

TABLE 3 | Associations of the new functional score with all-cause mortality in CHARLS.

		No. of events/No. of participants	Model 1		Model 2		Model 3	
			OR (95% CI)	*P*	OR (95% CI)	*P*	OR (95% CI)	*P*
New functional score	Per 1 score	574/3,929	1.13 (1.11,1.16)	<0.001	1.11 (1.09, 1.14)	<0.001	1.10 (1.07, 1.13)	<0.001
Quintiles	Q1	67/894	Ref.	–	Ref.	–	Ref.	–
	Q2	117/944	1.75 (1.27, 2.39)	<0.001	1.60 (1.15, 2.21)	0.005	1.47 (1.06, 2.04)	0.021
	Q3	85/657	1.83 (1.31, 2.57)	<0.001	1.77 (1.24, 2.51)	0.002	1.64 (1.15, 2.34)	0.006
	Q4	135/819	2.44 (1.79, 3.32)	<0.001	2.25 (1.62, 3.13)	<0.001	1.96 (1.40, 2.74)	<0.001
	Q5	170/615	4.72 (3.48, 6.40)	<0.001	3.70 (2.65, 5.16)	<0.001	3.20 (2.28, 4.50)	<0.001
	P for trend		—	<0.001	—	<0.001	—	<0.001

CHARLS, China Health and Retirement Longitudinal Study; OR, odds ratio; CI, confidence interval; Q1, the first quintile; Q2, the second quintile; Q3, the third quintile; Q4, the fourth quintile; Q5, the fifth quintile.
Model 1 was a crude model.
Model 2 adjusted for age and sex.
Model 3 further adjusted for residence and education based on Model 2.

education because of the same reason, and more importantly, because it may have some effects on the cognition-related items in the functional score (i.e., serial subtraction of 7 from 100). The integration then allows the user to get to know about his/her 6-year all-cause mortality risk after answering all items. For example, suppose there was a 60-year-old Chinese male, who graduated from middle school, could only count backward to 93 from 100 when doing the serial subtraction, had a BMI of 25 kg/m^2, had hypertension and diabetes now, was limited in running 1 km and climbing several flights but was perfect in walking. Then he could get his 6-year all-cause mortality prediction of 13.1% from our simple online tool (**Figure 3**).

In sensitivity analyses: (1) further adjustment for depression did not change results substantially (**Supplementary Table 3**); (2) the new functional score added predictive utility for all-cause mortality relative to the model including one existing metric (i.e., cognitive frailty, FI, or MCR), age, and sex in CHALRS (**Supplementary Figure 1**). For instance, relative to that of a model with cognitive frailty, age, and sex, adding the new functional score contributed significant increases in IDI (0.016, $P < 0.001$) and continuous NRI (0.264, $P < 0.001$) for predicting all-cause mortality.

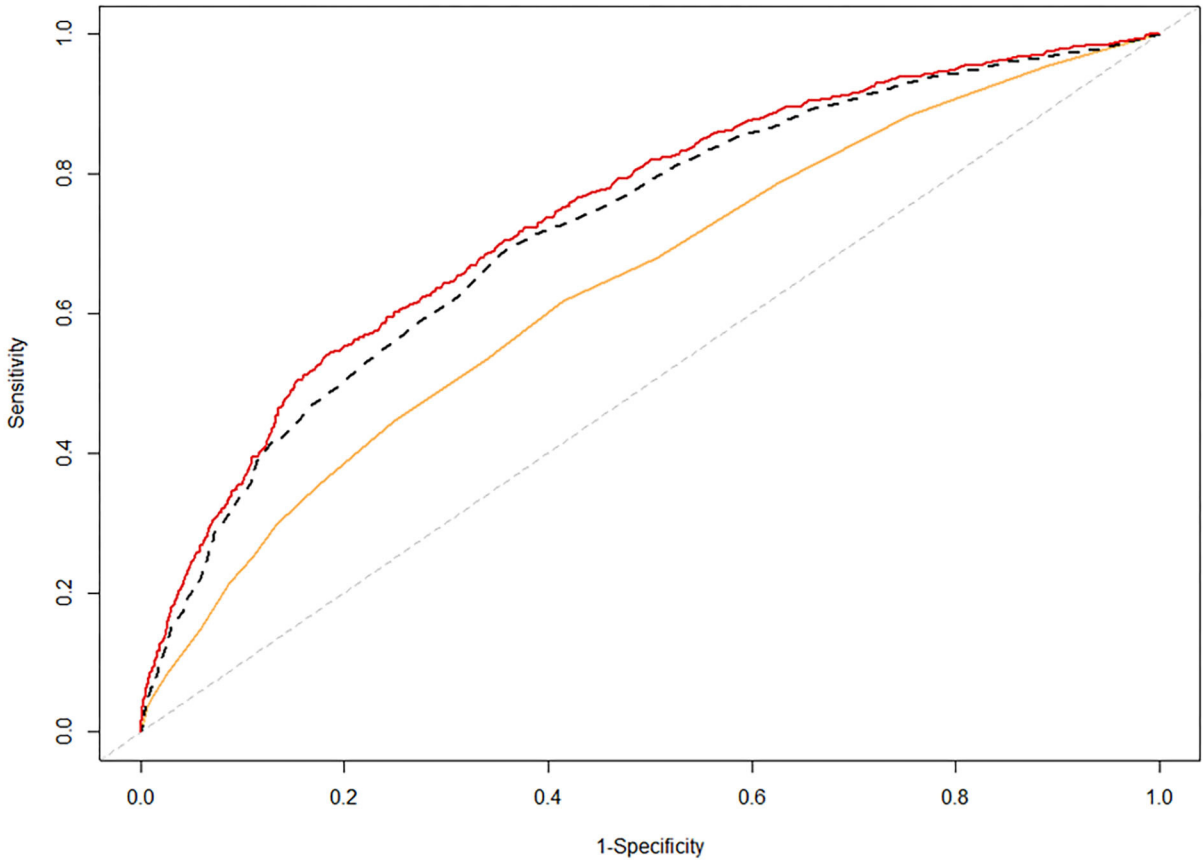
DISCUSSION

As an illustrative example of how to balance feasibility and performance, we successfully developed and validated a new simple functional score using six self-reported items concerning cognitive and physical function in CHARLS. We demonstrated that this functional score was significantly associated with all-cause mortality risk. Moreover, its predictive utility was confirmed by increased AUC, IDI, and continuous NRI. The new functional score was well-replicable in another cohort of the Chinese population (i.e., RLAS). The findings suggest that the new functional score could assist in identifying vulnerable populations at risk in China, the largest developing country with a rapidly growing aging population.

There were many well-validated functional tools, such as BADL (3), IALD (4), SPPB (5), and function impairment screening tool (FIST) (25). However, these tools mainly focused on physical function and did not consider cognitive function. To the best of our knowledge, this is the first study to use self-reported items to develop a functional score incorporating cognitive and physical function. This new functional score comprised both cognitive (i.e., serial subtraction) and physical function domains (e.g., walking 1 km), representing two aspects of functional aging. Furthermore, six items contained in the new functional score were given different weights depending on their contribution to the heterogeneity of all-cause mortality risk. For instance, having limitations in climbing several flights of stairs was defined as 1 risk point, while having limitations in walking 1 km was defined as 5 risk points. This improved aging metrics previously developed [i.e., cognitive frailty (17), FI (18), and MCR (19)] which roughly give equal weight to each item of cognitive and physical function. In addition, the new functional score was developed on the basis of CHARLS, a nationally presentative cohort in China, and it was also validated in RLAS, another cohort of the aging population. These findings support the robustness of predicting all-cause mortality risk using the new functional score in the Chinese population.

The development of the new functional score has important implications for public and clinical work, not just because of its validity of all-cause mortality risk prediction, but also due to that the items included do not require time-consuming physical examinations. The new functional score has a great potential for early identification of functional aging, and thus, helps with effective interventions in time. Also, this new functional score could be used as an alternative endpoint to assess the effectiveness of clinical anti-aging interventions, without requiring long-time follow-up. For instance, the FI has been widely used as an indicator to evaluate the effect of anti-aging interventions, such as calorie restriction (e.g., metformin, rapamycin, and resveratrol) (26, 27). Furthermore, with the illustrative online tool, where each participant could calculate his/er 6-year all-cause mortality risk prediction, the new functional score has great feasibility and practicability.

A



B

		AUC	SE	P value
	Age and sex	0.721	0.012	Reference
	New functional score	0.639	0.013	<0.001
	New functional score + age and sex	0.740	0.011	<0.001

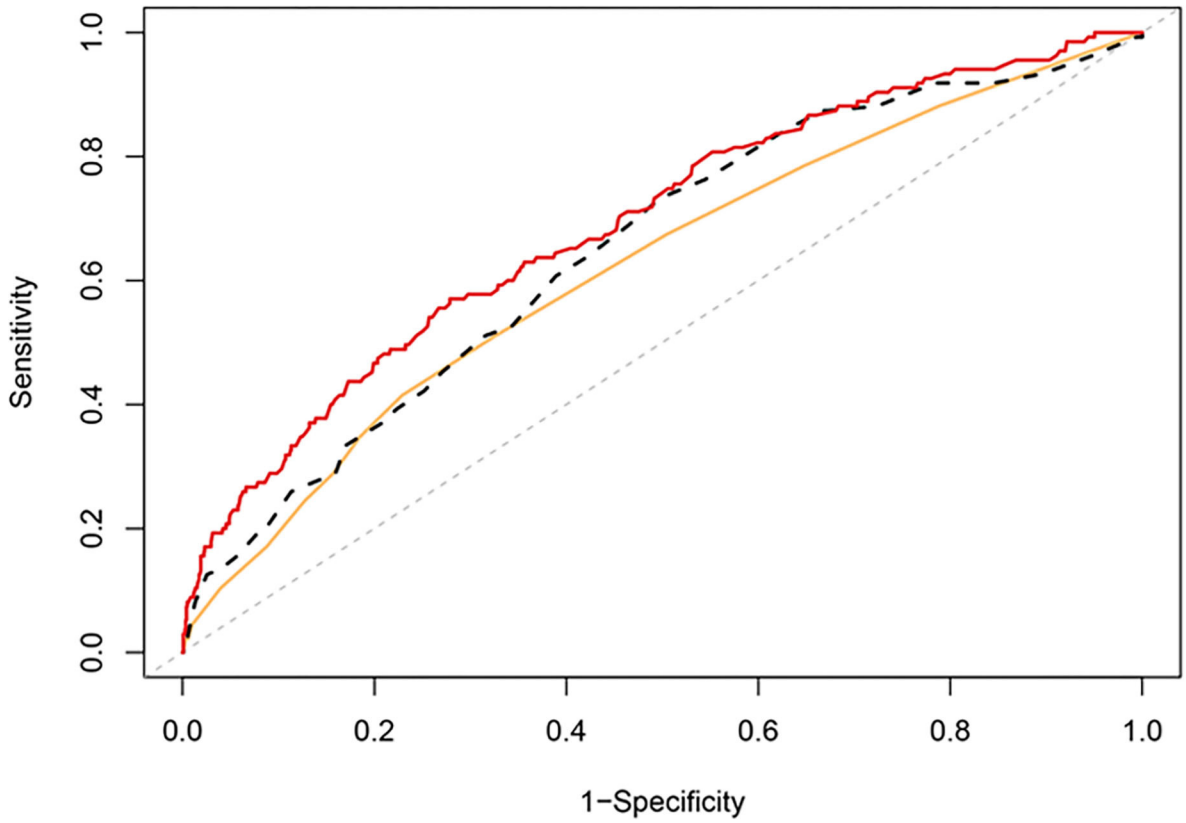
C

Delta C-statistic	P value	IDI	P value	NRI	P value
0.020	<0.001	0.025	<0.001	0.307	<0.001

FIGURE 1 | Association of the new functional score with all-cause mortality in CHARLS. CHARLS, China Health and Retirement Longitudinal Study; AUC, area under the curve; SE, standard error; IDI, integrated discrimination improvement; NRI, net reclassification index. We calculated the continuous NRI and IDI using R package "PredictABEL," in comparison to that of the basic model with age and sex. NRI equals to x% means that compared with persons without outcome, persons with outcome were almost x% more likely to move up a category than down. IDI equals to x% means that the difference in average predicted risks between the persons with and without the outcome increased by x% in the updated model. **(A)** Shows receiver-operator characteristics curves for prediction of all-cause mortality for the new functional score. **(B)** Shows the AUC for each model. **(C)** Shows delta C-statistic, IDI, and NRI, in comparison to that of the basic model with age and sex.

The strength of this study is the study sample from two cohorts in China, including one national representative cohort and one cohort of the regional aging population. The development and validation of the new functional score were performed in two separate cohorts of the Chinese population, respectively, reinforcing our findings. However, there are also some limitations. First, one of the main limitations is the short follow-up period of our study (i.e., 6 years). Because of this,

A



B

		AUC	SE	P value
	Age and sex	0.649	0.025	Reference
	New functional score	0.618	0.026	0.402
	New functional score + age and sex	0.689	0.025	0.049

C

Delta C-statistic	P value	IDI	P value	NRI	P value
0.039	0.049	0.036	<0.001	0.485	<0.001

FIGURE 2 | Association of the new functional score with all-cause mortality in RLAS. RLAS, Rugao Longitudinal Aging Study; AUC, area under the curve; SE, standard error; IDI, integrated discrimination improvement; NRI, net reclassification index. We calculated the continuous NRI and IDI using R package "PredictABEL," in comparison to that of the basic model with age and sex. NRI equals to x% means that compared with persons without outcome, persons with outcome were almost x% more likely to move up a category than down. IDI equals to x% means that the difference in average predicted risks between the persons with and without the outcome increased by x% in the updated model. **(A)** Shows receiver-operator characteristics curves for prediction of all-cause mortality for the new functional score. **(B)** Shows the AUC for each model. **(C)** Shows delta C-statistic, IDI, and NRI, in comparison to that of the basic model with age and sex.

we are unable to examine the long-term effect of the new functional score on adverse health outcomes. Second, the new functional score and its predictive utility for all-cause mortality risk across various countries/regions may be different due to the influence of genetics, demographics, and economics on aging. Thus, more studies are required to repeat our analyses in various countries/regions and populations to test the validity of this new functional score. Finally, the predictive utility for all-cause mortality risk was relatively low in RLAS, which may be induced by either the short-term follow-up period or the exclusion of other important variables (e.g., BADL disability) that affect mortality when constructing this new functional score.

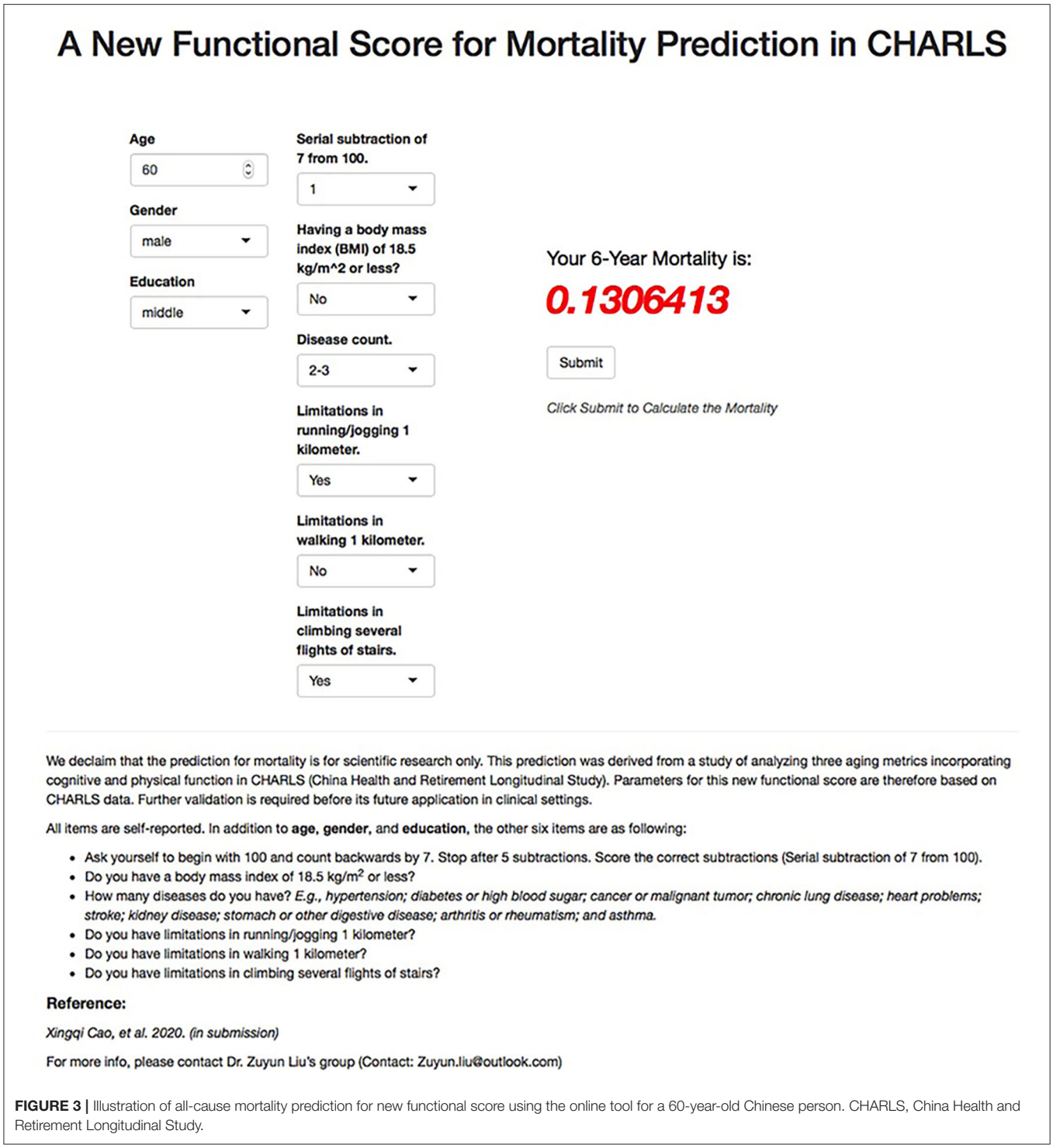


FIGURE 3 | Illustration of all-cause mortality prediction for new functional score using the online tool for a 60-year-old Chinese person. CHARLS, China Health and Retirement Longitudinal Study.

In summary, we developed a new functional score consisting of six self-reported cognitive and physical function items in the Chinese population, which was demonstrated to be able to predict all-cause mortality risk, showing good feasibility and performance. Furthermore, this functional score was validated in an independent cohort, strengthening its predictive utility across the Chinese population. Thus, the new simple functional score we developed has a great potential for early identification and prevention of functional aging in the older Chinese population. Nevertheless, it requires further validation in other countries/regions and populations.

DATA AVAILABILITY STATEMENT

The China Health and Retirement Longitudinal Study data (CHARLS) are available in the CHARLS website: http://charls.pku.edu.cn/en. The Rugao Longitudinal Ageing study (RLAS) data are available on request from the corresponding authors (Xiaofeng Wang and Zuyun Liu).

ETHICS STATEMENT

The China Health and Retirement Longitudinal Study (CHARLS) was approved by the Biomedical Ethics Review Committee of Peking University, and all participants provide informed consent. The Rugao Longitudinal Ageing study (RLAS) was approved by the Human Ethics Committee of the School of Life Science at Fudan University, and all participants provide informed consent.

AUTHOR CONTRIBUTIONS

ZL: conceived and designed the study. XC and CC: performed the analysis and wrote the initial draft of the manuscript. LH, ZZ, JZ, EH, XL, SL, XW, YZ, and ZL: helped to interpret the results and edit the manuscript. EH, XW, YZ, and ZL: contributed to the critical revision of the manuscript for important intellectual contents. All authors read and approved the final version of the manuscript.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpubh.2022.813323/full#supplementary-material

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Prevalence and Health-Adjusted Life Expectancy Among Older Adults With Hypertension in Chinese Rural Areas

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Background: The objectives of the present study were to explore the epidemiological characteristics of hypertension among rural older adults in resource-limited regions, and then evaluate the loss of health-adjusted life expectancy due to hypertension.

Methods: Participants aged between 60 and 79 years were enrolled from Henan rural cohort study. The prevalence, awareness, treatment, and control of hypertension were detailed across subgroups. Variances within subgroups were identified *via* Student's t tests or one-way ANOVA for continuous variables and chi-squared tests for categorical ones, and logistic regression model was employed to detect the potential influencing factors. The health-adjusted life expectancy was calculated by the Sullivan method with EuroqOL-5D data.

Results: Among 16,785 participants, 7,472 (44.52%) were attacked by hypertension, 4,858 (65.02%) had been already aware of their condition, 4,009 (53.65%) were taking antihypertensive medication for treatment, while only 1,478 (19.78%) had their hypertension controlled. The prevalence of hypertension was significantly higher among women than men and it increased with age for both genders. For the older ones aged 60 years, the life expectancy was 22.0872 years and the health-adjusted life expectancy was 15.5578 and 15.9418 for those with or without hypertension, respectively. Namely, in this particular age group, subjects without hypertension could gain 0.3840 years of health-adjusted life expectancy.

Conclusion: The prevalence of hypertension was relatively high while the awareness, treatment, and control were fairly low. The health-adjusted life expectancy of older adults in resource-limited areas could increase from the reduction of hypertension. There is an urgent need for strategies pertaining to the prevention and treatment of hypertension.

Clinical Trial Registration: The Henan Rural Cohort Study has been registered at the Chinese Clinical Trial Register (Registration number: ChiCTR-OOC-15006699). Date of registration: 06 July, 2015. http://www.chictr.org.cn/showproj.aspx?proj=11375.

Keywords: hypertension, prevalence, the elderly, rural regions, health-adjusted life expectancy

INTRODUCTION

Hypertension, characterized as blood vessels having persistently raised pressure (1), was a well-known risk factor leading to cardiovascular diseases (CVDs), and has contributed to the majority of premature death globally (2). It has been reported that half of CVDs were caused by elevated blood pressure (BP), and more than 1.5 billion people are suffering from hypertension nowadays (3).

As the most populous country, China has been having soaring cases of hypertensives over the decades (4). With the rapid development of economy and a huge transition in dietary and life habits in China, the prevalence of hypertension has increased over the decades (5). It is worth mentioning that blood pressure increases with age (6), therefore, old population are of greater risk of hypertension. Additionally, a national survey published recently suggested that the prevalence of hypertension was higher in rural areas than urban ones in some developed areas in our country (7). The acceleration of aging and urbanization plays an important role in this phenomenon as well (8). Therefore, old population aged over 60 living in rural areas was a noteworthy crowd to which more attention should be paid to.

Over decades, substantial studies had presented the epidemiological characteristics and influencing factors of hypertension at home and abroad (4, 9, 10). However, researches covering a large sample among rural old population in central China was still limited. Hence, this large sample crosssectional study which involved the levels of blood pressure in conjunction with prevalence, awareness, treatment, and control of hypertension was conducted to provide the latest evidence on the current status of hypertension among older population in central rural China. Moreover, the present study also calculated life expectancy (LE) and health-adjusted life expectancy (HALE) in people with or without hypertension to intuitively illustrate the burden caused by hypertension in this population.

MATERIALS AND METHODS

Study Population

Data was from the Henan Rural cohort and details of that were published elsewhere (11). Briefly, participants in this study were recruited from the Henan rural cohort, the baseline of which was launched from July 2015 to September 2017 and follow-up survey of which are still running. With a high response rate (93.7%), the Henan Rural Cohort Study containing 39,259 participants was carried out in five rural areas (Suiping, Yuzhou, Xinixiang, Tongxu, and Yima) of Henan province through a multistage, stratified cluster sampling method. Participants were excluded if they: (1) were under the age of 60 (n = 22,206); (2) were diagnosed with cancer (n = 174); (3) had serious renal disease (n = 10); (4) were diagnosed with gestational hypertension previously (n = 60); (5) did not have information on data of blood pressure (n = 20) and taking antihypertensive medications during previous 2 weeks (n = 4). Ultimately, 16,785 subjects (7,370 men and 9,415 women) were included in the present study. Among 16,785 study participants, 9,920 individuals finished the EQ-5D-5L questionnaire and were included in the analysis of health-adjusted life expectancy. A flow chart for the inclusion and exclusion of participants are displayed in the **Supplementary Appendix**.

The study was approved by Zhengzhou University Life Science Ethics Committee (Code: [2015] MEC (S128)) and was conducted following the principles of the Declaration of Helsinki. Additionally, written informed consent was obtained from each participant.

Data Collection

A standard questionnaire containing information on general demographic characteristics, lifestyle characters, personal, and family history of diseases was employed by well-trained investigators during face-to-face interviews. Body mass index (BMI), as an index of general obesity, was calculated as weight (kg) divided by the average of height readings squared (m^2) and further categorized as underweight (BMI$<$18.5 kg/m^2), normal (18.5 kg/m^2 $\leq$ BMI $<$ 24 kg/m^2), overweight (24 kg/m^2 $\leq$ BMI $<$ 28 kg/m^2), or obese (BMI $\geq$ 28 kg/m^2). The subjects' height and weight were measured in light clothes and without shoes following standard protocols.

Subjects were divided into four age groups: 60–64 years, 65–69 years, 70–74 years, and $>$75 years. Education levels were classified into three categories: illiterate, primary school, and middle school or above. Smoking and drinking status were categorized as never, former, and current. Taking vegetable and fruit more than 500 g per day was defined as more vegetable and fruit intake, and a high-fat diet was defined if someone on an average eats meat of livestock and poultry of more than 75 g per day (12). Physical activity was categorized as low, moderate, and high according to the International Physical Activity Questionnaire (IPAQ) (13). The IPAQ and the cutoffs used for low, moderate, and high activity have been provided in the **Supplementary Appendix**.

Measurement of Blood Pressure

According to the JNC 7 Report in 2003 measurements (14), participants were asked to rest for at least 5 min before measurements. With an electronic sphygmomanometer (HEM-770AFuzzy, Omron, Japan), the resting blood pressure (BP) was measured three times with 30-s intervals between measurements, and then the average reading was applied in further analyses.

Outcome Definition

Subjects would be diagnosed with prehypertension if their BP meet the following criteria (15): 120 mmHg $\leq$ SBP $<$140 mmHg and/or 80 mmHg $\leq$ DBP $<$ 90 mmHg. Hypertension was defined as the following standards (16): (1) SBP $\geq$140 mmHg and/or DBP $\geq$ 90 mmHg; (2) self-reported hypertension diagnosed by physicians previously and

Abbreviations: DBP, Diastolic blood pressure; SBP, Systolic blood pressure; BMI, Body mass index; IPAQ, Physical Activity Questionnaire; BP, Blood pressure; OR, Odds ratio; PTN, Prehypertension; NTN, Normotensive; HTN, Hypertension; PP, Pulse pressure; SD, Standard deviation; LE, Life expectancy; HALE, Health adjusted life expectancy; EQ-5D, EuroqOL-5D.

TABLE 1 | Demographic of study participants according to blood pressure status.

Variable	Normotension (*N* = 4,265)	Prehypertension (*N* = 5,048)	Hypertension (*N* = 7,472)	*P*
Age (year), mean ± SD	65.97 ± 4.58	66.50 ± 4.80	67.32 ± 4.97	<0.001
Age group (year)	1,941 (45.51)	2,075 (41.11)	2,583 (34.57)	<0.001
60∼64	1,379 (32.33)	1,658 (32.84)	2,455 (32.86)	
65∼69	694 (16.27)	893 (17.69)	1,640 (21.95)	
70∼74	251 (5.89)	422 (8.36)	794 (10.63)	
75∼				
Gender (men), *n* (%)	2,151 (50.43)	2,303 (45.62)	2,916 (39.03)	<0.001
Marital status, *n* (%)				<0.001
Married/cohabiting	3,619 (84.85)	4,217 (83.54)	6,056 (81.05)	
Widowed/single/divorced/separation	646 (15.15)	831 (16.46)	1,416 (18.95)	
Education*, *n* (%)				<0.001
Illiterate	1,287 (30.18)	1,558 (30.86)	2,404 (32.17)	
Primary school	1,514 (35.50)	1,791 (35.48)	2,920 (39.08)	
Middle school and above	1,464 (34.33)	1,699 (33.66)	2,148 (28.75)	
Per capita monthly income (RMB), *n* (%)				0.026
<500	1,971 (46.21)	2,313 (45.82)	3,554 (47.56)	
500∼1000	1,304 (30.57)	1,565 (31.00)	2,340 (31.32)	
>1000	990 (23.21)	1,170 (23.18)	1,578 (21.12)	
Body mass index (kg/m^2), mean ± SD	22.96 ± 3.18	24.29 ± 3.39	25.49 ± 3.61	<0.001
High fat diet, *n* (%)	639 (14.98)	697 (13.81)	802 (10.73)	<0.001
More vegetable and fruit intake, *n* (%)	1,899 (44.53)	1,968 (38.99)	2,470 (33.06)	<0.001
Smoking, *n* (%)				<0.001
Never	2,707 (63.47)	3,449 (68.32)	5,560 (74.41)	
Former	452 (10.60)	582 (11.53)	913 (12.22)	
Current	1,106 (25.93)	1,017 (20.15)	999 (13.37)	
Drinking, *n* (%)				<0.001
Never	3,283 (76.98)	3,938 (78.01)	6,033 (80.74)	
Former	320 (7.50)	305 (6.04)	481 (6.44)	
Current	662 (15.52)	805 (15.95)	958 (12.82)	
Physical activity, *n* (%)				<0.001
Low	1,313 (30.79)	1,717 (34.01)	3,173 (42.47)	
Moderate	1,621 (38.01)	1,823 (36.11)	2,325 (31.12)	
High	1331 (31.21)	1508 (29.87)	1974 (26.42)	
Family history of hypertension, *n* (%)	265 (6.21)	349 (6.91)	1,465 (19.61)	<0.001
Dyslipidemia, *n* (%)	1,224 (28.74)	1,770 (35.11)	3,426 (45.94)	<0.001
Diabetes, *n* (%)	328 (7.71)	568 (11.27)	1,234 (16.55)	<0.001

**In our study, primary school represents six schooling years, and middle school represents three more years based on primary school.*

took antihypertensive medications in the past 2 weeks. The criteria of diabetes and dyslipidemia are described in detail in the **Supplementary Appendix**.

Assessment of Health Adjusted Life Expectancy

With information on population in this study and death data from the 2017 China Cause-of-death Surveillance Data set, life expectancy (LE) was measured. Health adjusted life expectancy (HALE) of participants with or without hypertension was further calculated using the Sullivan method (17) with life expectancy (LE) and EuroqOL-5D (EQ-5D) data. The steps of HALE calculation are displayed in **Supplementary Appendix**.

Statistical Analysis

Continue variables were expressed as means ± SDs, and intergroup differences were detected *via* Student's *t*-test or one-way ANOVA, while categorical ones were presented as frequencies (percentages) and chi-squared tests were applied to compare variances between groups. In this survey, a full-adjusted logistic regression model was employed to analyze the connection of potential influencing factors with the prevalence, awareness, treatment, and control of hypertension. Age-standardized prevalence, awareness, treatment, and control of hypertension were computed according to data from the 2010 Chinese census (18). $P < 0.05$ (two-sided test) was considered to be statistically significant in the present study. SPSS version 21.0 was used to carry out statistical analysis.

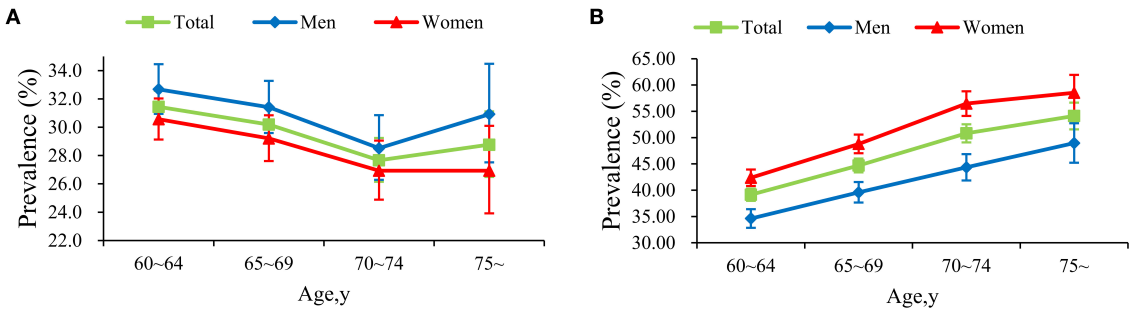

FIGURE 1 | Prevalence of prehypertension **(A)** and hypertension **(B)** among different subgroups.

RESULTS

Demographic Characteristics

As presented in **Table 1**, among 16,785 participants covered in this study, 5,048 (30.07%) individuals were suffering from prehypertension and 7,472 (44.52%) were diagnosed with hypertension. Participants with prehypertension and hypertension were more inclined to be older, women, single/widowed/separated/divorced, lower educated, never drinkers and never smokers, and more likely to have lower monthly income, higher body mass index (BMI), lower physical activity, higher family history of hypertension, and higher prevalence of diabetes or dyslipidemia (all $P < 0.05$). However, they were less likely to have high-fat diet and more vegetable and fruit intake ($P < 0.05$). The self-reported damage of participants (no, slight, moderate, severe, or extreme problems) based on the EQ-5D-5L questionnaire are summarized in **Supplementary Table 1**.

Prevalence of Prehypertension and Hypertension

Overall, the prevalence of prehypertension and hypertension was 30.07 and 44.52%, and age-standardized prevalence was 29.83 and 45.36%, respectively. The prevalence of prehypertension with age was distributed as U-shape, touching the bottom at the age of 70–74 for both genders. **Figure 1** also sheds light on that the prevalence of hypertension increased with age for both genders. Hypertension was more prevalent among women (48.39 vs. 39.57%, $P < 0.001$), while prehypertension was more common among men (31.25 vs. 29.16%, $P = 0.003$). In addition, the prevalence of hypertension increased with age and BMI (both $P_{trend} < 0.001$). More details toward the prevalence of prehypertension and hypertension were displayed in **Table 2**.

Awareness, Treatment, and Control of Hypertension

The awareness, treatment, and control of hypertension was 65.02%, 53.65%, and 19.78%, respectively. As was illustrated in **Supplementary Table 2**, the awareness and treatment of hypertension were significantly higher among women than men ($P < 0.001$), while no statistically significance in control of hypertension was found in men and women ($P = 0.967$). Moreover, the awareness and treatment of hypertension continued to rise in subjects aged over 65, but began to decrease sharply at 70 for both genders. Simultaneously, the control of hypertension increased from 60 years old but began to fall dramatically at 65, especially for women (**Figure 2**).

Analyses of Potential Influencing Factors

Age, single/widowed/separated/divorced, overweight or obese, and family history of hypertension were positively related to hypertension (all ORs > 1, all $P < 0.05$), whereas, underweight, more vegetable and fruit intake, high fat diet, and current smoking had negative association (all ORs < 1, all $P < 0.05$). What's more, those who were suffering from diabetes or dyslipidemia were more likely to have hypertension, whereas they also tended to be aware of treatment to control hypertension (all ORs > 1). More detailed descriptions concerning the potential risk factors of the awareness, treatment, and control of hypertension are revealed in **Supplementary Figure 1**.

Evaluation of Health-Adjusted Life Expectancy

The life expectancy (LE) decreased with increasing age among participants in both genders, and the similar trend was also observed for the health-adjusted life expectancy (HALE) in the counterparts with or without hypertension. Across all the age groups in both genders, the HALE was higher among participants without hypertension compared with those with hypertension. For those aged 60 years, the LE was 22.0872 years (men, 20.3282 years; women, 23.9752 years) and the HALE was 15.5578 (men, 15.1060 years; women, 16.1084 years), and 15.9418 (men, 15.4428 years; women, 16.4581 years) for those with or without hypertension, respectively. Namely, in this particular age group, subjects without hypertension could gain 0.3840, 0.3368, and 0.3497 years of HALE for total, men, and women, respectively. Additionally, in the age group of 65, 70, and 75, the projected HALE was 0.3548, 0.3115, and 0.1927 years longer among participants without hypertension compared with their counterparts with hypertension. More details of LE and the HALE for men

TABLE 2 | The prevalence of prehypertension and hypertension of total participants.

Variable	Prehypertension, *n* (%)	*P*	Hypertension, *n* (%)	*P*
Gender		0.003		<0.001
Men	2,303 (31.25)		2,916 (39.57)	
Women	2,745 (29.16)		4,556 (48.39)	
Marital status		0.082		<0.001
Married/cohabiting	4,217 (30.36)		6,056 (43.59)	
Widowed/single/divorced/separation	831 (28.72)		1,416 (48.95)	
Education*		0.001		<0.001
Illiterate	1,558 (29.68)		2,404 (45.80)	
Primary school	1,791 (28.77)		2,920 (46.91)	
Middle school and above	1,699 (31.99)		2,148 (40.44)	
Per capita monthly income (RMB)		0.145		0.004
<500	2,313 (29.51)		3,554 (45.34)	
500∼1000	1,565 (30.04)		2,340 (44.92)	
>1000	1,170 (31.30)		1,578 (42.22)	
Body mass index (kg/m2)		<0.001		<0.001
Underweight	150 (26.41)		122 (21.48)	
Normal	2,289 (31.70)		2,485 (34.42)	
Overweight	1,918 (30.37)		3,149 (49.87)	
Obese	676 (25.93)		1,671 (64.10)	
High fat diet	697 (32.60)	0.006	802 (37.51)	<0.001
More vegetable and fruit intake	1,968 (31.06)	0.031	2,470 (38.98)	<0.001
Smoking		0.003		<0.001
Never	3,449 (29.44)		5,560 (47.46)	
Former	582 (29.89)		913 (46.89)	
Current	1,017 (32.58)		999 (32.00)	
Drinking		<0.001		<0.001
Never	3,938 (29.71)		6,033 (45.52)	
Former	305 (27.58)		481 (43.49)	
Current	805 (33.20)		958 (39.51)	
Physical activity		<0.001		<0.001
Low	1,717 (27.68)		3,173 (51.15)	
Moderate	1,823 (31.60)		2,325 (40.30)	
High	1,508 (31.33)		1,974 (41.01)	
Family history of hypertension	349 (16.79)	<0.001	1,465 (70.47)	<0.001
Dyslipidemia	1,770 (27.57)	<0.001	3,426 (53.36)	<0.001
Diabetes	568 (26.67)	<0.001	1,234 (57.93)	<0.001

**In our study, primary school represents six schooling years and middle school represents three more years based on primary school, and we added the schooling years in the revised manuscript.*

and women subgroups across age groups are displayed in **Table 3**.

DISCUSSION

The crude and age-standardized prevalence, awareness, treatment, and control of hypertension were 44.52%, 65.02%, 53.65%, 19.78% and 45.36%, 65.05%, 53.74%, 19.68%, respectively. The prevalence of hypertension was lower than 53.24% reported in a national study conducted in 2012–2015, and the awareness, treatment, and control rates were slightly higher than that national level of the older population (19). The LE and HALE were decreased with increasing age among participants in both genders, which was in line with other studies. Furthermore, within people in the age of 60, 65, 70, and 75, they would gain 0.3840, 0.3548, 0.3115, 0.1927 years of HALE after eliminating hypertension, respectively, which revealed the impact of hypertension on health to be more realistic. Therefore, increased attention should be paid to older adults in rural China, and more reasonable strategies and measures should be urgently proposed and adopted. Additionally, the huge prehypertension population (29.83%) in this study suggested a remarkable risk

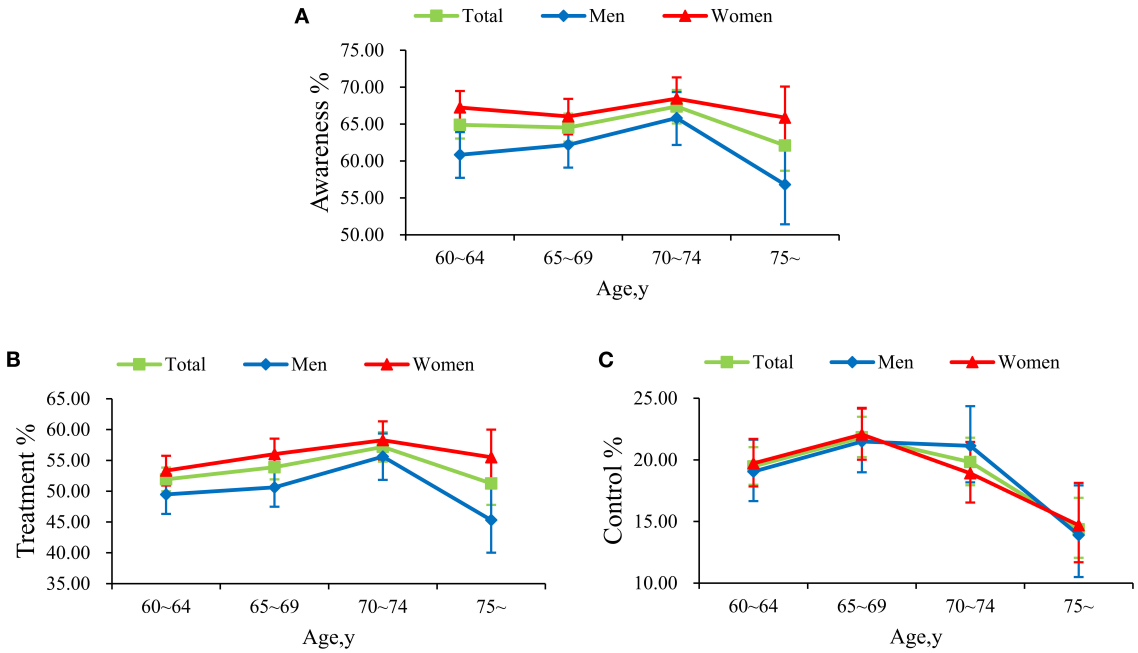

FIGURE 2 | Awareness **(A)**, treatment **(B)**, and control **(C)** of hypertension between various genders.

burden of cardiovascular and cerebrovascular diseases among older adults in rural regions. Investigators of Framingham Heart Study have reported that individuals with prehypertension were two-fold to three-fold more likely to progress to hypertension compared with those with normal BP (20).

The current study also demonstrated that hypertension was more common among old female than their male counterparts, which was in line with previous researches (15, 21). This phenomenon may be explained by the hormonal changes at different ages for men and women (15). It has been previously reported that the prevalence of hypertension in postmenopausal women was higher than in premenopausal ones (22). It is worth noting that the prevalence of hypertension kept increasing with age, whereas, as for prehypertension, the prevalence was maintained decreasing with age among participants, with the exception of the age group of 75–79. The findings might be because prehypertension, a phase in the progression to hypertension from normal BP, tends to be more severe over time and was inclined to progress to hypertension with aging (23). Another cohort study also reported that prehypertension tends to become severe over time (24). Simultaneously, the increasing trend of prehypertension that began at age 75 remained unexplainable in our study and needs to be elucidated by further studies. Concerning participants in the age group of 60, those without hypertension can live 0.3840 years more (0.3368 and 0.3497 years for men and women, respectively) in healthy status, compared with their counterparts suffering from hypertension. With the exception of those aged over 75, the difference between the gap of HALE in nonhypertensive and hypertensive groups was higher among women than men. In addition, the LE and HALE decreased sharply with increasing age among both genders, showing that the quality of life of rural older population deteriorated with age, which has been reported in other areas (25).

As was published in other epidemiologic studies conducted at home and abroad, age was associated positively with hypertension (26, 27). Simultaneously, what was displayed in logistic regression analysis was that the ORs displayed a significant increase with increasing age for them, which hinted that more attention should be paid to older people. In addition, being overweight and obese is associated with a higher risk of hypertension, as has been found in a great many investigations (5, 28). An obvious association between BP increase and weight gain was discovered (28–30), and a dose-response effect of the magnitude of weight loss on BP reduction was reported by the American obesity guideline (31). For overweight and obese individuals, hence, several lines of evidence suggest that weight loss strategy is of utmost importance to refrain from higher blood pressure readings (29). Demonstrated in numerous observational and intervention studies, more vegetable and fruit intake offered a considerable benefit against the risk of hypertension (32), and this phenomenon was also found in this study. Additionally, those suffering from diabetes or dyslipidemia were more inclined to develop hypertension, which was consistent with studies published previously (33, 34). Yin Ruixing et al., discovered that dyslipidemia was associated with hypertension in many aspects, and this excited several common risk factors among these chronic noncommunicable diseases (35). More attention ought to be paid to those with diabetes and dyslipidemia when

TABLE 3 | The life expectancy and health adjusted life expectancy of participants across various age groups.

Age group (years)	Total LE[#] (years)	HALE[&] (years)		
		Without HTN	With HTN	Difference*
Total				
60∼64	22.0872	15.9418	15.5578	0.3840
65∼69	18.1549	11.9173	11.5625	0.3548
70∼74	14.5802	8.0844	7.7729	0.3115
75∼	11.3126	4.2231	4.0304	0.1927
Men				
60∼64	20.3282	15.4428	15.1060	0.3368
65∼69	16.6262	11.5932	11.2865	0.3067
70∼74	13.3108	7.9327	7.6645	0.2682
75∼	10.2554	4.1685	3.9820	0.1865
Women				
60∼64	23.9752	16.4581	16.1084	0.3497
65∼69	19.7475	12.2307	11.9081	0.3226
70∼74	15.8435	8.2127	7.9250	0.2876
75∼	12.2877	4.2667	4.0832	0.1835

HTN, hypertension; LE, life expectancy; HALE, health adjusted life expectancy.
**Gain in health adjusted life expectancy after eliminating hypertension.*
[#]Total life expectancy = life expectancy in healthy status + life expectancy in unhealthy status.
[&] life expectancy in healthy status.

screening for hypertesnion. Futhermore, the results suggested that moderate or high physical activity was related to lower risk of having hypertension, in line with other publications. Given what was reported in a review from 27 randomized controlled trials, medium-to-high-intensity aerobic activity would reduce the BP by 11/5 mmHg among hypertensives (36). Therefore, for people with hypertension it would better to exercise more to lower BP.

The strengths of the study should be highlighted. Firstly, this was the latest study to explore the status of hypertension and health-adjusted life expectancy focusing on older population in rural regions. In addition, the present study covered a large sample of study population, which made the results more convincing. Nevertheless, several limitations of this study should be noted as well. Firstly, due to the crosssectional nature, the HALE was calculated by Sullivan method with death data from the 2017 China Cause-of-death Surveillance Data set. As the LE and HALE were calculated with crosssectional data, the LE and HALE in our study may be relatively underestimated. Indeed, follow-up surveys of this cohort are still ongoing and subsequent data would make the HALE more convincing by evaluating *via* multistate life table method. Secondly, considering all participants contained in the present study were older adults from rural areas in China, the generalizability of the current reported information to other regions or populations could be limited. Finally, the information on lifestyles and personal history of diseases was collected *via* a standardized questionnaire, as a consequence, recall bias was unavoidable. However, the questionnaire was concerned with high reliability and validity, and the researchers had been well-trained, and so the results in the present study were convincing even if there exsited recall bias.

In conclusion, the prevalence of hypertension was relatively high while the awareness, treatment, and control were fairly low. The HALE of older adults in resource-limited areas could increase from the reduction of hypertension. Unhealthy lifestyles should be adjusted and relevant policies should be formulated to help the older ones in rural areas access to reduce hypertension prevalence and increase the health-adjusted life expectancy for this population.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The study was approved by Zhengzhou University Life Science Ethics Committee (Code: [2015] MEC (S128)) and conducted following the principles of the Declaration of Helsinki. Additionally, written informed consent was obtained from each participant.

AUTHOR CONTRIBUTIONS

ZH: carried out data analysis and wrote the manuscript. XL, WL, NK, LM, ZM, JH, and WH: recruited the participants and administered the assessment. YL and CW: designed this study and guided the writing. All authors listed have read, corrected, and approved the final manuscript.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpubh.2022.802195/full#supplementary-material

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Mental Health Changes in Older Adults in Response to the COVID-19 Pandemic: A Longitudinal Study in Mexico

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This study examined changes in some aspects of mental health, as well as worries and behaviors related to the COVID-19 pandemic in a sample of older adults, during three different moments of the first year of the pandemic in Mexico. The sample consisted of 2,307 older adults (38% men and 62% women). The results indicated that older adults presented less concern about the COVID-19 pandemic, as well as less adherence to preventing procedures in the first wave, compared to subsequent evaluations. In addition, greater depressive symptoms, anxiety and stress were found in older adults in the last wave; however, the proportion of older adults identified with high scores in these variables was lower than that reported in national data.

Keywords: older adults, longitudinal, depression, COVID-19, mental health

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INTRODUCTION

The COVID-19 pandemic has generated a global change in terms of the health of the population, including prevention, early detection, timely and appropriate care of this disease, not only in physical aspects but also in people's mental health, partly as a consequence of the social changes to which the population of almost all countries has been subjected, characterized by social distancing, which represents a risk for the development of stress, anxiety, depression, violence and other mental health disorders (1–4).

Initially, reports indicated that the disease caused by SARS-CoV-2 affected mostly adults and that certain comorbidities were consistently associated with severe cases or even death. However, cases were later reported in other population groups, such as children under 1 year of age (5) and pregnant women (6), which complicated the global picture and opened new questions about how it was affecting various population groups, not only in physical health, but also in mental health, and not only of those who suffered from this disease, but of everyone in general.

Regarding mental health, various psychological responses to a pandemic are reported in the literature, including: maladaptation, emotional distress and defensive responses, anxiety, fear, frustration, loneliness, anger, boredom, depression, stress, avoidance behaviors, among others (which in themselves represent a health risk for individuals and communities) (2, 7, 8). Lee et al. (9) conducted a longitudinal study with people who had SARS disease in 2003, who at the time of the pandemic presented high levels of stress compared to a group of people who did not have the virus; in addition, at the follow-up assessment (1 year later), the people who had suffered from SARS not only continued to show high levels of stress, but also showed

high levels of depression, anxiety, posttraumatic symptoms and psychiatric morbidity, which could be an indicator of the persistence of such symptoms, despite the time elapsed and the absence of the triggering event.

In Mexico, the first case of coronavirus was confirmed on February 28, 2020, when 85,403 cases and 2,924 deaths from COVID-19 had been reported worldwide up to that moment (10). Until then, cases had been reported in 53 countries outside of China, in six regions of America, Europe, Southeast Asia, Eastern Mediterranean, Western Pacific and Africa (11). On March 24, 2020, the Mexican Ministry of Health published the preventive measures to be implemented to mitigate and control the health risks posed by COVID-19 (12). By March 30, the General Health Council declared the epidemic of the disease generated by the SARS-CoV-2 virus (COVID-19) as a health emergency (13) and, on March 31, the extraordinary actions to address this emergency were published (14). According to these documents, the immediate suspension of non-essential activities in the public, private and social sectors, until April 30, was established aiming to mitigate the spread and transmission across the communities, to reduce overrunning of the health system and the rates of severe cases and deaths in the population residing in the national territory (15).

At the beginning of this study (April 7, 2020), 2,785 cases and 141 deaths due to COVID-19 were registered in Mexico (see **Figure 1**) (16) and, at the second recollection of data for this study (May 10, 2020), there were already 35,022 confirmed cases and 3,465 deaths due to COVID-19 (17). That is, during just 1 month there was an increase of more than 30,000 cases (∼1,257%) and more than 3,000 (2,457% more). However, even with these data and with the observed trend, on May 17, 2020, the health authorities published the strategies to begin the gradual reopening of activities, including the introduction of the Epidemiological Risk Traffic Light Monitoring System (18), which would guarantee permanent monitoring of nation states regarding the regulation of the use of public space in accordance with the risk of COVID-19 contagion. The system works as follows: red light indicates that only essential economic activities can operate; orange light that, in addition to essential economic activities, companies considered as non-essential are allowed to work with 30% of their personnel, and open public spaces may operate with a reduced capacity of people; with yellow light all work activities are allowed with due precautions, and open spaces may operate regularly, though public enclosed places must operate with a reduced capacity of people; finally, green light indicates that all activities, including physical attendance to school, are allowed.

The gradual reopening of activities, called by health authorities as the "new normal" phase, began on June 1, 2020 (**Figure 1**), when 93,435 cases and 10,167 deaths from COVID-19 were reported (19) and when, according to the data presented by the page Our World In Data (20), there was an upward trend in both confirmed cases and deaths by COVID-19 in Mexico (21), which, at the moment of writing this report, has remained relatively constant and has only shown a considerable drop in cases on some occasions.

In addition to this, Mexico has been repeatedly questioned by international authorities regarding its control the COVID-19 pandemic; for example, being one of the countries with the lowest testing rate throughout the pandemic, estimating only 2.29 tests per thousand inhabitants by the end of May, 2020 (22), which suggests underreporting of both cases and deaths by COVID-19 in official reports by the government. Unfortunately, the different strategies implemented by the Mexican government do not seem to have had a significant impact in halting the increase in COVID-19 infections and deaths since. by the beginning of the last step of this research (September 28, 2020), the country already had 733,717 cases and 76,603 deaths (23), which placed it among the countries with the highest number of cases and deaths from COVID-19 where, according to official data, the age group between 60 and 69 years is the group with the highest number of deaths due to COVID-19 (24), despite the fact that there is a greater number of accumulated cases in people between 25 and 49 years of age (25), which confirms that older adults could be the most vulnerable to survive this disease.

It is very likely that the different moments experienced during the COVID-19 pandemic could have a psychological effect on people, especially in those population groups that are considered vulnerable, such as the elderly; however, the literature is not conclusive in this regard. For example, Di Santo et al. (26) found a reduction in healthy behaviors as a result of the preventing measures for COVID-19 (e.g., physical activity, diet, productive and cognitively stimulating activities), which could put older adults at an increased risk for dementia. In addition, the authors found a higher proportion of older adults with depression, anxiety and stress compared to data available before the start of the COVID-19 pandemic.

Li et al. (27) found that residents of regions that were quarantined due to COVID-19 had twice the prevalence of depression and anxiety compared to residents of regions where isolation measures were not applied. Ali et al. (28) conducted a study assessing the impact of COVID-19 pandemic restrictions on mental wellbeing in a sample of Bangladeshi adults, through a day-to-day comparisons of mental wellbeing measures from March 27 to April 7. They found that individuals over 50 years old showed high variability in scores compared to the younger groups of participants, suggesting greater difficulty in their mental health, according to the authors.

However, Plomecka et al. (29) assessed the mental health impact of the COVID-19 pandemic confinement on adults in 12 countries (including the USA, Spain, Italy, France, Germany, UK, Iran, Turkey and Switzerland), finding less psychological distress in older age groups, which could suggest better adaptability to this type of events. In this same sense, Röhr et al. (30) analyzed mental wellbeing in a sample of older adults during the COVID-19 closure in Germany, reporting that wellbeing in this population remained practically the same as before the closure, interpreting that, although concern about the situation was found, older adults felt socially supported and showed acceptance and resiliency in the face of these challenging conditions.

Bruine de Bruin (31), analyzing a sample of older adults in California, found greater perception of higher risks of dying if they contracted the SARS-CoV-2 virus, but with lower perceived

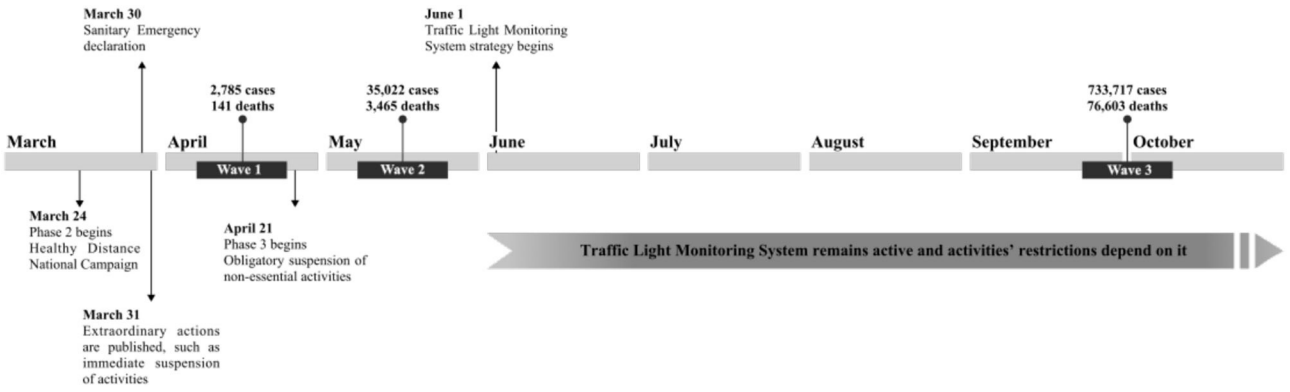

FIGURE 1 | Survey timeline.

risks of contracting the disease, being quarantined or running out of money, in addition to having low scores on depression and anxiety. Other studies (32–34) suggest that, compared to young adults, older individuals are less mentally affected by the COVID-19 pandemic.

On the other hand, García-Fernández et al. (35), found that Spanish adults over 60 years of age were less vulnerable to suffer depression and acute stress compared to younger individuals. Furthermore, they found no differences in anxiety levels during the peak of the pandemic compared to the younger group; thus, according to the authors, older people could not be considered especially vulnerable to the development of anxiety, depression and acute stress during the peak of the COVID-19 pandemic. Likewise, the results showed no gender differences for any of the clinical variables.

Stanton et al. (36) examined the associations between psychological distress and changes in healthy behaviors in a sample of Australian adults during the COVID-19 pandemic, comparing different age groups (18–45, 46–65, and over 65 years), They found that the most affected in depression, anxiety and stress were the youngest (18–45 years), and that those over 65 years showed the lower scores. However, the authors did find associations between changes in physical activity, sleep, tobacco and alcohol consumption, and severity of depression, anxiety and distress in all age groups.

As we have been able to observe, the health emergency being experienced worldwide due to COVID-19 will leave many consequences in the different countries that have been affected, but it is most likely that countries like Mexico will have a greater challenge in order to survive this crisis, due to the fact that the country already had deficiencies in health, economy and social development. Among some factors are the high prevalence of diabetes and cardiovascular diseases, job insecurity, problems of access to water and overcrowding that prevent the generalized adoption of preventive measures and multiple gaps in access to social rights, especially in vulnerable populations such as older adults (37).

In addition to this, the vast majority of the studies that have been carried out on the psychological consequences of the COVID-19 pandemic are cross-sectional, which, although valuable because they help to understand a phenomenon at a specific time, they do not allow us to know if changes can occur in the same population at different times and under different conditions, which can favor the understanding of phenomena such as the one being experienced with the COVID-19 pandemic. Thus, the present investigation examined changes over three difference timepoints in some aspects of mental health, as well as worries and behaviors related to the COVID-19 pandemic, in a sample of Mexican older adults.

MATERIALS AND METHODS

Study Design

This is a longitudinal study, for which the Direction for the Welfare of Older Adults of the Government of the State of Mexico, provided support for the application of the instruments *via* telephone. As shown in **Figure 1**, the study included an initial evaluation and two follow-up evaluations: the first evaluation (wave 1) was conducted between April 7 and 17, 2020, with a total of 2,867 older adults. The second evaluation (wave 2) was completed the same year between May 10 and 22, obtaining information from 2,602 older adults who were previously evaluated. The third evaluation (wave 3) was carried out between September 28 and October 5, obtaining responses from 2,307 older adults evaluated in the two past moments; that is, the sample of this study corresponds to the same group of older adults who were evaluated at three different times.

Data Collection and Participants

The universe of the study was older adults from the State of Mexico. According to data from the State Population Council in the State of Mexico for 2019, there was an estimate of 1,517,425 individuals aged 60 years or more. Considering a confidence level of 95% and a margin of error of 2%, the desired sample size was set at 2,398 participants.

The sample was selected non-probabilistically through a database available to the Direction for the Welfare of Older Adults of the State of Mexico. Information was obtained from

TABLE 1 | Distribution of participants by sociodemographic variables.

	N = 2,307	
	%	*f*
Sex		
Male	38.0	877
Female	62.0	1,430
Level of education		
No schooling	15.0	346
Primary school	61.2	1,411
Secondary school	14.1	325
High school	2.9	68
Techincal career	3.5	80
Bachelor's degree	3.2	74
Postgraduate degree	0.1	3
Occupation		
Unemployed	17.1	394
Retired	13.9	320
Employed	11.9	274
Housework	57.2	1,319
Marital status		
Single	6.5	149
Married	66.8	1,541
Civil union	2.0	47
Divorced/separated	4.6	107
Widowed	20.1	463
Number of people they live with		
Live alone	4.7	109
Live with someone else	28.7	662
Live with two or three people	36.5	841
Live with four or more people	30.1	695
Medical conditions		
None	39.1	893
One	39.9	911
Two or more	21.0	480

the three waves of 2,307 older adults, residents from 19 regions of the State of Mexico. From the first wave, 38% of participants were men and 62% women, aged 60–100 years old ($M = 70.69$, $SD = 7.35$). As shown in **Table 1**, more than half of the participants indicated primary school as their highest level of education; and a high percentage indicated being married. Regarding occupation, the highest proportion of participants reported doing household chores and a second large proportion of them reported being unemployed. More than a third of the participants indicated having at least one of the following conditions: hypertension, diabetes, cancer, respiratory and autoimmune diseases, obesity, or dyslipidemia. A similar percentage reported not having any of the evaluated conditions, and approximately one fifth indicated having two or more conditions (see **Table 1**).

Personnel from the Direction for the Welfare of Older Adults, consisting of nurses, social workers, psychologists and doctors, were trained for the instruments' application *via* telephone. Older adults were informed about the objective of the study, were inquired concerning their understanding of their participation, and asked to state if they agreed to participate in the study. Older adults who agreed to participate in the study were asked a couple of questions ("What date is today?", or "Where are you right now; for example, in which town?") to assess their sense of space and time aiming to provide evidence of sufficient cognitive capacity. In addition, the criteria and experience of the interviewer were considered (because they are professionals who work with this population everyday), to determine if the older adults were answering consistently each of the questions. The interviewers were instructed that they could interrupt the interview if they considered that there were inconsistencies or incongruities in the responses of participants.

Measures

A sociodemographic questionnaire was used, including questions regarding sex, age, level of education, marital status, occupation, number of people the older adult lives with, and diagnosed medical conditions (hypertension, diabetes, cancer, respiratory diseases, autoimmune disease or immunosuppression, obesity, dyslipidemia).

The Impact of Event Scale-6 (IES-6), a brief form of the widely used Impact of Event Scale-revised (38), was used to assess posttraumatic stress reactions. The IES-6 includes two items for each of the dimensions of posttraumatic stress: intrusion, avoidance, and hyperarousal, and five response options ranging from 0 ("Not at all") to 4 ("Extremely"). A total score is computed, with higher scores indicating more severe event-related stress (39). For this study, we used corresponding Spanish translated items (40), and we instructed the respondents to answer them, considering the COVID-19 pandemic as the potentially stressful event, as follows: "Some people often experience difficulties during stressful events. In the following statements, think about the last 7 days and how stressful the situation we are living due to the coronavirus pandemic has been for you."

The Patient Health Questionnaire (PHQ-9) was also used, which is a self-administered 9-item scale that inquires the respondent about specific depressive symptoms corresponding to DSM-IV criteria in the last 2 weeks, according to a Likert scale with 0-to-3 values. A total score is computed, with upper values indicating a higher severity of depression, which can be ranked as follows: 0–4 = none, 5–9 = mild, 10–14 = moderate, 15–19 = moderately severe, 20–27 = severe (41). The PHQ-9 is a very common scale in clinical research worldwide; evidence of its validity has been reported for Latin American and Mexican populations (42, 43) and it has been used in online surveys (44, 45).

We also employed the Generalized Anxiety Disorder-7 (GAD-7), a seven-item self-administered scale based on the DSM-IV symptom criteria for general anxiety disorder (46) which also can be used to evaluate other forms of anxiety (47). Like the PHQ-9, the GAD-7 has 0-to-3 response options, with a total score between 0 and 21. Higher scores indicate higher severity of anxiety, with the following ordinal values: 0–4 = minimal, 5–9 = mild, 10–14 = moderate, 15–21 = severe. Values of good internal

consistency and validity have been reported for Mexican samples (48, 49). This scale has been used in an online survey (50).

Finally, a questionnaire of concerns and behaviors related to the COVID-19 pandemic was applied, consisting of 12 items designed aster a questionnaire by Wang et al. (51). The questionnaire is divided into five areas: (a) monitoring and usefulness of prevention measures against COVID-19; (b) information about the pandemic; (c) concern about COVID-19; (d) daily-life impairments due to COVID-19, and (e) family care. The first area contains four items that evaluate how much older adults have followed hygiene and social distancing measures to prevent infection by COVID-19, as well as the usefulness that these prevention measures have. The second area contains two items that assess both how often older adults seek information about the course of the pandemic, as well as the trust they have on that information. The area of concern about COVID-19 contains four items that assess the concern that older adults feel about themselves or a member of their family becoming infected and about their economic situation and security issues in their communities as a result of the pandemic. The perception of impact by COVID-19 is assessed with an item that asks older adults how much their daily lives have been affected by the pandemic. The last area of this questionnaire assesses the perception of the elderly regarding the care provided by their family from the start of the COVID-19 contingency. Participants were instructed to respond to each of these questions in a 0-to10 scale. The granulation of the scale was established in this fashion in order to allow for a more continuous variability of the responses, for each item was considered independently in the main analyses.

Information Analysis

Descriptive statistics were calculated for the sociodemographic characteristics of the participants. Considering the cut-off points of each of the scales used for the detection of older adults with stress, anxiety and depression, the participants were classified in each of the waves, and Cochran's Q test was performed to compare the proportions in the three waves. In addition, the total scores of the psychometric instruments, as well as each of the indicators of the questionnaire of concerns and behaviors related to the COVID-19 pandemic, were used to analyze the longitudinal changes through analysis of variance (ANOVA) for repeated measures, setting a value for statistical significance at $p < 0.05$ (two-tailed). For the effect size, η^2 was used, considering a value equal or below 0.01 as a meaningful effect. Statistical analyses were performed with SPSS version 25 software.

Ethical Considerations

All principles from the Declaration of Helsinki were followed. Participants were provided with information regarding the objectives of the study, the subject-matter addressed by the questions, voluntariness, and confidentiality of participation, and the institutions involved in the implementation of the study, and all were asked to provide informed consent. Before beginning the study, ethical approval was obtained from the Research Bioethics Committee from the Health Sciences Faculty, Anahuac University under the registration code CONBIOETICA-15-CEI-004-20160729.

RESULTS

Table 2 shows that significant differences were found in all indicators. Regarding the monitoring and usefulness of preventing measures against COVID-19, significant differences were found between the first wave with respect to the two follow-ups; that is, older adults in the first wave reported perceiving less usefulness from preventing measures, and complied less with the measures of both hygiene and social distancing compared with the two subsequent waves. Furthermore, concerning the indicators on monitoring and perceived utility of social distancing measures, a significant decrease was identified from the second to the third wave.

Older adults also reported searching less information, as well as lesser trust in the information about the pandemic in the first wave compared to the next two follow-ups; between the second and third waves, no significant differences were identified. Further, significant differences were found between the first wave compared to the follow ups. Specifically, at baseline, older adults reported having a lower concern of infection, both for them and their families, as well as a lower concern for security aspects in their community as a result of the pandemic. Likewise, the results showed that older adults reported lower impact of the pandemic on their daily life in the first evaluation than in the two subsequent waves, between which no significant differences were found. No significant difference was observed in this regard between the second and third wave. Results also showed that older adults reported greater concern in the second wave, compared to the first and third waves. Finally, results of the questionnaire indicated significant differences between the three waves in relation to perceived family care; specifically, perceived care was higher in the second wave compared for the first one, though the score dropped again in the third wave (see **Table 2**).

Regarding the differences in the proportions of older adults who presented stress, a high symptomatology of depression and anxiety was found in the three waves. Results in **Figure 2** showed differences in the distributions of the proportions so much in stress [$Q\ (2) = 20.89$, $p < 0.001$], as in depressive symptoms [$Q\ (2) = 74.14$, $p < 0.001$], as well as in anxiety [$Q\ (2) = 45.25$, $p < 0.001$]. In the case of anxiety and depressive symptoms, the proportion of older adults who were classified with the diagnosis increased in each of the waves; however, for post-traumatic stress, the percentage decreased in the second wave but increased again in the third one.

When analyzing if there were significant differences in stress, depressive and anxiety symptoms throughout the three waves, the findings showed significant differences in all the variables (see **Table 3**). The results indicated that older adults presented higher scores in the third wave with respect to the two previous ones. Likewise, significant differences were found between the first and second wave, except for the stress variable.

TABLE 2 | Comparisons of means of the indicators on concerns and behaviors related to the COVID-19 pandemic by wave.

Area	Indicator	Time	Comparison of means						*Post-hoc*
			Wave 1 (M1)		Wave 2 (M2)		Wave 3 (M3)		
			M	*SD*	*M*	*SD*	*M*	*SD*	
Monitoring and usefulness of prevention measures against COVID-19	1. Monitoring of hygiene measures	$F_{(2,2,302)} = 65.73$, $p < 0.001$; $\eta^2 = 0.02$	8.68	1.64	9.04	1.52	8.98	1.43	M1 < M2, M3 M2 = M3
	2. Usefulness of hygiene measures	$F_{(2,2,303)} = 20.99$, $p < 0.001$; $\eta^2 = 0.01$	8.92	1.49	9.12	1.44	9.06	1.38	M1 < M2, M3 M2 = M3
	3. Monitoring of social distancing measures	$F_{(2,2,303)} = 63.43$, $p < 0.001$; $\eta^2 = 0.05$	8.52	1.83	8.92	1.63	8.76	1.60	M1 < M2, M3 M2>M3
	4. Usefulness of social distancing measures	$F_{(2,2,303)} = 32.15$, $p < 0.001$; $\eta^2 = 0.02$	8.80	1.60	9.08	1.53	8.96	1.46	M1 < M2, M3 M2>M3
Information on the pandemic	5. Information search	$F_{(2,2,303)} = 16.42$, $p < 0.001$; $\eta^2 = 0.01$	7.55	2.41	7.83	2.32	7.72	2.32	M1 < M2, M3 M2 = M3
	6. Trust in information	$F_{(2,2,303)} = 49.80$, $p < 0.001$; $\eta^2 = 0.04$	7.37	2.35	7.80	2.25	7.89	2.09	M1 < M2, M3 M2 = M3
Concern about COVID-19	7. Concern about getting infected	$F_{(2,2,303)} = 61.48$, $p < 0.001$; $\eta^2 = 0.05$	8.21	2.28	8.68	2.07	8.72	1.88	M1 < M2, M3 M2 = M3
	8. Concern that a family member will get infected	$F_{(2,2,346)} = 40.01$, $p < 0.001$ $\eta^2 = 0.03$	8.65	2.00	8.99	1.93	9.01	1.61	M1 < M2, M3 M2 = M3
	9. Concern about their economic situation	$F_{(2,2,302)} = 23.44$, $p < 0.001$; $\eta^2 = 0.02$	8.91	1.71	9.12	1.60	8.91	1.66	M2>M1, M3 M1 = M3
	10. Concern for safety	$F_{(2,2,302)} = 26.10$, $p < 0.001$; $\eta^2 = 0.02$	8.27	2.09	8.58	2.02	8.52	1.89	M1 < M2, M3 M2 = M3
Daily-life impairment	11. Impact on their daily life because of the pandemic	$F_{(2,2,302)} = 116.54$, $p < 0.001$; $\eta^2 = 0.09$	8.08	2.27	8.80	1.94	8.71	1.77	M1 < M2, M3 M2 = M3
Family care	12. Family care as of the pandemic	$F_{(2,2,302)} = 43.37$, $p < 0.001$; $\eta^2 = 0.04$	8.85	1.82	9.17	1.63	9.07	1.49	M1 < M2, M3 M2>M3

DISCUSSION

The present study analyzed changes over time in behaviors and concerns regarding the COVID-19 pandemic, as well as changes in symptoms of depression, anxiety and stress at different times during the COVID-19 pandemic in a group of older adults. The findings showed that, overall, older adults reported lower scores of concerns about COVID-19 in the first wave than in subsequent waves. Although significant differences were not found in all cases between the second and third waves, the data showed a general increase in scores in the second one, which then dropped again by the last wave; however, while the scores dropped, they did not go back to the scores of the first moment. These results could be due to the moment that was being experienced, since there was a substantial increase in cases and deaths due to COVID-19 in the country (17) during the second wave. That is, the second wave was carried out at a time characterized by a significant increase in the number of cases and deaths; in addition, between 2 and 3 weeks had passed in within the third phase of the pandemic, where non-essential activities had been suspended in the country. By the third wave of this study (where scores decreased again), almost 4 months had passed since the start of the "new normal" phase, and although there were already a significant number of cases and deaths from COVID-19 (23), it appears that older adults progressively habituated themselves to an environment characterized by illness and death.

Regarding symptoms of depression, anxiety and stress, older adults presented the highest scores in the third wave, compared to the previous evaluations; however, in the case of stress, no significant differences were found between the first and second waves. In this sense, the comparison analyses between the proportion of adults who could be classified as having high scores for stress, anxiety and depression, also showed significant differences, where the proportion of older adults identified with significant symptomatology (according to the scales' cut-off scores) was higher within the third wave.

It is important to note that the percentages found were lower than those reported in national surveys, at least for depressive symptomatology, since this is the one for which information is available at a national level in this population. For example, the National Institute for Older Adults (52) suggests that depression is the most frequent affective disorder in people over 60 years of age in Mexico, and that it is present in 15–20% of the older adult population. Similarly, the National Health and Aging Survey 2018 (ENASEM), reports that 30.6% of the population aged 50 years or older, report five or more depressive symptoms, with women being the ones reporting more of these types of symptoms (37.2%) in contrast to men (21.9%) (53). In the present study, the

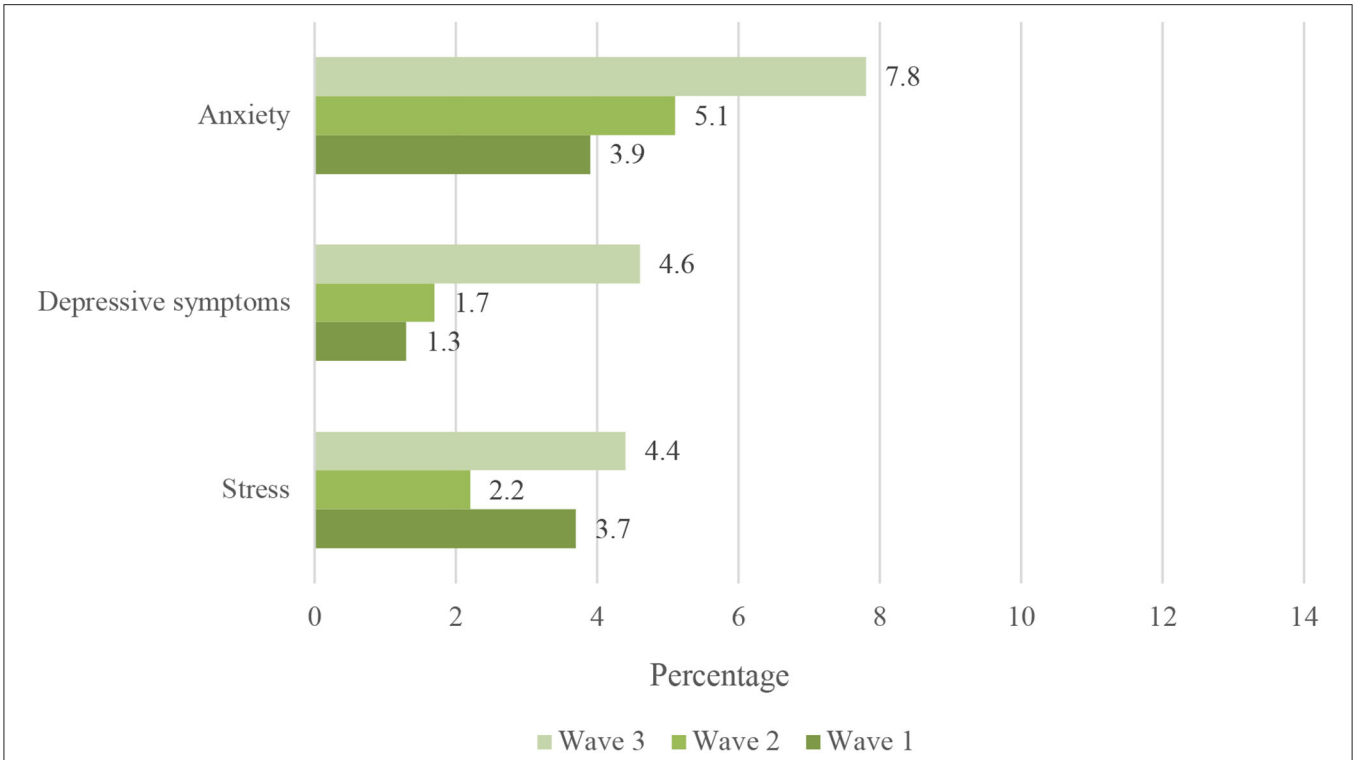

FIGURE 2 | Comparison of the proportion of older adults with detection of anxiety, depression and stress in the three waves.

TABLE 3 | Comparisons of means in stress, depressive symptoms and anxiety by wave.

	Statistical difference	Comparison of Means						*Post-hoc*
		Wave 1 (M1)		Wave 2 (M2)		Wave 3 (M3)		
		M	*SD*	*M*	*SD*	*M*	*SD*	
Stress	$F_{(2,2,303)} = 18.51$, $p < 0.001$; $\eta^2 = 0.01$	4.10	3.88	3.99	3.69	4.54	4.30	M3>M2, M1 M1 = M2
Depressive symptoms	$F_{(2,2,301)} = 67.05$, $p < 0.001$; $\eta^2 = 0.05$	2.51	3.49	2.70	3.77	3.63	4.85	M3>M2, M1 M2>M1
Anxiety	$F_{(2,2,303)} = 28.34$, $p < 0.001$; $\eta^2 = 0.02$	2.56	3.19	2.75	3.49	3.17	3.97	M3>M2, M1 M2>M1

highest percentage of older adults who were classified with high scores in depressive symptoms were 4.6% (data from the third wave), which is a percentage far below from what is reported at a national level, although we should not lose sight of the fact that the severity of depressive symptoms tends to worsen over time and that, most likely, we are only witnessing the natural course followed by this condition, given the situation that was experienced, without it having reached significant levels yet.

In addition to this, it is interesting that, although the evidence pointed to an alarming situation, mainly in terms of the number of cases and deaths, that would justify the presence of certain levels of stress, anxiety and depressive symptoms as part of an adaptive process to the prevailing situation, the narrative imposed by the federal authorities presented a different reality; that is, the messages issued indicated that the pandemic was under control, and that in a short time the situation would return to normal, which generated a sense of certain tranquility and relaxation on the part of the population.

As previously mentioned, it is very likely that the COVID-19 pandemic will have a psychological effect on people; however, by the time this paper was prepared, the evidence is still not entirely clear about the type of effects that could occur, and which populations are most affected. Some research (26–28) suggests that older adults showed some impairment in variables related to mental health, such as anxiety, depression and stress as a consequence of the COVID-19 pandemic. The present study adds to this direction of findings.

However, although effects on the mental health of the elderly were found in this study, these were of very mild effect size. It is important to consider some characteristics of this population,

which apparently has been able to adapt to the changes and challenges posed by the pandemic and the social distancing, since in some way this population did not see their daily dynamics significantly altered, given that most of them were already retired, had at least one support network (mostly a spouse or partner), maintained a certain economic stability, either because of the pension they receive or because of the support received through one of the government welfare programs, which places them in a stable situation, at least in basic needs. This is consistent with a report by Röhr et al. (30), where no changes in mental wellbeing related to the pandemic were found in a sample of older adults and, although some concern about the situation was reported by these participants, they also reported high perceived social support which could have allow them to cope with the adverse conditions of the pandemic.

Concerning limitations of this study, it is important to highlight that our recruitment was non-probabilistic, and thus generalization of results is limited. The participants were older adults included in a welfare program by the government of the State of Mexico, and thus are characterized by low income and, most likely given the demographics of this region of the country, residing in places with medium-to-low conditions of living, suggesting at least some homogeneous characteristics. A second important limitation is the fact that the interviews were conducted *via* telephone, and thus responses could have been biased from both the part of the respondent and the interviewer, since non-verbal information was not available. Besides, returning to the problem of sample representation, it is likely that we excluded an important sector of the population that has no access to a telephone line. We tried to control possible interviewer bias by providing training on the administration of the questionnaires.

Despite the fact that a significant number of studies have been generated for the understanding of the mental health repercussions that the COVID-19 pandemic has had on different populations, including the elderly, we cannot ignore the fact that there are many variables that could be contributing to the way in which the subjects are facing this problem, among them those of the context itself, like the type of decisions made by the different health authorities of the countries to face the pandemic. Thus, the present research provides evidence regarding the changes in the mental health of Mexican older adults, contributing to the monitoring of mental health during this pandemic, particularly in vulnerable populations, and also adding to the international evidence to be used in cross-cultural comparative studies.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the Research Bioethics Committee from the Health Sciences Faculty, Anahuac University, Number 202003 under the registration CONBIOETICA-15-CEI-004-20160729. The Ethics Committee waived the requirement of written informed consent for participation.

AUTHOR CONTRIBUTIONS

DB-O established cooperation with the recruitment site. DB-O and AG-G designed the online survey and prepared the database. AT-F drafted the manuscript and conducted statistical analyses. AG-G, AT-F, and DB-O provided critical review of the manuscript. All authors participated in the conceptualization and conduction of the study. The final version of this manuscript was approved by all authors.

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The Relationship Between Health Changes and Community Health Screening Participation Among Older People

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The utilization of health screening and other community health services has been a hot topic in China. Thus, this study examined the effect of health changes (self-rated health, physical health, and mental health) on older people's community health screening participation in China. We derived the data from the 2016 and 2018 waves of the Chinese Longitudinal Aging Social Survey (CLASS). This paper included 10,992 observations in two waves. We tested the causal relationship using the fixed effects model. Approximately 29.56% of the respondents participated in a health screening. Notably, after controlling for covariates, changes in mental and physical health both significantly influenced seniors' participation in health screenings (self-rated health: β = 0.188, 95% CI [−0.037, −0.413]; physical health: β = 0.078, 95% CI [0.032, −0.124]; mental health: β = 0.034, 95% CI [−0.057, −0.002]). The findings showed age, educational level, income level, and family support to be significant factors associated with community health screening participation. Additionally, we identified a partial mediating effect of mental health between self-rated health and health screening participation and a partial mediating effect of depression between physical health and health screening participation. The results highlight the important role of health changes in influencing participation and promoting health screening in China. On this basis, healthcare providers in the community may consider health changes as a screening criterion to promote health screening, guiding other health promotion and prevention programs while promoting healthy aging.

Keywords: older people, community health screening, health promotion, fixed effects model, health change

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INTRODUCTION

Successful aging originates from healthy aging. Healthy aging requires older people to improve and maintain their health (1). Poor health conditions increase healthcare costs and the caregiving burden (2). Primary health services for older adults are beneficial to improving the quality of life and preventing disease. However, it is difficult for community healthcare centers to target different reasons behind an uninvolved population, improve the participation initiative of older people, and expand the health service coverage.

Health screening is a primary preventive service in the community. It helps identify potential risk factors older people face, improve the effective use of health services, and carry out daily health management (3). The Chinese health department requires each community to conduct free health screening once a year for people over 65 years. In practice, most communities have made the policy more flexible to cover residents over 60. Previous studies have shown a negative association between health screening utilization and healthcare expenditures among older people (4). Thus, it is a valuable academic topic to increase the participation rate in health screening (5). Recent studies focus on reviews or reports. Empirical studies always pay attention to the health or economic effects of health screening utilization (6). However, few studies have investigated the role of health in promoting the participation of health screening services among community residents.

According to the Andersen healthcare utilization model, four dimensions influence healthcare utilization: environment, demographic characteristics, health behaviors, and health outcomes (7). In addition, the sixth iteration of the Andersen model considers the individual as the analytical unit. It goes beyond healthcare utilization to include health outcomes as the endpoint of interest. This model illustrates how health outcomes may influence health beliefs and needs with feedback loops. The Anderson model can provide theoretical support for using community health screening services.

Based on the Andersen model, utilization of health services affects health outcomes. Some studies argued older people with poor physical conditions would be unwilling to use healthcare services (8). However, other studies considered that healthy people have weak prevention awareness, so they are less likely to participate in health programs (9). Research also suggests that older adults inevitably experience discomfort due to the loss of social roles and support. From a psychological perspective, older people experience depression and anxiety after retirement from social production. This adverse mental status hinders their participation in community programs (10); thus, physical and mental health may interact with each other. For instance, limited physical ability may lead to negative self-rated health (11). The poor physical condition of older people may also lead to some psychological problems that prevent them from participating in community health programs (12). Therefore, we can infer the need for exploring internal mechanisms between different aspects of health factors.

Previous studies have mainly used health-related variables as dependent variables or applied only one dimension of health to examine its impact on health service utilization. As a result, these studies lack a multidimensional examination of health influence on health service participation. In this study, we divided health changes into three dimensions: self-rated health (SRH), physical health, and mental health, to examine the effects of health changes in each dimension on changes in community health screening participation. First, we analyzed the impact of health changes on health screening participation based on different health dimensions. Second, if we found an influence, we further analyzed whether there is an influence mechanism between different health dimensions and health screening participation, such as a mediation or moderation effect. Finally, we provided suggestions to improve the utilization of community health services.

This study's contributions are as follows. First, where previous studies focused on health screening focus in the clinical area, this study describes the current participation rate of health screening and improved participation rate from a public health perspective. Second, this study used panel data to explore the impact of health changes on participation changes from a dynamic perspective. Third, this study also argues for an internal mechanism between the three health dimensions, which can help community workers pinpoint the health status of non-participants more rigorously from a practical perspective.

METHOD

Sampling

We selected data from the 2016 and 2018 Chinese Longitudinal Aging Social Survey (CLASS). Class is a national and continuous large-scale social survey project designed by Renmin University of China's Institute of Gerontology. The baseline survey included 11,511 respondents in 2014. The first follow-up survey traced 6,583 older people from the baseline survey and added 4,888 new samples in 2016. The second follow-up survey traced 9,672 samples, and 1,746 samples were new in 2018. The 2016 survey introduced an investigation of community health services, so we only used data from the 2016 and 2018 surveys. After removing missing samples, newly added samples in 2018 (to avoid non-uniform weights for different time point groups), and missing data in main variables, we had 10,992 observations finally.

Measurements

Dependent Variable

The dependent variable was participation in community health screening. We measured it by the experience of free community health screening participation in the past 12 months (1 = *yes*; 0 = *no*).

Independent Variables

We measured health changes with three variables: physical health, mental health, and self-rated health (SRH). We used the score of activities of daily living (ADL) to measure physical health. Furthermore, the CLASS questionnaire uses the Lawton scale to evaluate ADL (13). This scale has 14 items to identify respondents' ability to bathe, dress, go to the toilet, eat, visit a neighbor's house, wash clothes, and cook. Each item has three selections (1 = *No need for help from others,* 2 = *Some help is needed,* 3 = *I can't do it at all*). We added 14 items and obtained the total score of ADL. The higher the score, the poorer the individual's ability to perform the activities of daily living. The Cronbach's α coefficient of the scale was 0.912.

To measure mental health, we used the "Center for Epidemiological Studies Depression Scale" (14) to report negative psychological experiences in the last week. The scale includes nine items. The higher the total score, the more severe the depression. The Cronbach's α coefficient of the scale was 0.756.

We asked, "How do you feel about your health compared with your peers?" to measure SRH. The question response range was 1 = *Very good*, 2 = *good*, 3 = *fair*, 4 = *not good*, 5 = *very bad*. We merged the first two categories to represent "healthy" and the latter three categories to represent "unhealthy."

Covariates

Covariates included demographic factors and social factors. Demographic factors were age, gender, residence (0 = *rural*, 1 = *urban*), marital status (0 = *unmarried*, 1 = *married*), education level (0 = *illiterate*, 1 = *primary school*, 2 = *middle and high school*, 3 = *junior college and above*), income (the logarithm of annual income). The social factors included living with children (0 = *No*, 1 = *Yes*), family support, friend support, and community type (1 = *neighborhood community*, 2 = *mixed unit community*, 3 = *affordable housing communities*, 4 = *commercial housing complex*, 5 = *high-end residential area*, 6 = *urban village*, 7 = *rural*).

Data Analysis

Model Selection

Mixed regression, random effects, and fixed effects models are all different strategies with longitudinal data. Mixed regression only aggregates all time points and assumes no individual effects. We drop mixed regression model because it only expands the sample size and ignores the omitted heterogeneity among individuals. The fixed effects and random effects models can solve the estimation bias of missing variables. The main difference is that the fixed-effects model requires the explanatory variables to vary over time, while the random-effects model requires as many control variables as possible that do not vary over time. In this study, the key independent variables all vary over time, but there are also many control variables that do not vary over time. Thus, we further performed the Hausman test to determine the final model and found that the fixed effects model was more suitable than the random effects model ($p < 0.001$).

The specific model settings are as follows:

$$\ln\left(\frac{p_{i1}}{1-p_{i1}}\right) = u_{i1} + \beta_1 health_{i1} + \beta_2 controlA_{i1} + \beta_3 controlB_i + \nu_i + \varepsilon_{i1} \quad (1)$$

$$\ln\left(\frac{p_{i2}}{1-p_{i2}}\right) = u_{i2} + \beta_2 health_{i2} + \beta_2 controlA_{i2} + \beta_3 controlB_i + \nu_i + \varepsilon_{i2} \quad (2)$$

We use a subtraction formula: Equation (2)-Equation (1):

$$\ln\left[\Pr(y_{i1}=0, y_{i2}=1)/\Pr(y_{i1}=1, y_{i2}=0)\right] = (u_{i2}-u_{i1}) + \beta_1\left(health_{i2} - health_{i1}\right) + \beta_2\left(control\ A_{i2} - control\ A_{i1}\right) + (\varepsilon_{i2}-\varepsilon_{i1}) \quad (3)$$

Equation (1) represents the model from the 2016 wave in the survey (t = 1), whilst equation (2) represents the model from the 2018 wave (t = 2). y_{it} represents whether individual *i*will participate in the community health screening during the two periods, y has only two values, 0 and 1. p_{it} is the probability when y_{it}=1. u_{it} represents the intercept over time. $health_{it}$ represents the independent variables at two time periods, $controlA_i$ represents the control variable that varies with time, including age, marital status, economic level, family support and friend support, $controlB_i$represents the control variable that does not change over time, including gender, education level, community type, cohabitation, and place of residence. ν_i represents the unobserved heterogeneity, which is regarded as a fixed parameter that does not change with time. ε_{it} represents the random error that changes over time. $\beta_1\beta_2\beta_3$ represents the influence of the explanatory variable on the dependent variable. It can be seen from equation (3) that the parts of the control variables and missing variables that do not change with time are all differentiated. We have achieved the main purpose of controlling other missing variables that have not been observed.

Analysis Process

First, we established three nested models to examine the impact of three dimensions of health change on the community health screening participation changes during the two time periods (2016 and 2018). Second, we performed mediation analysis to identify the internal relationship between three health variables in the health screening participation. Third, we used Stata and Mplus software for data analysis.

RESULTS

Descriptive Analysis

Table 1 shows the basic information of variables. We found that community health screening increased from 25.56 to 33.55% in 2 years. In the total sample, the participation rate in health screening was 29.56%. The average score of ADL was 15.11, which represents a healthy physical condition of the older persons (the range of the ADL score was 14–40). However, the psychological status of the older people is not good, as the average score of depression was 14.44, and the range of depression scores was 0–27. In addition, while only 27.51% of the seniors ranked themselves as healthy, this percentage declined by 1.93% between 2016 and 2018.

The average age of the older people was 70.63. Both sexes were about equally represented in the analysis. Regarding education, 36.09% of the seniors reported at least a middle school education. Most seniors lived in the urban area (64.37%), remained married (71.96%), and lived with their children (63.74%). In **Table 1**, we reported the Logarithmic form of income; the average income of the older people was ¥15,473.51 per year. Based on State Statistics Bureau data, the national per capita income is ¥32,189 (15), so the economic condition of the older persons was a little lower than the overall level.

Results From the Fixed Effects Model

Model 1 (shown in **Table 2**) examined the influence of health changes in SRH on survey participants' involvement in health screenings. The results showed that improvement of the SRH has a very significant positive impact on seniors' participation in health screenings (*sig*0.05). Compared with 2016, older people

TABLE 1 | Basic information of all variables.

	Total sample		2016		2018	
	***N* (%)**	**Mean (SD)**	***N* (%)**	**Mean (SD)**	***N* (%)**	**Mean (SD)**
Participation in health screening	3,249 (29.56)	0.29 (0.46)	1,405 (25.56)	0.25 (0.44)	1,844 (33.55)	0.33 (0.47)
ADL		15.11 (2.88)		15.16 (2.81)		15.07 (2.96)
Depression		14.44 (3.50)		14.75 (3.70)		14.10 (3.24)
SRH (healthy)	3,024 (27.51)	0.27 (0.45)	1,565 (28.48)	0.28 (0.45)	1,459 (26.55)	0.26 (0.44)
Age		70.63 (7.27)		69.63 (7.20)		71.63 (7.20)
Gender (male)	5,504 (50.07)	1.50 (0.50)	2,752 (50.07)	1.50 (0.50)	2,752 (50.07)	1.50 (0.500)
Residence (urban)	7,059 (64.37)	0.64 (0.48)	3,546 (64.81)	0.65 (0.48)	3,513 (63.92)	0.64 (0.48)
Marital status (married)	7,910 (71.96)	0.72 (0.45)	4,041 (73.54)	0.73 (0.44)	3,868 (70.38)	0.70 (0.46)
Educ (illiterate)	3,640 (33.11)	2.06 (0.89)	2,125 (38.66)	2.01 (0.94)	1,515 (27.57)	2.12 (0.83)
Primary school	3,385 (30.80)		1,443 (26.26)		1,942 (35.33)	
High and middle school	3,573 (32.51)		1,653 (30.08)		1,920 (34.93)	
Junior college and above	394 (3.58)		275 (5.00)		119 (2.17)	
Income		8.80 (1.47)		9.24 (1.42)		8.38 (1.39)
Cohabit with children (Yes)	7,006 (63.74)	0.64 (0.48)		1.00 (0.00)		0.27 (0.45)
Family support		7.93 (3.52)		8.57 (4.06)		7.28 (2.72)
Friend support		6.89 (3.95)		7.47 (4.56)		6.31 (3.12)
Community type (neighborhood community)	2,099 (19.99)	4.49 (2.38)	1,030 (20.59)	4.43 (2.43)	1,069 (19.45)	4.54 (2.33)
Mixed unit community	993 (9.46)		586 (11.71)		407 (7.41)	
Affordable housing communities	162 (1.54)		92 (1.84)		70 (1.27)	
Commercial housing complex	2,375 (22.62)		968 (19.35)		1,407 (25.60)	
High-end residential area	106 (1.01)		61 (1.22)		45 (0.82)	
Urban village	846 (8.06)		368 (7.36)		478 (8.70)	
Rural	3,918 (37.32)		1,898 (37.94)		2,020 (36.75)	

TABLE 2 | The effect of health changes on community health screening participation.

Variables	**Model 1**			**Model 2**			**Model 3**		
	Coef. (SE)	***P*-Value**	**95% CI**	**Coef. (SE)**	***P*-Value**	**95% CI**	**Coef. (SE)**	***P*-Value**	**95% CI**
SRH	0.206 (0.104)	0.047	(0.003, 0.409)	0.130 (0.113)	0.249	(−0.091, 0.351)	0.188 (0.115)	0.102	(−0.037, 0.413)
Depression				−0.028 (0.014)	0.044	(−0.055, −0.001)	−0.029 (0.014)	0.034	(−0.057, −0.002)
ADL							0.078 (0.023)	0.001	(0.032, 0.124)
Age	0.643 (0.066)	0.000	(0.513, 0.774)	0.707 (0.072)	0.000	(0.565, 0.849)	0.722 (0.073)	0.000	(0.578, 0.865)
Residence	−0.546 (0.295)	0.064	(−1.126, 0.033)	−0.427 (0.322)	0.185	(−1.058, 0.204)	−0.432 (0.319)	0.176	(−1.058, 0.194)
Marital status (married)	0.360 (0.253)	0.154	(−0.135, 0.856)	0.381 (0.272)	0.162	(−0.153, 0.914)	0.474 (0.277)	0.087	(−0.069, 1.016)
Educ (illiterate)	−0.179 (0.072)	0.013	(−0.320, −0.038)	−0.213 (0.077)	0.006	(−0.364, −0.061)	−0.208 (0.078)	0.008	(−0.361, −0.055)
Income	0.075 (0.045)	0.097	(−0.014, 0.163)	0.108 (0.051)	0.035	(0.008, 0.208)	0.118 (0.052)	0.022	(0.017, 0.220)
Cohabit with children (Yes)	0.333 (0.147)	0.023	(0.045, 0.620)	0.281 (0.158)	0.075	(−0.029, 0.591)	0.290 (0.159)	0.068	(−0.021, 0.601)
Family support	0.087 (0.016)	0.000	(0.055, 0.119)	0.082 (0.018)	0.000	(0.047, 0.117)	0.080 (0.018)	0.000	(0.045, 0.115)
Friend support	−0.013 (0.015)	0.385	(−0.042, 0.016)	0.006 (0.016)	0.712	(−0.026, 0.038)	0.006 (0.016)	0.700	(−0.026, 0.038)
Community type (neighborhood community)	−0.030 (0.037)	0.415	(−0.102, 0.042)	−0.020 (0.038)	0.604	(−0.093, 0.058)	−0.015 (0.038)	0.695	(−0.091, 0.060)
LR Chi2		229.75			249.11			261.22	

**The gender variable did not differ between groups and was therefore automatically excluded by the model.*

with good SRH in 2018 were more likely to participate in community health screening.

Model 2 introduced the depression score based on Model 1. The influence of SRH changes on dependent variables was no longer significant, and its coefficient was significantly reduced (from 0.206 to 0.130). Notably, the effect of change in mental health status on health screening participation was significant ($sig < 0.05$). Compared with 2016, older people with improved mental health in 2018 were more likely to participate in community health screening.

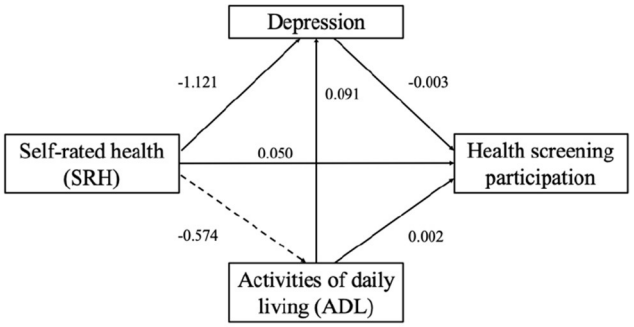

FIGURE 1 | Structural equation model for the relationship between SRH, ADL, depression and health screening participations.

TABLE 3 | Bootstrapping test results for mediation effects.

Path	95% CI	
SRH→depression→health screening participation		
Direct effect	0.023	0.065
Indirect effect	0.0001	0.006
SRH→ADL→health screening participation		
Direct effect	0.028	0.068
Indirect effect	−0.001	0.003
Depression→ADL→health screening participation		
Direct effect	−0.006	−0.001
Indirect effect	−0.0003	0.0001
ADL→depression→health screening participation		
Direct effect	−0.006	−0.001
Indirect effect	−0.001	−0.0001

Model 3 included an ADL score based on Model 2. We found that the impact of SRH changes on the dependent variable was no longer significant, although the effects of mental health changes remained statistically significant ($sig < 0.05$). After including all health variables, the incidence ratio of older adults' participation in community health screening increased by 8% ($e^{0.078} - 1 = 0.08$), accompanied by a statistically significant one point increase in their ADL scores ($sig < 0.05$). This finding suggested that a decline in older adults' physical health can influence their decision to participate in community health screening.

In summary, the improvement across all three dimensions of health positively impacted the community health screening participation among older people. However, with the control of change in mental and physical health, the SRH coefficient changed and was no longer significant. In terms of other control variables, compared with 2016, older adults who enjoyed better living standards and better family relationships had an increased probability of participating in community health screening in 2018.

Results From the Mediation Effect Model

We found that health changes (SRH, ADL, and depression) affect health screening participation differently (see **Table 2**). SRH was significantly associated with health screening participation in Model 1 (**Table 2**), while the coefficient of SRH was insignificant after including ADL and depression. We performed a structural equation model (SEM) to test the internal relationship between three heath variables (16–19). **Figure 1** shows a simplified version of the mediated model.

We tested the mediating effects with a bias-corrected bootstrap procedure (16, 17). If the 95% confidence interval for the indirect effect did not include 0, the mediating effect was statistically significant. On the other hand, if the 95% confidence interval for the direct effect included 0, it was fully mediated (**Table 3**).

Overall, we found a partial mediating effect of depression in SRH and health screening participation and no mediating effect of ADL in SRH and health screening participation. However, there was a partially mediated role of depression in ADL and health screening participation.

DISCUSSION

While life expectancy in China is increasing, older persons may spend more of their advanced years in poor health and living with disabilities. As a result, the demand for health services amongst older people is higher than in other groups. This demand is diverse, complex, and specialized. To transfer demand to effective utilization, many scholars have conducted studies on the current utilization of and participation in health services by older persons. However, against the backdrop of population aging in China, the mismatch between health service demand and health service utilization has led to health service non-utilization among older adults in China. With this in mind, this paper investigated the utilization of community health screening by older persons from the different health dimensions based on a nationally representative survey.

Theoretical Implications

Consistent with the results from previous studies (20–22), the present study identified a significant relationship between age, education level, income, family support, and participation in health screening. Notably, socioeconomic factors were significant predictors of involvement in community health screening amongst older people. Age influences participation in community health screening, with relatively high participation rates among older seniors, a finding that is consistent with previous studies (23). However, the participation rate decreased the higher the individual's education level. We speculated that seniors with higher education levels are more health-conscious. Therefore, they demand higher quality and quantity of health screenings, and the community health screenings provide only basic screening items. We also found income level as another important influencing factor for health service utilization. However, although community health screenings are free for residents, our results still showed that the participation rate of low-income groups in community health screening was low. We propose two reasons for this: first, low-income groups do not know about the health screening program; second, the

awareness of self-health management among low-income groups is insufficient.

In addition, this study provides new empirical evidence. We found that older adults' higher ADL scores and improvements in mental health and self-rated health can increase the participation rate in community health screening. However, we note that the relative roles of physical and mental health changes were greater. Meanwhile, there was a mediating effect of depression between SRH and community health screening participation. The results of the mediating effect indicate the importance of psychological adjustment for older adults, especially those with poor self-rated health. Psychology research has found that positive experiences and optimism can balance the frustration caused by negative events (e.g., physical illness). In addition, adopting effective multiple coping strategies can encourage the active participation of older adults in community activities.

Limitations and Future Directions

Previous studies have generally only used cross-sectional data for analysis, lacking causal inference for the changes in different periods. In addition, previous research tends to choose one-dimensional indicators for health measurements, thus lacking comparisons of the extent and mechanisms of health effects on health screening participation in different dimensions—our research addressed this gap. However, this paper also has several limitations. First, the community health screening was free of charge, so its impact may differ from self-paying health screening when examining the impact of health changes on health screening participation. Due to the limits imposed by the questionnaire setting, future studies could compare two forms of health screening programs to understand factors influencing participation and adopt different strategies to promote health management among older people. Second, although this study applied panel data to analyze the causal relationship, the influencing factors were pre-set by the questionnaire. We suggest that future studies could explore a deeper range of influencing factors through in-depth interviews. Third, we lack the inclusion of other community health services variables, which may lead to some missing findings and limit the generalizability of our results. For instance, if an individual has other health issues and is seeing health professional(s) regularly, they are likely not to present for this type of generalist health screening. Further studies could include other health services as control variables.

Practical Implications

This study has several important policy and intervention implications. First, the government should implement more psychological interventions for older adults with poor self-rated health to help them adopt positive and effective coping strategies, increasing their motivation to participate in community health programs. Second, we need to change the awareness of "remedial" participation. Studies have shown that older adults with deteriorating physical health will increase their engagement in community health screening. However, the community should disseminate preventive knowledge and transfer "remedial" to "preventive" participation by targeting those who have not developed problems or are in good health. Third, we recommend targeting low-income groups when designing community health screening plans because community health screening is free and should not be related to income level. However, the study results still show a positive association between income level and community health screening. Therefore, at the level of policy guidance, it is necessary to promote the keyword "free" and bolster the awareness of health management among low-income groups. In addition, GPs and their assistants can further promote this program when making follow-up visits.

CONCLUSION

This study investigated the impact of health changes among older people on participation in community health screening. The findings suggest that mental health, physical health, age, educational level, income level, and family support promote older persons' participation in community health screening programs in China. Community health screening is a welfare policy, and it is free of charge. Participating in community health screening helps older persons understand their basic health conditions and lets their GPs know more about their needs to develop updated and precise prevention plans. Thus, the ultimate goal of the community is to have all seniors participate in the health screening program. This study can help communities target those groups that do not participate in the programs and recommend measures to promote their uptake.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary materials, further inquiries can be directed to the corresponding author/s.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Renmin University of China. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

BD has undertaken data curation and methodology. YM has performed the formal analysis and finished the final editing. Both authors read and approved the final manuscript.

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Epidemiology of Constipation in Elderly People in Parts of China: A Multicenter Study

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Purpose: To investigate the epidemiological characteristics of constipation in people aged 65 years and older in several regions of China.

Patients and Methods: A cross-sectional study based on a cluster sampling design was conducted in four cities of China: Tianjin, Xiamen, Cangzhou and Harbin. A total of 5,222 cases (age ≥ 65 years) were recruited, and the survey was conducted *via* centralized and household questionnaires that included the following: basic demographic characteristics such as sex, age, education, marital status, living status and occupation; social activities; duration of sleep at night; duration of menstruation and delivery times (in females); and if the participant had constipation symptoms, the severity of constipation. Constipation was diagnosed according to the Rome IV criteria.

Results: Of the 5,222 participants, 919 were diagnosed with constipation. The prevalence of constipation was 17.60% in elderly people ≥65 years old. Prevalence increased with age and was significantly higher in females than males ($P < 0.05$). Prevalence was lower in the manual compared to the non-manual worker group, and significantly increased with decreasing duration of night sleep ($P < 0.05$). Older age, female sex and shorter sleep duration at night were risk factors for constipation in elderly people.

Conclusion: The prevalence of constipation in the elderly people in four cities of China was 17.60%, and was significantly affected by age, sex and sleep duration at night.

Keywords: constipation, elderly, epidemiology, prevalence, risk factors

INTRODUCTION

Constipation is one of the most common functional gastrointestinal (GI) disorders and has the following symptoms: lumpy or hard stools, difficulty in defecation and decreased defecation frequency (1). It is a heterogeneous disorder with multiple causes, including dysfunction of intestinal motility, visceral sensitivity, anorectal musculature and the enteric nervous system (1, 2). The prevalence of constipation in the general population worldwide ranges from 0.7 to 79%

(median 16%) (2). Constipation can be divided into two main categories: primary and secondary. Primary constipation is further divided into three main types: functional, outlet dysfunction, and slow transit constipation. Secondary constipation may be caused by dietary and exercise patterns, disease processes and adverse effects of medication (3, 4).

In recent years, constipation in elderly people has become a worldwide problem because of the characteristics of this population, such as decreased social activity, psychological disorders, pelvic floor aging, co-morbidity and effects from multiple drug use (5). Constipation has a major negative impact on quality of life relevant to both physical and emotional wellbeing and poses a large economic burden (4, 6–8), because constipation not only causes pain in elderly people but also leads to many complications such as hemorrhoids, fecal impaction, bowel perforations, fecal incontinence, rectal prolapse, volvulus, and excessive perineal or inadequate perineal descent (3, 4, 9). The therapies that can eliminate constipation include change of lifestyle and diet, alleviation of risk factors, over-the-counter or prescription laxatives and enemas. Nevertheless, only 22.2% of patients seek medical advice (10). It was reported that only 15.7–48.0% of patients use laxatives to treat their symptoms and 19.0% of patients do not proceed with any intervention (2).

There have been many studies on the prevalence of constipation, but the results differ greatly and there are few multicenter epidemiological investigations for constipation in Chinese elderly people. Population-based studies have reported that the prevalence range of constipation in North America is 2–27%, with most clustering around 15% (11, 12), while the prevalence of constipation in China is 3–11%, with prevalence of 13–32.6% in elderly people (5, 10, 13). Previous studies have shown that constipation prevalence is significantly affected by such factors as age, sex, occupation type, education, dietary habits, physical exercise and past history of other related illnesses (2, 5, 10, 13, 14). However, there are limited studies concerning the effects of sleep, menstruation and delivery on constipation. The aim of this study was to investigate the epidemiological characteristics of constipation in people aged 65 years and older in several regions of China and to identify the associated factors so that new preventive measures and therapeutic strategies can be applied.

MATERIALS AND METHODS

Research Subjects

A cross-sectional study based on an epidemiological survey of dementia in elderly people (≥65 years old) in four cities in China was conducted during June–October 2019. Based on the cluster sampling design, we recruited samples from the communities of Tianjin, Xiamen, Cangzhou and Harbin cities, located in the north, northeast and south regions of China, constituting the baseline population structure data of China.

Based the multistage cluster sampling design, we considered geographical region, economic development level and population size according to 2010 census data and selected the four cities as centers. In the second stage, we selected a total of four urban areas and three towns for which the per capita gross domestic product (GDP) was closest to the median GDP of urban and rural populations. Finally, a total of nine communities and 69 villages were selected from the selected urban areas and towns.

All participants included were 65 years or older, were listed in the census of the community registry office and had lived in the community for at least 1 year preceding the survey date. Those listed in the census but institutionalized were not included in the study. Subjects who refused to participate, were untraceable, had a life-threatening illness, were deceased, or were unable to participate in the assessment because of inadequate hearing, speaking or vision were excluded. The protocol for this study was reviewed and approved by the Ethics Committee at Tianjin Huanhu Hospital. Informed consent was obtained from each subject either directly or from his or her guardian.

Research Method

The survey was conducted *via* centralized and household questionnaires that included the following: basic demographic characteristics such as sex, age, education, marital status, living status and occupation; social activities; duration of sleep at night; duration of menstruation and delivery times in females; and, if the participant had constipation symptoms, the severity of constipation. Prior to conducting this survey, a pilot study surveyed one village to test the epidemiological methods. The research team was composed of clinicians and assistants who were trained for 1 week and unified the survey methods and standards. The questionnaire survey was conducted face to face with the assistance and coordination of community workers. The survey forms were filled manually by the research team, and the questionnaires were reviewed and administered by qualified and experienced neurologists with the assistance of gastroenterologists who all underwent the same training at Tianjin Huanhu Hospital in Tianjin, China. All research teams and experts received the same 1-week training on collecting information, neuropsychiatric scale assessments and diagnosis, and participated in a retraining course every 2 months.

The Rome IV criteria for constipation were taken as the standard reference with the following constipation assessment indicators. These included two or more defecation difficulties of the following: straining, having lumpy or hard stools, having sensation of incomplete evacuation, having sensation of anorectal obstruction/blockage, needing manual maneuvers to facilitate defecation more than one quarter of times or having fewer than three spontaneous bowel movements per week. The criteria were fulfilled for the last 3 months, with symptom onset at least 6 months prior to diagnosis (1). The participants who met the above criteria for constipation were asked about the severity of constipation, which was classified into four grades according to the frequency of constipation symptoms and interference in daily life: occurs rarely, sometimes, usually or always and interferes with daily life, represented by values of 1, 2, 3 and 4, respectively (15).

Statistical Method

All analyses were performed with SPSS version 22.0. The prevalence of constipation was estimated for the entire study population and was also stratified by basic information such

as age, sex, education years and so on. The measurement data were expressed as mean ± standard deviation. The enumeration data were expressed as constituent ratios (%) or rates (%), and comparisons were performed by Chi-square test. Binary logistic regression analysis was conducted to obtain the risk factors of constipation by taking age, sex, sleep duration at night and occupation as independent variables, which were significant in the Chi-square test. Two-tailed $P < 0.05$ was considered significant.

RESULTS

The total number of participants aged ≥65 years in these communities and villages was 5,461; however, due to refusal ($n = 106$), death ($n = 10$), migration ($n = 12$), hearing loss ($n = 91$), aphasia ($n = 11$) or other life-threatening illness ($n = 9$), a total of 5,222 completed the final interview. Overall, we studied 5,222 participants from four cities in China and the mean age of the sample was 72.26 ± 6.09 years.

Demographic Characteristics of Participants

Of all participants, 2,269 were male (43.45%) with mean age of 72.57 ± 6.32 years and 2,953 were female (56.55%) with mean age of 72.02 ± 5.90 years. Regarding age of the participants, 2,139 were 65–69 years (40.96%), 1,467 were 70–74 years (28.09%), 849 were 75–79 years (16.26%), 758 were 80 years and older (14.52%) and nine had missing data (0.17%). The total participants were divided into groups by years of education: 1,218 had no schooling (23.32%), 2,408 received 1–6 years of education (46.11%), 927 received 7–9 years of education (17.75%), 409 received 10–12 years of education (7.83%), 242 received more than 12 years of education (4.63%) and 18 had missing data (0.34%).

Of all participants, 45 were single (0.86%), 3,939 were married (75.43%), 45 were divorced (0.86%), 1,156 were widowed (22.14%) and 37 had missing data (7.09%). Concerning living status, 3,599 lived with a spouse (68.92%), 1,115 lived without a spouse (21.35%) and 508 lived alone (9.73%). Regarding occupation of participants, 4,183 were manual workers (80.10%), 972 were non-manual workers (18.61%) and 67 had missing data (1.28%). Of all participants, 2,336 took part in social activities for 0–3 days every week (44.73%), 2,833 took part in social activities for 4–7 days every week (54.25%) and 53 had missing data (1.01%).

Participants were divided into groups by the duration of sleep at night: 31 cases slept <2 h every night (0.59%), 411 slept 2–4 h every night (7.87%), 1,331 slept 4–6 h every night (25.49%), 2,253 slept 6–8 h every night (43.15%), 953 slept more than 8 h every night (18.25%) and 243 had missing data (4.65%) (**Table 1**).

The total female participants were divided into groups by the duration of menstruation: 183 cases had duration of <25-years (6.2%), 343 had 25–29-years (11.6%), 1,143 had 30–34-years (38.7%), 998 had more than 35-years (33.8%) and 286 had missing data (9.7%). In addition, the total female participants were divided into groups by delivery times: 2,277 cases (77.1%) had three deliveries or less, 568 (19.2%) had more than three deliveries and 108 had missing data (3.7%).

TABLE 1 | Demographic characteristics of the study participants.

Items	Num	Percentage
All study participants	5,222	100%
Sex		
Male	2,269	43.45%
Female	2,953	56.55%
Age group (y)		
65–69	2,139	40.96%
70–74	1,467	28.09%
75–79	849	16.26%
≥80	758	14.52%
MD	9	0.17%
Education (y)		
0	1,218	23.32%
1–6	2,408	46.11%
7–9	927	17.75%
10–12	409	7.83%
>12	242	4.63%
MD	18	0.34%
Marital status		
Single	45	0.86%
Married	3,939	75.43%
Divorced	45	0.86%
Widowed	1,156	22.14%
MD	37	0.71%
Living status		
With spouse	3,599	68.92%
Without spouse	1,115	21.35%
Alone	508	9.73%
Occupation		
Manual worker	4,183	80.10%
Non-manual worker	972	18.61%
MD	67	1.28%
Social activities		
0–3 d/week	2,336	44.73%
4–7 d/week	2,833	54.25%
MD	53	1.01%
Sleep duration		
<2h	31	0.59%
2–4h	411	7.87%
4–6h	1,331	25.49%
6–8h	2,253	43.15%
≥8 h	953	18.25%
MD	243	4.65%

MD, Missing data.

Prevalence of Constipation

Of all participants, 919 were diagnosed with constipation, making a total prevalence rate of 17.6% (**Table 1**). The number of people with severity grades of 1, 2, 3 and 4 were 613, 263, 41

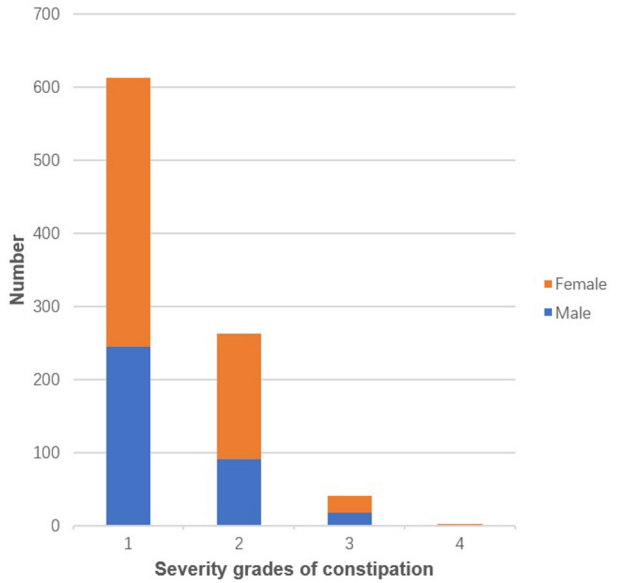

FIGURE 1 | The number of different severity grades of constipation.

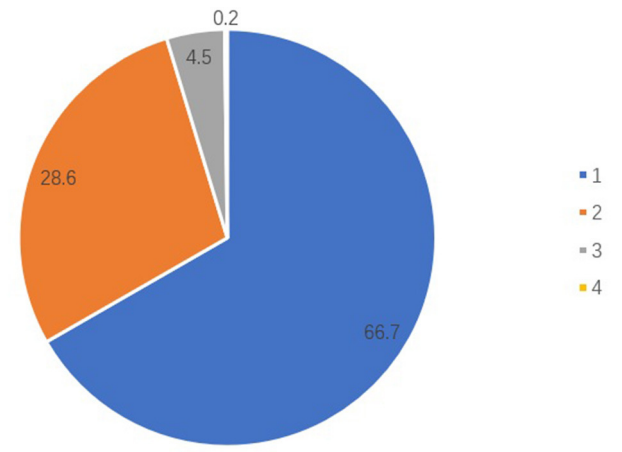

FIGURE 2 | The proportion of different severity grades in people with constipation.

and 2, respectively (**Figure 1**); in people with constipation, the proportions of these different severity grades were 66.7, 28.6, 4.5 and 0.2%, respectively (**Figure 2**). The proportion decreased with increasing severity grades.

Prevalence of Constipation According to Different Characteristics of Respondents

The prevalence of constipation was significantly higher ($\chi 2 = 12.030$, $P = 0.001$) in the female (19.2%) than the male group (15.5%). There were 299 (14.0%), 263 (17.9%), 159 (18.7%) and 197 (26.0%) cases with constipation in the respective age groups proceeding from younger to older. The prevalence of constipation significantly increased with age ($\chi 2 = 56.959$, $P < 0.001$). Regarding occupation, there were 713 cases (17.0%) and 194 cases (20.0%) with constipation in the respective groups. The prevalence of constipation was significantly lower in the manual compared to non-manual worker group ($\chi 2 = 4.618$, $P = 0.032$). Regarding the duration of sleep at night, there were 10 (32.3%), 91 (22.1%), 280 (21.0%), 361 (16.0%) and 139 cases (14.6%) with constipation in the respective groups, with prevalence significantly increasing with decreasing sleep duration at night ($\chi 2 = 30.951$, $P < 0.001$). In women, there were 422 cases (18.5%) with constipation in those with three deliveries or less and 127 (22.4%) for those with more than three deliveries. The prevalence of constipation was significantly higher in the latter group ($\chi 2 = 4.273$, $P = 0.039$). In addition, there were no significant differences in constipation prevalence among the education, marital status, living status, social activity and menstruation duration groups ($P > 0.05$) (**Table 2**).

Logistic Regression Analysis of Risk Factors for Constipation

Binary logistic regression analysis was conducted to determine the risk factors of constipation by taking age, sex, sleep duration and occupation as independent variables, which were significant in the Chi-square test. The logistic regression chose forward stepwise regression method. The results showed that females had a significantly increased risk of constipation compared to males [odds ratio (OR) = 1.238, 95% confidence interval (CI) 1.064–1.441, $P = 0.006$]. Compared to the youngest group (65–69 years), increasing age significantly increased the risk of constipation (70–74 years: OR = 1.350, 95% CI 1.122–1.624, $P = 0.001$; 75–79 years: OR = 1.421, 95% CI 1.144–1.765, $P = 0.002$; ≥80 years: OR = 2.181, 95% CI 1.767–2.692, $P < 0.001$). Compared to the longest sleep duration group (≥8 h), too short a sleep duration at night (<6 h) significantly increased the risk of constipation (4–6 h group: OR = 1.534, 95% CI 1.225–1.921, $P < 0.001$; 2–4 h group: OR = 1.517, 95% CI 1.126–2.043, $P = 0.006$; <2 h group: OR = 2.395, 95% CI 1.095–5.239, $P = 0.029$) (**Table 3**). The results revealed that old age, female sex and shorter sleep duration at night were risk factors for constipation.

DISCUSSION

In the four studied cities, the total prevalence of constipation was 17.6% in people 65 years and older and increased with age. This is similar to the study by Chu et al., who reported a prevalence rate of 18.1% for constipation in the elderly population in China (10). Yang et al. showed that the prevalence of constipation among elderly people, over 60 years old, in the Beijing region was 13% (13), which was lower than our finding. There are some likely reasons for this disparity, such as age of participants, regional difference and different assessments of constipation. According to a review by Mugie et al., the prevalence of constipation in the general population worldwide is in the ranges of 0.7–79% (median 16%), with median prevalence in the general population of 19.2% in Europe and 19.7% in Oceania, indicating higher rates than in this study (2). The prevalence of constipation may vary with such factors as geographical areas, diagnostic criteria,

TABLE 2 | Comparison of the prevalence of constipation between different groups.

Group	With constipation (percentage)	Without constipation (percentage)	χ^2	*P*
Sex			12.03	**0.001**
Male	352 (15.5)	1,917 (84.5)		
Female	567 (19.2)	2,386 (80.8)		
Age group (y)			56.959	**<0.001**
65–69	299 (14.0)	1,840 (86.0)		
70–74	263 (17.9)	1,204 (82.1)		
75–79	159 (18.7)	690 (81.3)		
≥80	197 (26.0)	561 (74.0)		
MD	–	–		
Education (y)			6.000	0.199
0	219 (18.0)	999 (82.0)		
1–6	432 (17.9)	1,976 (82.1)		
7–9	146 (15.7)	781 (84.3)		
10–12	67 (16.4)	342 (83.6)		
>12	53 (21.9)	189 (78.1)		
MD	–	–		
Marital status			1.813	0.612
Single	9 (20.0)	36 (80.0)		
Married	691 (17.5)	3,248 (82.5)		
Divorced	5 (11.1)	40 (88.9)		
Widow	211 (18.3)	945 (81.7)		
MD	–	–		
Living status			0.105	0.949
With spouse	632 (17.6)	2,967 (82.4)		
Without spouse	195 (17.5)	920 (82.5)		
Alone	92 (18.1)	416 (81.9)		
Occupation			4.618	**0.032**
Manual worker	713 (17.0)	3,470 (83.0)		
Non-manual worker	194 (20.0)	778 (80.0)		
MD	–	–		
Social activities			0.161	0.688
0–3 d/week	414 (17.7)	1,922 (82.3)		
4–7 d/week	490 (17.3)	2,343 (82.7)		
MD	–	–		
Sleep duration			30.951	**<0.001**
<2h	10 (32.3)	21 (67.7)		
2–4h	91 (22.1)	320 (77.9)		
4–6h	280 (21.0)	1,051 (79.0)		
6–8h	361 (16.0)	1892 (84.0)		
≥8 h	139 (14.6)	814 (85.4)		
MD	–	–		
Duration of menstruation in females (y)			2.145	0.543
<25	30 (16.4)	153 (83.6)		
25–29	60 (17.5)	283 (82.5)		
30–34	220 (19.2)	923 (80.8)		
≥35	201 (20.1)	797 (79.9)		
MD	–	–		
Delivery times in females			4.273	**0.039**
≤3	422 (18.5)	1,855 (81.5)		
>3	127 (22.4)	441 (77.6)		
MD	–	–		

MD, Missing data. Bold values represent P value less than 0.05 to make the results distinct and obvious.

TABLE 3 | Logistic regression analysis of risk factors for constipation.

Group	OR	95% OR Lower limit	95% OR Upper limit	*P*
Sex				
Male	1	–	–	
Female	1.238	1.064	1.441	**0.006**
Age (y)				**<0.001**
65–69	1	–	–	
70–74	1.35	1.122	1.624	**0.001**
75–79	1.421	1.144	1.765	**0.002**
≥80	2.181	1.767	2.692	**<0.001**
Sleep duration				**<0.001**
<2h	2.395	1.095	5.239	**0.029**
2–4h	1.517	1.126	2.043	**0.006**
4–6h	1.534	1.225	1.921	**<0.001**
6–8h	1.133	0.915	1.402	0.253
≥8 h	1	–	–	
Occupation				
Non-manual worker	1	–	–	
Manual worker	0.858	0.715	1.031	0.101

Bold values represent P value less than 0.05 to make the results distinct and obvious.

age distributions of study populations, methods of investigation, socioeconomic conditions and diverse cultural characteristics. Regardless, the prevalence of constipation in this study seemed to be lower than in Western countries (2, 10). This may be due to higher diet quality, more physical activity and a different life style in China (16).

In our study, the prevalence of constipation increased with age and older age was one of the risk factors of constipation, which is consistent with other studies (2, 5, 10, 11, 14, 17). There are some likely primary causes that accompany aging. It is well-known that there are changes in mechanical properties (e.g., loss of plasticity and compliance), macroscopic structure (e.g., diverticulosis) and control of the pelvic floor impact bowel structure and function with advancing age (18, 19). Colonic transit time slows with aging, with propulsive efficacy of the colon decreasing (2, 18). Regarding the enteric nervous system, age-related loss of colonic neurons and changes in the morphology of the myenteric plexus of the human colon may cause slower colonic transit time or other physiological changes. Also, pelvic floor dysfunction is frequent in the elderly, especially women, which manifests as paradoxic contractions or inadequate relaxation of the pelvic floor muscles, or inadequate propulsive forces during attempted defecation (18, 19). The secondary causes of constipation include illness and multiple medication use, which are more common in elderly people. Several diseases including diabetes, dementia, Parkinson's disease, rheumatoid arthritis, stroke and multiple sclerosis, and various medications such as anticholinergic drugs, antiparkinsonism drugs, calcium-channel blockers, non-steroidal anti-inflammatory drugs, antihistamines and antihypertensives can increase occurrence of constipation (2–4). Elderly people are more prone to these diseases and to take medicine, which may increase the risk of constipation.

Furthermore, elderly people may be particularly sensitive to the adverse effects of many medications and are more likely than their younger counterparts to manifest symptoms of constipation because of age-related physiological changes (4). In addition, elderly people often have a decreased appetite with lower fiber and fluid intake, and less physical exercise because of poor physical condition, which are high risks for constipation (3).

This study showed that the prevalence of constipation was lower in the manual compared to the non-manual worker group, consistent with other studies (5, 14). The non-manual group has a more sedentary lifestyle, which means less physical exercise, higher risk for obesity and greater mental stress. Because these factors are related to a trend toward increased prevalence of constipation, it is not hard to understand the result (2).

The prevalence of constipation was higher in the female than the male group, consistent with existing studies (2, 5, 10, 11, 17), which is related to female-specific physiological characteristics. It is known that men have a greater skeletal muscle mass and a longer anal sphincter compared to women, and that the increased anterolateral abdominal wall musculature in men may allow for increased abdominal pressure during defecation. Men also have a higher sphincter resting pressure and squeeze pressure than women (20). In addition, this result may be attributed to unique hormonal fluctuations in females. Receptors of female sex hormones such as estrogen and progesterone are expressed throughout the GI tract. These hormones can influence visceral sensitivity and visceromotor, and slow gastric emptying and intestinal transit (21, 22). Under the effect of progesterone during the luteal phase of the menstrual cycle or gestation period, the contraction of intestinal smooth muscle is inhibited and the transit time of the small intestine and colon is increased, which cause difficulty in defecation (10, 23, 24). This study showed that the prevalence of constipation increased with longer menstruation time, although this was not significant, and may be due to the longer effect of female sex hormones. Menopause means decreasing levels of estrogen and progesterone. The study by Huang et al. found that women in the premenopausal period were more likely to suffer from constipation than those in the postmenopausal period (14), which may support the views above. Moreover, menopause has been shown to affect muscle strength, tissue elasticity and resilience to load bearing in the pelvis (19, 20). Dyssynergic defecation is associated with pelvic floor dysfunction and particularly with paradoxical contraction or insufficient relaxation of the levator ani, anal sphincter and abdominal wall muscles. However, the role of menopause in pelvic floor dysfunction is unclear. There may be involvement of hormones such as estrogen, progesterone, catecholamines and prostaglandins (25, 26). This study showed that the prevalence of constipation was higher in females who had more deliveries. Damage to pelvic floor muscles and nerves during delivery cause pelvic floor dysfunction, which is frequent in older women and increases the risk of constipation (10, 19, 20, 27). All these factors may explain the higher prevalence of constipation in females and why female sex is a risk factor for constipation.

The prevalence of constipation increased with decreasing sleep duration at night, and logistic regression analysis revealed that shorter sleep duration (<6 h) increased the risk of constipation in elderly people. This is consistent with some previous studies in which participants were younger (14, 28–30). Tam et al. found that nighttime sleep duration <7 h was an independent risk factor for constipation among elementary school children in Hong Kong (31). Some studies indicated that poor sleep increased the risk of functional constipation among college students (32, 33). A study of functional GI disorders and sleep duration found that functional constipation was associated only with decreased sleep rather than other sleep disorders like drowsiness (34). Too short a duration of night sleep is likely caused by sleep disturbances, such as difficulties falling asleep, difficulties maintaining sleep during the night, waking up too early in the morning and non-restorative sleep (35). Some studies have shown that sleep disturbances increase the prevalence of constipation and cause more severe constipation symptoms (14, 28, 36–38). Jiang et al. hypothesize that sleep disturbances may result in dysfunction of the anal sphincter, enhance pelvic floor muscle tone and cause anorectal contradictory movements or paresthesia, which may aggravate constipation symptoms. There may also be specific neuroendocrine regulatory mechanisms for the visceral hypersensitivity-related symptoms which need to be explored (28). Sleep disturbances may disrupt the communication between areas in the brain (insula, anterior cingulate cortex, thalamus and prefrontal cortex) and the GI tract, causing GI autonomic dysfunction (39). Additionally, there may be an inflammatory cytokine mechanism, such as tumor necrosis factor and interleukin−1 and −6 (33, 39). Patients with sleep disturbances suffer from more severe anxiety and depression associated with constipation and this leads to negative effects by modulating the brain–gut axis and affecting gut motility (28, 29, 31, 38). Sleep disturbances may aggravate constipation symptoms separately or in combination with anxiety and depression (28, 36).

As a part of this multicenter study, samples from multiple regions in China were collected, which tended to eliminate regional differences, and the numerous samples reduced error. However, our results may not reflect the situation of all regions in China and may be more representative of only the four investigated regions. In addition, there have been few studies examining the effect of sleep duration on constipation, while the present study revealed that the duration of sleep at night was one risk factor for constipation. Owing to some limitations of the investigation, other factors such as dietary habits, physical exercise and illness and medication histories were not considered in this study, which may have affected the occurrence of constipation. Moreover, the result depended on the recall of participants, which might have caused recall bias. Future studies will further expand the geographical coverage, increase the sample size and use better designs of questionnaires to accurately reflect the prevalence of constipation in elderly people in China and explore more of the risk factor.

CONCLUSION

The prevalence of constipation in elderly people in four cities of China was 17.60%, and it is significantly affected by age, sex and sleep duration at night. Constipation in elderly people may

be managed by controlling these risk factors, which should be of interest to physicians.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The protocol for this study was reviewed and approved by the Ethics Committee at Tianjin Huanhu Hospital [2019-40]. Informed consent was obtained from each subject either directly or from his or her guardian. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

XD, SL, and PJ have designed, implemented, and wrote the article. XW, JG, WH, HZ, and YS have helped to implemented the article and collected the cases. YJ and JN have directed the article. All authors contributed to the article and approved the submitted version.

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Psychometric Properties and Measurement Invariance of the Chinese Version of the Brief Assessment of Impaired Cognition Questionnaire in Community-Dwelling Older Adults

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This study aimed to verify the Chinese version of the Brief Assessment of Impaired Cognition Questionnaire (C-BASIC-Q), and provide a new tool for the future large-scale epidemiological investigation of cognitive function in China. From March to May 2021, a cross-sectional study of 2,144 Chinese community-dwelling older adults (men = 1,075, mean age = 72.01 years, *SD* = 6.96 years, ranging from 60–99 years) was conducted in Jinan. Exploratory and confirmatory factor analyses were performed to evaluate the factor structure of the C-BASIC-Q. Convergent validity was evaluated by correlations with the Mini-Mental State Examination (MMSE). Internal consistency and test-retest reliability were evaluated using Cronbach's alpha and retest correlations in a sub-sample ($n = 129$). Linear regression was used to analyze the impact of demographic factors on the MMSE and C-BASIC-Q scores. Measurement invariance was evaluated using a multi-group confirmatory factor analysis. The mean C-BASIC-Q score was 15.94 ($SD = 3.43$). Factor analysis suggested a three-factor structure of C-BASIC-Q (self-report, orientation, and informant report). The C-BASIC-Q score was significantly positively associated with the MMSE score, showing good convergent validity. Cronbach's alpha of the C-BASIC-Q was 0.862, and the test-retest correlation coefficient was significant ($r = 0.952$, $p < 0.001$), indicating good internal consistency and test-retest reliability. Measurement invariance analysis showed that C-BASIC-Q had configural, metric, and scalar invariance across sex, age, residence, education level and marital status. C-BASIC-Q was less affected by age, residence, education, and marital status than the MMSE. In summary, the C-BASIC-Q had good reliability, validity, and measurement invariance, and is a valid tool for evaluating cognitive functioning in Chinese community-dwelling older adults.

Keywords: cognitive function, validation, reliability, measurement invariance, older adults, China

INTRODUCTION

As a result of economic development and the advancement of medical technology, the average life expectancy of human beings has gradually increased. Concomitantly, the degree of aging of the world's population has continued to increase (1), and age-related decline in cognitive functioning has become a public health problem worldwide. Mild cognitive impairment (MCI) is widely regarded by researchers as an intermediate phase between normal cognitive aging and overt dementia. Data from earlier epidemiological surveys showed that the prevalence of cognitive impairment without dementia was between 5.1 and 35.9% (2). A recent meta-analysis found that the incidence of MCI per 1,000 person-years was 22.5 for ages 75–79 years, 40.9 for ages 80–84 years, and 60.1 for ages 85+ years (3). Cognitive impairment has a great negative impact on the physical and mental health of older adults and their caregivers, not only because it can reduce their quality of life (4, 5), but it also creates a great care and economic burden (6, 7). Studies have found that cognitive impairment in the elderly was greatly affected by midlife or early age cognitive functioning (8). Therefore, early investigation of cognitive function has important public health implications for the prevention of cognitive impairment. In this field, the development and use of cognitive function assessment tools is a core issue.

Currently, cognitive function is generally evaluated by means of commonly used scales such as the Mini-Mental State Examination (MMSE), the Montreal Cognitive Assessment (MoCA), and the clock drawing test (CDT) (9, 10). Among them, the MMSE and MoCA are the most commonly used tools in this field, especially in China. A meta-analysis showed that the MMSE's pooled sensitivity was 0.89 (95% CI, 0.85 to 0.92) and specificity was 0.89 (95% CI, 0.85 to 0.93), which suggests good accuracy for detecting dementia (11). However, the MMSE is susceptible to the education level of participants, is prone to false-positive or false-negative results, and has poor sensitivity in identifying MCI and may not be suitable for screening for MCI in primary care and community research (12). In addition, a recent study found MMSE was less accurate in distinguishing MCI from subjective cognitive decline (SCD); meanwhile, even when the MMSE was used in combination with a quick test of cognitive speed, the MCI and SCD cannot be distinguished with sufficient accuracy (13). To mitigate these limitations of the MMSE, Nasreddine et al. compiled the MoCA specifically for MCI screening (14). A systematic review indicated that the MoCA was superior to the MMSE in identifying MCI (15). Meanwhile, previous study also found that MoCA was more efficacious in identifying subtle cognitive decline than MMSE (16). However, it should be noted that the difficulty level of the MoCA's items is higher, making it difficult for older participants with lower education levels to understand (17), resulting in lower scores which do not accurately reflect their level of cognitive functioning (18). In light of the differences in regional dialects and culture in China, the MoCA is available in multiple versions (19–23) and there is no uniformly recognized version and cut-off value (24–26). In addition, the MMSE and the MoCA have several common limitations, such as too many items, long measurement time, and a heavier survey burden on investigators and participants in community screening and large-scale epidemiological surveys. Therefore, it is necessary to introduce or develop a shorter Chinese version of a cognitive function assessment tool.

In 2019, Jørgensen et al. (27) combined cognitive testing with both patient and informant reports to develop a Brief Assessment of Cognitive Impairment (BASIC), a new brief case-finding tool for dementia and cognitive impairment. BASIC was a case-finding instrument in clinical settings, including patient-directed questions (three questions), Supermarket Fluency (one question), Category Cued Memory Test (one questions), and informant-directed questions (three questions), a total of eight questions (27). However, it should be noted that BASIC may not be appropriate in a community setting because its two cognitive tests take more time and was not easy to manage (need additional tools to cooperate with the test). For example, a stimulus card is needed for the Category Cued Memory Test, which may increase the investigation time and the burden of investigators (28). Obviously, when conducting surveys in community settings, the assessment tool should be easily managed by non-specialists and save time. Therefore, Jørgensen et al. substituted cognitive testing (Supermarket Fluency and Category Cued Memory Test) with questions regarding orientation, and developed a questionnaire version based on BASIC for community settings, the Brief Assessment of Impaired Cognition Questionnaire (BASIC-Q). The questionnaire included three components: self-report, orientation, and informant report, a total of 10 items; its sensitivity was 0.92 and its specificity was 0.97 to detect cognitive impairment, both of which were significantly higher than the sensitivity and specificity of the MMSE (28). In addition, its measurement time is short, which effectively reduces the survey burden on investigators and participants. Currently, there is no research to verify its use on the Chinese population. In only one study, the BASIC was translated into Chinese, and it was validated in stroke patients at a stroke treatment center (29). However, as we mentioned earlier, the Chinese version of BASIC is also not suitable for community settings.

In addition, to the best of our knowledge, no research has focused on the measurement invariance of the BASIC-Q. As a prerequisite for group comparison, measurement invariance refers to whether the meaning of measurement is equivalent between different groups (30). When comparing between groups, only the structure of the measurement was invariant between different groups, and statistical inference could be made (31). Considering that cognitive functions are easily affected by demographic factors such as sex, age, and education level, it is necessary to test the BASIC-Q for measurement invariance across sociodemographic factors.

In large-scale epidemiological surveys with more research content and larger sample sizes, short survey tools can reduce the workload of the survey, reduce the burden on the surveyed

Abbreviations: C-BASIC-Q, Chinese version of the Brief Assessment of Impaired Cognition Questionnaire; MMSE, Mini-Mental State Examination; MCI, Mild cognitive impairment; EFA, Exploratory Factor Analysis; CFA, Confirmatory Factor Analysis; CFI, Comparative Fit Index; TLI, Tucker–Lewis Index; RMSEA, Root-Mean Square Error of Approximation; SRMR, Standardized Root-Mean Square Residual.

and the response bias, and are widely demanded by researchers. Based on the above considerations, in order to provide Chinese researchers with a shorter cognitive function assessment tool, this study aims to verify the Chinese version of the BASIC-Q (C-BASIC-Q) and explore its psychometric properties and measurement invariance.

MATERIALS AND METHODS

Participants

From March to May 2021, a cross-sectional study of Chinese community-dwelling older adults was conducted in Jinan. A stratified cluster random sampling method was used to select the participants. First, using the 2020 annual per capita gross domestic product (GDP) level of the districts or counties of Jinan City, we divided the 12 districts and counties into three levels: high, medium, and low, with two districts or counties randomly selected from each level. Second, we randomly selected two townships or streets in the six selected districts or counties; therefore, a total of 12 streets or townships were selected. Third, we selected all older adults in two communities from the 12 randomly selected streets or towns to participate in a survey. Participants were included in the survey based on the following criteria: that they were 60 years or older, had lived in the area for more than 6 months, had no hearing or language impairment (self-reported), and voluntarily participated in the survey. Older persons who were clinically diagnosed with severe and terminal diseases or severe cognitive impairment, such as dementia (reported by family members), were excluded.

Before the survey, we communicated with community staff by telephone and determined the investigation time after obtaining their informed consent. We recruited participants by placing posters on publicity boards in the communities. To facilitate the inclusion of participants who were unable to read the questionnaire due to a low educational level, all questionnaires were completed by a uniformly trained investigator, using a face-to-face interview, instead of being filled out by the older adults themselves. A total of 2,201 participants who met the criteria were surveyed. After excluding invalid questionnaires with a wide range of missing content, 2,144 older adults (ranging in age from 60–99 years) participated in this study. The uniformly trained investigators completed the interview survey with the uniformly instructed language. The investigators were all medical undergraduates of grade 3 or above. It should be noted that in the factor structure analysis, we randomly divided the sample into two parts. Sample A (n = 1,072) consisted of 538 men and 534 women and was used for exploratory factor analysis. Sample B (n = 1,072) consisted of 537 men and 535 women and was used for confirmatory factor analysis. Moreover, 129 participants (67 men and 62 women, M = 72.9 years, SD = 7.1 years, ranging from 60–95 years) were selected to complete the retest of the C-BASIC-Q 2 weeks later. Unless otherwise specified, other reliability and validity indicators were based on the complete sample (N = 2,144).

All research procedures followed the principles of the Declaration of Helsinki. The study was approved by the Medical Ethics Committee of Xiangya School of Public Health, Central South University (identification code: XYGW-2020-101).

Translation Procedure

We contacted Dr. Kasper Jørgensen by email and obtained his consent to translate the BASIC-Q into Chinese. First, two psychiatry graduate students were invited to independently translate the English version of the BASIC-Q into Chinese. Second, two professors with more than 10 years' experience in cognitive function research combined the existing Chinese versions of the BASIC to integrate the Chinese version of the questionnaire translated by two graduate students and produced a draft. Third, two English teachers with teaching experience in English-speaking countries and who were not familiar with the scale jointly translated the Chinese version of the scale into English and compared it with the original English version. They confirmed that the sentences and meanings of the translated English version were essentially the same as the original English version. Finally, the C-BASIC-Q was produced and used to evaluate cognitive functioning in the older Chinese adults in our sample.

Measures

Brief Assessment of Impaired Cognition Questionnaire (BASIC-Q)

BASIC-Q was developed by Jørgensen et al. (28), which included three components: self-report (three items), orientation (four items), and informant report (3 items), a total of 10 items. Among them, self-report component uses three-category scoring method (0= *to a great extent*, 1= *to some extent*, 2= *no*). In the orientation component, two scores are possible (0 = wrong answer, 2 = correct answer). The informant report component also uses three-category scoring method (0= *much worse*, 1= *a bit worse*, 2= *unchanged*). The sum of all items gave the total score, ranging from 0 to 20 points. Higher scores indicated lower risks of cognitive impairment. Optimal cutoff score for case-finding of cognitive impairment was 16/17 in a previous study (28).

Mini-Mental State Examination (MMSE)

The MMSE was designed by Folstein et al. (32) to assess participants' cognitive function. The scale includes five dimensions: orientation, short-term memory, attention and calculation ability, recall ability, and language ability. Depending on the participants' answers, two scores are possible (0 = *wrong or unable to answer* or 1 = *true*). The sum of all items constituted the total score, ranging from 0 to 30 points. Higher scores indicated better cognitive functioning. With regard to the education level, the MMSE cut-off score for having MCI was <20 points for the illiterate group, <25 points for the primary school group, and <28 for the middle school and higher group (33). In this study, we used the Chinese version of the MMSE (34); Cronbach's alpha was 0.902.

Covariates

We used demographic characteristics, frequently used in previous studies of Chinese older adults (35), as covariates.

The covariates were the following: age, sex, residence, education level, and marital status through a self-designed questionnaire survey. Age was categorized into three groups (60–69 years, 70–79 years, and 80 years and above). Residence was categorized as urban vs. rural. Educational level was categorized into three groups (illiteracy, primary school, and middle school and higher). Marital status was categorized as unmarried or married.

Statistical Methods

SPSS version 25 (IBM SPSS Statistics, Armonk, NY, USA) was used to conduct descriptive statistical analysis, Student's *t*-tests, Pearson's r correlations, internal consistency tests and linear regression. Mplus version 8 was used to conduct the exploratory and confirmatory factor analyses. First, we ranked all participants according to their total C-BASIC-Q score from low to high, selecting the first 27% of participants as the low group, and the last 27% of participants as the high group. Item analysis was performed by comparing the score difference of each item in the high and low groups (used student's *t*-tests), and the correlation between each item score and the total score. The purpose of item analysis was to determine the homogeneity and discrimination of items to determine whether items need to be deleted. When the results of *t* test and correlation analysis were statistically significant, it indicated that all items had good homogeneity and differentiation.

Second, we used exploratory factor analysis (EFA) and confirmatory factor analysis (CFA) to evaluate the factor structure of the C-BASIC-Q. Specifically, we first used Mplus software to conduct EFA based robust maximum likelihood and explored three competition models: one factor, two factors, and three factors. Based on the fitting index, we selected an optimal model for the CFA. Given that the chi-square index is sensitive to sample size, the comparative fit index (CFI), Tucker–Lewis index (TLI), root-mean square error of approximation (RMSEA), and standardized root-mean square residual (SRMR) were used to evaluate model fit. The TLI and CFI are >0.900, and the RMSEA and SRMR are <0.080, indicating that the model fit well (36).

Convergent validity was evaluated by correlation with the MMSE score. Internal consistency and test-retest reliability were evaluated using Cronbach's alpha and retest correlations in a subsample ($n = 129$). In addition, in order to explore which MMSE and C-BASIC-Q scores were less affected by education level and age, we used linear regression models to analyze the impact of demographic factors on the MMSE and C-BASIC-Q scores. Finally, measurement invariance was evaluated using multi-group CFA. There are four levels of measurement invariance: configural, metric, scalar, and strict (37). Previous literature reviews suggested that scalar invariance was sufficient to evaluate the comparison between the mean values of latent factors, while strict invariance was more suitable for comparison between the mean values of observed factors (38, 39). Considering that the total score is generally used when comparing the cognitive function of participants with different demographic characteristics, we did not perform a strict invariance test. According to the fit criterion of the measurement invariance model (40), when the change in CFI (ΔCFI) and RMSEA (ΔRMSEA) is <0.010, compliance invariance is indicated.

RESULTS

Descriptive Statistics

The descriptive statistics for the participants are presented in **Table 1**.

Item Analysis

The t-test results showed that the score differences of all items of the C-BASIC-Q in the high and low groups were statistically significant. Correlation analysis showed that the scores of all items were significantly and positively correlated with the total score. The data are shown in **Table 2**.

Structural Validity

The fit results of the three competing models obtained using EFA are shown in **Table 3**. Of the three, the fit index of the three-factor structure model was significantly better than that of both the two-factor and the single-factor structures. Therefore, we used the three-factor structure for the CFA. A preliminary analysis suggested that the initial CFA model of C-BASIC-Q has a poor fit index, so we set a residual correlation (item five with item seven) to correct the model. The results showed that the fit index of the corrected three-factor structure met the model-fit requirements. Above all, the C-BASIC-Q suggested a three-factor structure, namely self-report, orientation, and informant report.

TABLE 1 | Descriptive statistics for the participants.

Variables	Total sample ($N = 2,144$) N(%)/Mean ± SD
Age (years)	72.01 ± 6.96
60–69	753 (35.1)
70–79	1,069 (49.9)
≥80	322 (15.0)
Sex	
Male	1,075 (50.1)
Female	1,069 (49.9)
Residence	
Urban area	829 (38.7)
Rural area	1,315 (61.3)
Educational level	
Illiteracy	509 (23.7)
Primary school	820 (38.2)
Middle school and above	815 (38.0)
Marital status	
Unmarried	498 (23.2)
Married	1,646 (76.8)
C-BASIC-Q	15.94 ± 3.43
MMSE	27.74 ± 3.89
Possible MCI (based on MMSE-score*)	
Yes	274 (12.8)
No	1,870 (87.2)

**MMSE cutoff-scores for possible MCI: Illiterate group <20, primary school group <25, middle school and higher group <28; SD, Standard deviation.*

The loading of each item of the three-factor structure of the EFA and CFA is presented in **Table 4**.

Convergent Validity

The results of correlation analysis showed that the total C-BASIC-Q score was significantly positively associated with the total MMSE score ($r = 0.590$, $p < 0.001$).

Internal Consistency and Test-Retest Reliability

Cronbach's alphas of the C-BASIC-Q and its three factors (self-report, orientation, and informant reports) were 0.862, 0.784, 0.840, and 0.782 in the total sample. The test-retest correlation coefficient was significant ($r = 0.952$, $p < 0.001$) in the retest sample ($n = 129$), indicating that the C-BASIC-Q has good internal consistency and test-retest reliability.

TABLE 2 | Correlation analysis between each item of C-BASIC-Q and the total score of the scale and the results of the high and low group *t*-test ($N = 2,144$).

Items	*r*	*t*
1	0.664***	33.418***
2	0.749***	49.685***
3	0.742***	50.849***
4	0.649***	9.973***
5	0.602***	7.472***
6	0.663***	14.857***
7	0.655***	8.098***
8	0.703***	60.733***
9	0.712***	51.087***
10	0.625***	32.803***

****P < 0.001.*

Measurement Invariance

Table 5 shows the fit index of the measurement invariance model of the C-BASIC-Q's three-factor model across sex, age, residence, education level, and marital status. All model fit indices meet the fit standard. In addition, from the configural invariance model to the metric invariance model, and then to the scalar invariance model, the ΔCFI and ΔRMSEA were all <0.010. These results supported the identification of configural, metric, and scalar measurement invariance in the C-BASIC-Q across sex, age, residence, education level, and marital status.

Factors Related to C-BASIC-Q and MMSE

The status of the C-BASIC-Q according to different participant characteristics is presented in **Table 6**. The results of linear regression analysis showed that age, residence, education level, and marital status all had an impact on the C-BASIC-Q and the MMSE scores (**Table 7**). By comparing the coefficients of determination, the impact of the four factors on the C-BASIC-Q was less than the impact on the MMSE (0.076 vs. 0.123).

DISCUSSION

In this study, the BASIC-Q was translated into Chinese for the first time, and it was verified among community-dwelling older adults. This study provides scientific evidence for the

TABLE 3 | EFA and CFA fitting indexes of the C-BASIC-Q.

Model	Factors	χ^2	*df*	CFI	TLI	RMSEA	SRMR
EFA	Single-factor	1838.198	35	0.655	0.556	0.219	0.143
EFA	Two-factor	509.436	26	0.907	0.840	0.132	0.058
EFA	Three-factor	69.282	18	0.990	0.975	0.052	0.017
CFA	Three-factor	186.956	31	0.970	0.956	0.069	0.040

TABLE 4 | Loadings and commonality of each item on three factors in EFA and CFA.

Items	Within sample A ($N = 1,072$)			Within sample B ($N = 1,072$)		
	Factor 1	Factor 2	Factor 3	Factor 1	Factor 2	Factor 3
Item 1	**0.479**	−0.009	0.378	**0.653**		
Item 2	**0.571**	0.019	0.407	**0.790**		
Item 3	**0.593**	−0.008	0.421	**0.766**		
Item 4	0.338	**0.629**	−0.015		**0.831**	
Item 5	−0.008	**0.863**	−0.001		**0.764**	
Item 6	0.156	**0.496**	0.186		**0.687**	
Item 7	−0.012	**0.908**	0.062		**0.804**	
Item 8	−0.022	−0.029	**0.860**			**0.814**
Item 9	−0.002	0.030	**0.807**			**0.771**
Item 10	0.009	0.151	**0.543**			**0.609**

The bold values indicate the corresponding items belonging to which factor.

TABLE 5 | Measurement invariances across sex, age, residence, educational level, and marital status.

Models	Measurement invariance	χ^2	df	RMSEA	CFI	TLI	ΔRMSEA	ΔCFI
Sex	Configural invariance	409.762	62	0.072	0.966	0.951		
	Metric invariance	430.024	69	0.070	0.965	0.954	0.002	0.001
	Scalar invariance	443.470	76	0.067	0.964	0.958	0.003	0.001
Age	Configural invariance	470.598	93	0.075	0.962	0.944		
	Metric invariance	495.972	107	0.071	0.960	0.950	0.004	0.002
	Scalar invariance	524.237	121	0.068	0.959	0.954	0.003	0.001
Residence	Configural invariance	422.550	62	0.074	0.965	0.949		
	Metric invariance	433.744	69	0.070	0.964	0.954	0.004	0.001
	Scalar invariance	441.485	76	0.067	0.964	0.958	0.003	<0.001
Educational level	Configural invariance	458.997	93	0.074	0.963	0.947		
	Metric invariance	529.441	107	0.074	0.957	0.946	<0.001	0.006
	Scalar invariance	565.399	121	0.072	0.955	0.950	0.002	0.002
Marital status	Configural invariance	388.539	62	0.070	0.969	0.954		
	Metric invariance	404.992	69	0.067	0.968	0.958	0.003	0.001
	Scalar invariance	423.871	76	0.065	0.966	0.960	0.002	0.002

TABLE 6 | The status of C-BASIC-Q by different characteristics.

Variables	Mean	SD	*t*/*F*	*P*-value
Age (years)			38.482	<0.001
60–69	16.52	3.00		
70–79	15.94	3.29		
≥80	14.55	4.33		
Sex			4.033	<0.001
Male	16.23	3.35		
Female	15.64	3.48		
Residence			5.374	<0.001
Urban area	16.42	3.12		
Rural area	15.63	3.58		
Educational level			41.279	<0.001
Illiteracy	14.88	4.10		
Primary school	15.92	3.25		
Middle school and above	16.61	2.95		
Marital status			6.821	<0.001
Unmarried	14.93	3.91		
Married	16.24	3.21		

SD, Standard deviation.

application of the C-BASIC-Q in Chinese older adults and even other Chinese speaking people outside China. Our results showed that C-BASIC-Q has a three-factor structure, showing good structural validity. The C-BASIC-Q score was significantly correlated with MMSE, had good convergent validity, and its internal consistency and retest reliability were both good. In addition, its configural, metric, and scalar measurement invariance across sex, age, residence, education level, and marital status were supported. In general, the C-BASIC-Q has good reliability, validity, and measurement invariance, and can be used to evaluate the cognitive functioning of community-dwelling older adults in China.

The results of item analysis showed that each item was significantly positively associated with the C-BASIC-Q total score, and the difference in the scores of each item in the high and low groups was statistically significant, indicating that each item had good homogeneity and discrimination. Because factor structure analysis was not performed in the development of the original scale (28), we divided the total sample into two parts to explore the factor structure of the C-BASIC-Q, which is one of the novel contributions of this study. The results suggest that C-BASIC-Q has a three-factor structure and good structural validity. Interestingly, the items of the three factors of the C-BASIC-Q confirmed the three components of the original scale (i.e., self-report, orientation, and informant report). Therefore, the original three component names were adopted for the Chinese version. Moreover, correlation analysis showed that the C-BASIC-Q was significantly positively correlated with the MMSE; that is, the higher the C-BASIC-Q score, the better the cognitive functioning, showing good convergent validity. In addition, Cronbach's α coefficient of the C-BASIC-Q was 0.863, and the test-retest reliability at the two-week interval was 0.952, indicating that C-BASIC-Q has good internal consistency and stability, and the reliability was good.

Another important contribution of this study is the test of the measurement invariance of the C-BASIC-Q. Future studies can analyze the potential mean differences between different groups by determining the measurement invariance of the C-BASIC-Q. This study found that the C-BASIC-Q had configural, metric, and scalar measurement invariance across sex, age, residence, education level, and marital status. Specifically, the establishment of configural invariance means that the factor structure of the C-BASIC-Q between different groups was the same. Second, the results of metric invariance tests showed that the factor loadings between different groups were equivalent, that is, participants in different groups have the same understanding of each item. Finally, the results of scalar invariance suggested that the intercept of the C-BASIC-Q has cross-group equivalence,

TABLE 7 | Linear regression analysis for the contributions of sex, age, residence, education level, and marital status on C-BASIC-Q and MMSE.

Factors	C-BASIC-Q				MMSE			
	B	SE of B	β	*P*-value	B	SE of B	β	*P*-value
Sex	−0.207	0.151	−0.030	0.171	−0.269	0.167	−0.035	0.108
Age	−0.690	0.108	−0.137	<0.001	−0.461	0.119	−0.080	<0.001
Residence	−0.446	0.154	−0.063	0.004	−0.581	0.170	−0.073	0.001
Education level	0.583	0.102	0.131	<0.001	1.161	0.113	0.231	<0.001
Marital status	0.842	0.177	0.104	<0.001	1.296	0.195	0.141	<0.001
R^2	0.076				0.123			
F value	35.049*				60.033*			

*B, unstandardized regression coefficients; SE, standardized error; β, standardized regression coefficients; R^2, coefficient of determination; *P < 0.001.*

that is, the measurement properties of the C-BASIC-Q are the same across different groups. In summary, the evidence of the three invariance measurements indicated that the scores of the C-BASIC-Q are comparable regardless of sex, age, residence, education level, and marital status.

In this study, the differences in the C-BASIC-Q scores of participants of different age, sex, residence, education level, and marital status were statistically significant. Specifically, participants who were younger, male, living in urban areas, had higher education levels, and were married had higher cognitive functioning, which was consistent with the results of previous studies (33, 35). The results of linear regression analysis suggested that age, residence, education level, and marital status all had an impact on the C-BASIC-Q and the MMSE scores. However, it is worth noting that the variance explained by the above four factors on the C-BASIC-Q was lower than on the MMSE. In other words, compared with the MMSE, the C-BASIC-Q was less affected by age, residence, education, and marital status. This means the C-BASIC-Q is more suitable for epidemiological investigations, than the MMSE.

This study had several limitations. First, we did not have a gold standard for identifying MCI and dementia in this sample (that is, the clinician's diagnosis), which made it impossible to infer the cut-off value of the C-BASIC-Q for judging MCI and dementia. In the future, it will be necessary to combine the diagnosis of clinicians with the C-BASIC-Q, and determine the cut-off value of the C-BASIC-Q, which will lay the foundation for future MCI and dementia screening. Second, the sample for this study was drawn from only one city in China, which may not be nationally representative. In the future, scholars can expand the scope of sampling, increase the sample size, and further verify the C-BASIC-Q nationwide in China. Third, this study only verified the C-BASIC-Q in community settings, and it is necessary to conduct psychometric tests in the clinical environment or nursing home environment. Fourth, it has poor adaptability among elderly people living alone because the C-BASIC-Q includes an informant report. In situations where reliable informant reports cannot be obtained, a prorated BASIC-Q score may be used, but with a possible reduction in validity. Finally, since we only selected 129 participants to retest after 2 weeks, the sample size was small and the time-span was short, so a longitudinal invariance test was not performed.

Despite the above-mentioned limitations, this research is groundbreaking in the exploration of the C-BASIC-Q's factor structure and measurement invariance, and provides a reference for future validation of the BASIC-Q in other languages. In addition, we have provided a short, easy-to-use measurement tool for conducting surveys on the cognitive functioning of older adults in the Chinese community, and this is also a starting point for the use of the C-BASIC-Q in the measurement of cognitive functioning in China.

CONCLUSIONS

The C-BASIC-Q is a valid tool for evaluating cognitive function in Chinese community-dwelling older adults with good reliability, validity, and measurement invariance.

DATA AVAILABILITY STATEMENT

The datasets can be made available to any interested person(s) contacting the corresponding author via email.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Medical Ethics Committee of Xiangya School of Public Health, Central South University. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

SL and GC designed the study, conducted surveys, analyzed data, and wrote the first manuscript. KJ provided suggestions on additional statistical analysis and manuscript writing and revised the original manuscript. ZC and ZL contributed to the scale translation process. HX revised the manuscript. All authors read and approved the final manuscript.

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The Impact of COVID-19 on Domestic Tourism by Older People in Taiwan

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Taiwan's older population (those over the age of 65) reached ∼3.95 million at the end of January 2022, accounting for around 16.9% of the country's total population. It is already an "aged society." With the gradual increase in the older population, the older people tourism market is also getting more and more attention. This article explores how older people tourism was affected by the COVID-19 pandemic (present in Tawian from early 2020), which was a major international public health event. This study adopts quantitative and PCA methods to statistically analyze the changes before and after the pandemic. The study results found that the frequency of tourism decreased after the pandemic: the number was 5.32, a decrease of 0.77, and instances of at least 1 tourist trip decreased by 3.87% after the pandemic. Regarding the reasons for not participating in tourism, during the COVID-19 pandemic, the COVID-19 accounted for a factor of 19.9%. Total travel expenses were NT$2,590, an increase of NT$229.67, and were not affected by the pandemic. We carried out a PCA analysis on tourism spending. The first component was food, accommodation, shopping, and other expenses. The factor loadings were 0.989, 0.931, 0.641 and −0.948, respectively. The second component was entertainment and transportation expenses. The factor loadings were 0.997 and 0.902, respectively. In conclusion, we put forward relevant discussions and suggestions to make tourism for older people healthier and more sustainable.

Keywords: tourism, COVID-19, Taiwan, healthy, older people

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INTRODUCTION

The aging of the population is a common phenomenon all over the world (1). According to the definition of the World Health Organization, when the population of those aged 65 or older in a country accounts for more than 7% of the total population, it is called an "aging society," when it is more than 14% it is called an "aged society," and when it is more than 21% it is called a "super-aged society."

Owing to the decline in the fertility rate and the increase in life expectancy, the young population continues to decrease and the older population to increase. Taiwan became an aging society in 1993 and an aged society in 2018 (2). Its population of those aged over 65 had reached 3.95 million by the end of January 2022 (3). It accounts for ∼16.9% of the total population, and the country is gradually moving toward becoming a super-aged society.

At present, a major international public health event is generally declared by the Emergency Committee under the World Health Organization (WHO), as a "Public Health Emergency of International Concern" (PHEIC). According to the International Health Regulations established in 2005, this is defined as an extraordinary event constituting a public health risk to other states through the international spread of disease, and potentially requires a coordinated international

response. The event is "serious, sudden, unusual or unexpected," "carries implications for public health beyond the affected State's national border," and "may require immediate international action" (4). COVID-19 was declared by the WHO emergency committee a Public Health Emergency of International Concern on 30 January 2020 (5).

The COVID-19 pandemic appeared in Taiwan in early 2020 (6), according to the database of the WHO and the Centers for Disease Control in Taiwan (7, 8), and the confirmed rates of infection and death in Taiwan are lower than the global average (**Table 1**). However, due to the emergence of successive mutant strains of COVID-19, the pandemic situation abroad is still severe, and most countries still have measures such as checks and quarantines in place on entry or exit. Therefore, the global tourism industry is still significantly affected by COVID-19.

However, though the currently available literature discusses the impact of COVID-19 on tourism (9, 10), tourists, and travel destinations (11–14), there is still a lack of literature on its impact on tourism by the older people. Therefore, this paper analyses the changes this major international public health event has caused in older people tourism, and puts forward relevant discussions and suggestions to make tourism for older people healthier and more sustainable.

LITERATURE REVIEW

There are some relevant articles describing the psychological distress and fear of COVID-19 experienced by older people during the COVID-19 pandemic. There was a study assessing the fear of COVID-19 among the older people in Iran and Taiwan (15). Although Iranian older people had a significantly higher level of fear of COVID-19 than Taiwanese older people, the latter still had a considerable fear of the disease. There was also a study to investigate the association between the fear of COVID-19 and preventive behaviors during the COVID-19 community outbreak of two severity levels in Taiwanese older people (16). The severity of a COVID-19 outbreak may alter older people's psychological status and related behaviors. Another study explored the gender differences related to the fear of COVID-19 among older women and men in Taiwan (17). As behaviors designed to prevent COVID-19 infection were associated with a lower fear of COVID-19, healthcare providers should consider strategies for improving preventive behaviors among the older people to help ease their worries and fears concerning COVID-19. Several studies have shown that during the pandemic, the older people, especially those with chronic diseases, were more vulnerable than youths (18, 19). This literature found older people's psychological distress, fear, and related behaviors were affected by the COVID-19 pandemic. It could explain why the number of older people tourism decreased during the COVID-19 pandemic.

MATERIALS AND METHODS

Data Sources

This research uses the database of Taiwanese tourism of the Tourism Bureau of the Ministry of Transport (20), the COVID-19 database of the Ministry of Health and Human Services, the WHO COVID-19 database, and relevant information from the government's official website and reports.

Research Methods

This study adopts quantitative methods to statistically analyze older people tourism in Taiwan from 2017 to 2020. We extracted the tourism-related data on the older people within the scope of the study from the above databases and information, and compiled it in Excel and SPSS 25 for consolidated analysis and illustrations to produce the tables and figures included. As a result of investigating the differences from before and after the pandemic, we also did comparative and trend analyses, which more clearly showed the impact of COVID-19.

After the outbreak of the pandemic, because of the entry-exit control and isolation measures, people mainly traveled domestically. Therefore, this paper focuses on the domestic travel of the older people in Taiwan. The study period was from 3 years before the outbreak, 2017–2019, to 1 year after the outbreak, 2020. The database of Taiwanese tourism status of the Tourism Bureau is a nationwide survey. The information needs to spend more time to investigate and update, and the latest information is from 2020.

Principal component analysis (PCA) was invented in 1901 by Karl Pearson, as an analog of the principal axis theorem in mechanics; it was later independently developed and named by Harold Hotelling in the 1930's (21, 22). PCA is a technique for reducing the dimensionality of large datasets, increasing interpretability, and at the same time minimizing information loss. It does so by creating new uncorrelated variables that successively maximize variance, hence making PCA an adaptive data analysis technique (23). PCA is a multivariate technique that analyzes a set of data in which observations can be described

TABLE 1 | The cases of COVID-19 in Taiwan and worldwide in 2020 and 2021.

	World cumulative case		World population (per million)		Taiwan cumulative case		Taiwan population (per million)	
Year	Confirmed case	Deaths	Confirmed rate	Death rate	Confirmed case	Deaths	Confirmed rate	Death rate
2020	82,386,776	1,801,095	10,653.92,163	232.9,102,548	800	7	34.7,826,087	0.304,347,826
2021	285,626,807	5,428,585	36,293.11,398	689.7,820,839	17,029	850	740.3913043	36.95652174

1. Confirmed rate = Confirmed case / Population.
2. Death rate = Deaths / Population.

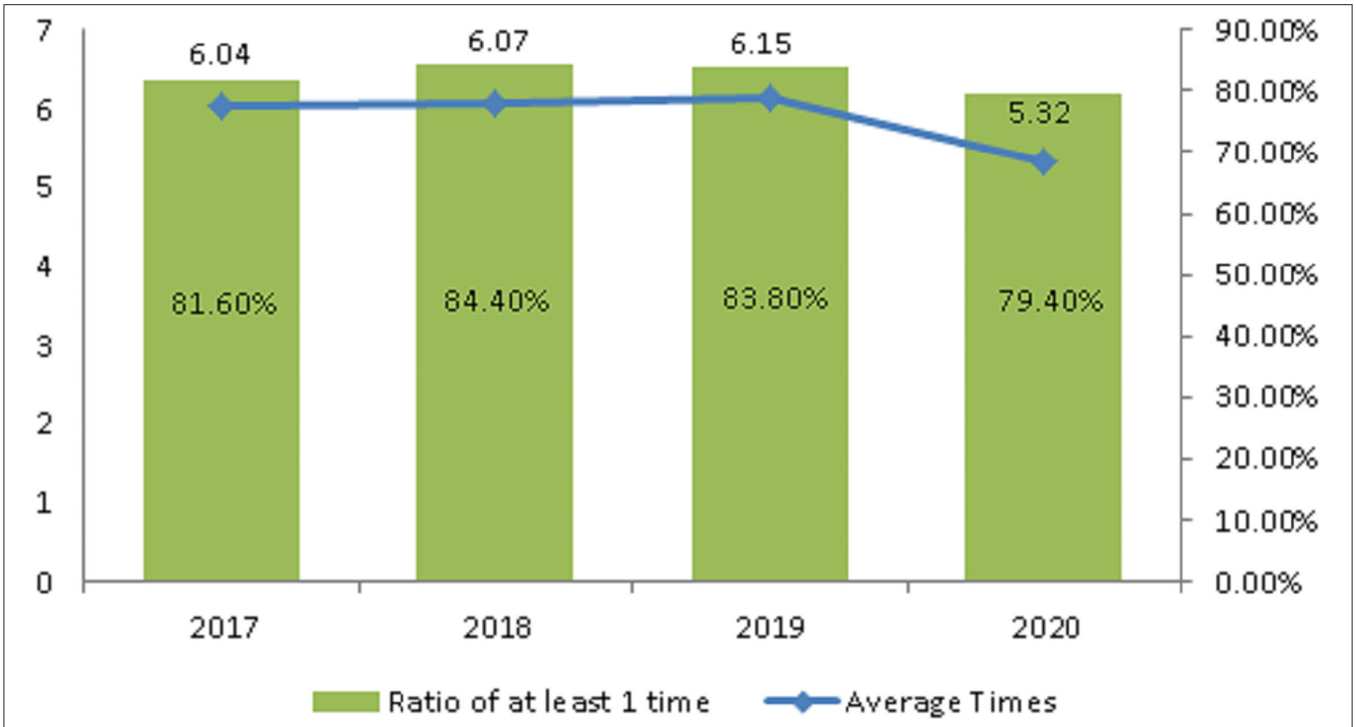

FIGURE 1 | The trend of tourism frequency.

by several correlated variables (24, 25). PCA defines a new orthogonal coordinate system that optimally describes variance in a dataset (26). Varimax rotation is done in PCA, so that the first axis contains as much variation as possible, and the second axis contains as much of the remaining variation as possible. It maximizes the sum of the variances of the squared loadings as all the coefficients will be either large or near zero; the goal is to associate each variable to at most one factor (27). The amount spent by older people tourists contained many items; to find the main component that contributed to the tourism industry, this study applied the PCA analysis method to reduce the number of variables and further understand the relationships between the items.

RESULTS

Frequency of Tourism

The average number of domestic trips for older people aged 65 and older was 6.04, 6.07, and 6.15 in 2017, 2018, and 2019, respectively (**Figure 1**). In the 3 years before the outbreak, the average number was 6.09. In 2020, after the outbreak, the number was 5.32, a decrease of 0.77 (**Table 2**).

The rate at which people took at least one trip was 81.6, 84.4, 83.8% in 2017, 2018, and 2019, respectively (**Figure 1**). The average rate in the 3 years before the outbreak was 83.27%. In 2020, after the outbreak, it was 79.4%, a decrease of 3.87% (**Table 2**).

It can be seen that the average number of trips and the rate of tourism both declined as a result of the pandemic.

TABLE 2 | Frequency of tourism.

Year	Average times	Rate of at least 1 trip
2017	6.04	81.60%
2018	6.07	84.40%
2019	6.15	83.80%
2020	5.32	79.40%
Before the pandemic (3-year average)	6.09	83.27%
Post-pandemic change	−0.77	−3.87%

Days of Tourism

The tourism day of the older people 65 ages and older was mainly 1 day. The rate was 73, 71.5, and 67.1% in 2017, 2018, and 2019, respectively (**Figure 2**). The average rate in the 3 years before the outbreak was 70.53%. In 2020, after the outbreak, it was 68.1%, a decrease of 2.43% (**Table 3**).

However, the rate of older people tourism 3 days was 10.2% after the outbreak, an increase of 2.37% compared with 7.83% before the outbreak (**Table 3**).

It can be seen that as a result of the pandemic, although the 1-day travel rate decreased, the 3-day travel rate increased, and the rate of increase and decrease is similar.

Purpose of Tourism

The purpose of tourism for people aged 65 and older was mainly sightseeing and recreation. The rate was 82.8, 83.8, and 83.2% in 2017, 2018, and 2019, respectively (**Figure 3**). The average rate

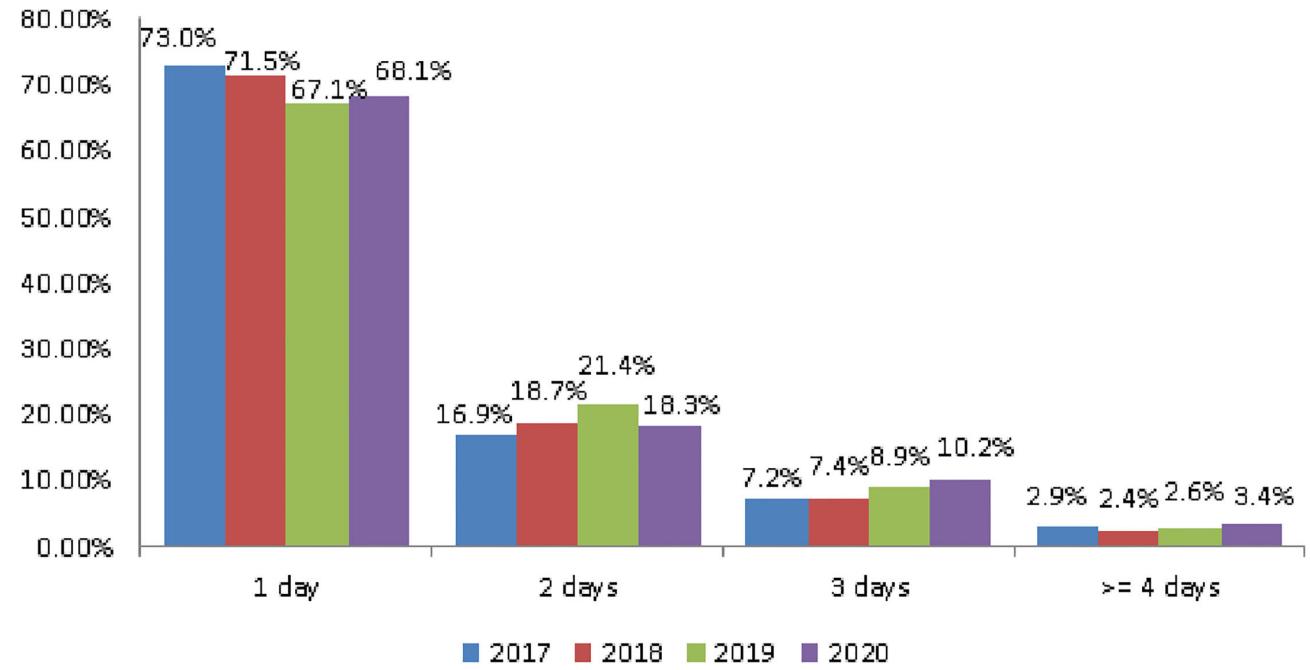

FIGURE 2 | The trend of tourism days.

TABLE 3 | Days of tourism.

Year	1 day	2 days	3 days	≥4 days
2017	73.00%	16.90%	7.20%	2.90%
2018	71.50%	18.70%	7.40%	2.40%
2019	67.10%	21.40%	8.90%	2.60%
2020	68.10%	18.30%	10.20%	3.40%
Before the pandemic (3-years average)	70.53%	19.00%	7.83%	2.63%
Post-pandemic change	−2.43%	−0.70%	2.37%	0.77%

in the 3 years before the outbreak was 83.27%. In 2020 after the outbreak, it was 80.1%, a decrease of 3.17% (**Table 4**).

However, after the outbreak, the rate of visiting relatives and friends was 19.6%, compared with 16.23% before the pandemic, an increase of 3.37% (**Table 4**).

It can be seen that although the rate of sightseeing and recreation decreased owing to the impact of the pandemic, the rate of visiting relatives and friends increased, and the rate of increase and decrease is similar.

Reasons for Choosing a Tourist Attraction

The reasons people aged 65 and older chose tourist attractions included convenient transportation, themed activities, food, visiting somewhere new, and their children's preferences. Among them, convenient transportation was the main reason, accounting for 48.3, 49.1, and 39.2% in 2017, 2018, and 2019, respectively (**Figure 4**). The average rate in the 3 years before the outbreak was 45.67%. In 2020, after the outbreak, it was 32.2%, a decrease of 13.47%. However, after the outbreak of the pandemic, leisure and health care accounted for 16.5%, and fewer crowds for 6% (**Table 5**).

It can be seen that the pandemic caused the importance of transportation convenience as a factor to fall, but the rate of fewer crowds to increase. Because leisure and health care only began to be represented in the survey data in 2019, it was 16.6%, similar to that in 2020.

Reasons for Not Participating in Tourism

The reasons that people aged 65 and older did not participate in tourism included poor health, not being interested, not having time, and cost. Among them, poor health was the main reason; the rates were 32.6, 32.5, and 32.2% in 2017, 2018, and 2019, respectively (**Figure 5**). The average rate in the 3 years before the outbreak was 32.43%. After the outbreak, it was 16.9% in 2020, a decrease of 15.53%. However, the COVID-19 pandemic factor was 19.9% in 2020 (**Table 6**).

The rate of poor health care as a factor decreased as a result of the pandemic. However, the increase in the rate of COVID-19 as a factor could also be regarded as a consideration of the overall health factor, and the total rate increased compared with that before the pandemic.

Tourism Expenses

People aged 65 and older generally spend <NT$2,000 per tourist trip. The rate of spending <NT$1000 was the highest, which was 39.10, 34.1, and 36.5% in 2017, 2018, and 2019, respectively (**Figure 6**). The average rate in the 3 years before the outbreak was 36.57%. In 2020 after the

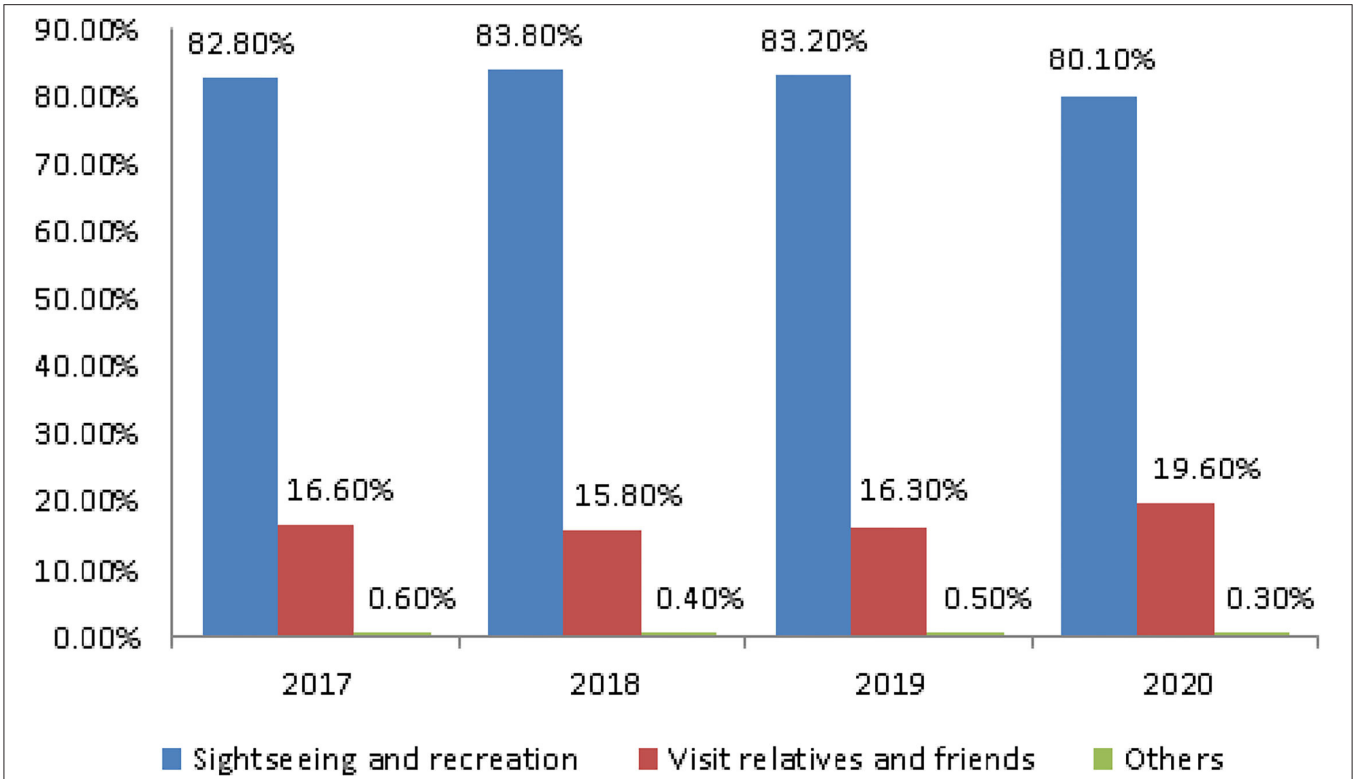

FIGURE 3 | The trend of tourism purpose.

TABLE 4 | The purpose of tourism.

Year	Sightseeing and recreation	Visiting relatives and friends	Other
2017	82.80%	16.60%	0.60%
2018	83.80%	15.80%	0.40%
2019	83.20%	16.30%	0.50%
2020	80.10%	19.60%	0.30%
Before the pandemic (3-year average)	83.27%	16.23%	0.50%
Post-pandemic change	−3.17%	3.37%	−0.20%

outbreak, it was 36.9%, an increase of 0.33%. However, after the pandemic, the rate from NT$1,000 to NT$1,999 was 22.6% compared with 25.63% before the pandemic, a decrease of 3.03%, and an increase of 3.17% for above NT$5,000 (**Table 7**).

Expenses included transportation, accommodation, food, entertainment, and shopping. The average total amounts were NT$2,308, NT$2,325, and NT$2,448 in 2017, 2018, and 2019, respectively (**Figure 7**). The average amount in the 3 years before the outbreak of COVID-19 was NT$2,360.33. In 2020, after the outbreak, it was NT$2,590, an increase of NT$229.67 (**Table 8**). Total travel expenses were not affected by the pandemic and still increased gradually.

The details of shopping expenses included clothing, souvenirs, fresh agricultural products, processing agricultural products, and traditional Chinese medicine or health food. Among them, processing agricultural products was the main expense (**Figure 8**). In 2019, it was NT$318. In 2020, it was NT$467, an increase of NT$149 (**Table 9**). Since shopping items were only included in the survey from 2019, only 2019 and 2020 data exist.

PCA Analysis

There are many tourism costs and related variables. To further understand the relationships between the items on which older people tourists spent money, a PCA analysis was applied to the amount spent on each item. PCA was performed on older people tourists' expenses from 2017 to 2020, and two main components were extracted. The PCA results are shown in **Table 10** and **Figure 9**.

The first component was food, accommodation, shopping, and other expenses. The factor loadings were 0.989, 0.931, 0.641, and −0.948, respectively. The second component was entertainment and transportation expenses. The factor loadings were 0.997 and 0.902, respectively. There was a high and significantly positive relationship between food, accommodation, and shopping expenses. Older people tourists who spent more on food also spent more on accommodation and shopping, but had lower spending on other expenses. On the other hand, older people tourists who spent more on entertainment also spent more on transportation.

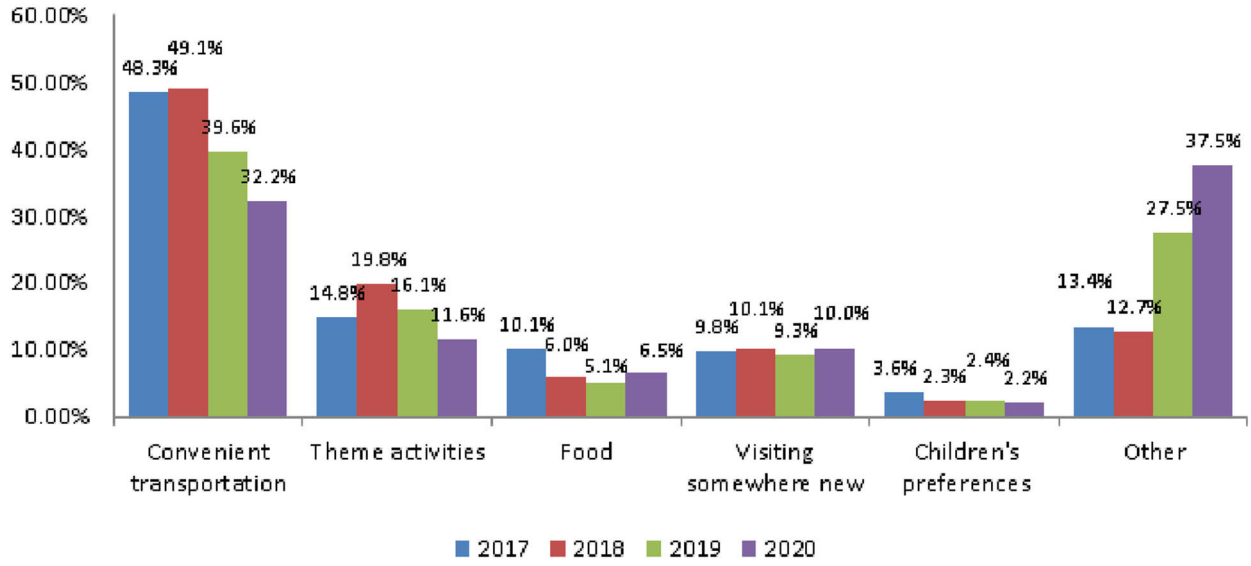

FIGURE 4 | The trend of reasons for choosing a tourist attraction.

TABLE 5 | The reasons for choosing a tourist attraction.

Year	Convenient transportation	Themed activities	Food	Visiting somewhere new	Children's preferences	Other
2017	48.30%	14.80%	10.10%	9.80%	3.60%	13.40%
2018	49.10%	19.80%	6.00%	10.10%	2.30%	12.70%
2019	39.60%	16.10%	5.10%	9.30%	2.40%	27.50%
2020	32.20%	11.60%	6.50%	10.00%	2.20%	37.50%
Before the pandemic (3-years average)	45.67%	16.90%	7.07%	9.73%	2.77%	17.87%
Post-pandemic change	−13.47%	−5.30%	−0.57%	0.27%	−0.57%	19.63%

"2020 other" includes the "leisure and health care" and "fewer crowds" factors, 16.50 and 6.00%, respectively.

DISCUSSION AND SUGGESTIONS

From the above statistical and analysis results, we provide several suggestions for relevant government departments and industry operators.

1. Before the COVID-19 pandemic, the average number of tours was 5.32 and the rate of participating in tours was 79.4%. Both showed a decline: of 0.77 number and 3.87%, respectively (**Figure 1** and **Table 2**). Older people's psychological distress, fear, and related behavior was affected by the COVID-19 pandemic (15–19). Therefore, if the pandemic can be controlled, it will help to increase the frequency of travel. The pandemic control factors are mainly based on the vaccination rate and pandemic prevention measures (28). The vaccination rate in Taiwan had reached 80% by the end of January 2022 (29). The effectiveness of the current government's anti-pandemic measures, mean that its confirmed rate and mortality rate are lower than the global average, which is also worth affirming (7, 8).
2. The number of days older people tourists engaged in tourism, regardless of the pandemic situation, was predominantly 1 day, accounting for about 70% of tourism by this group (**Table 3**). Therefore, relevant industries could launch 1-day travel itineraries to meet the demand. However, there is still a lot of space for operators to develop tourism for longer than 1 day (**Figure 2**).
3. The purpose of tourism for the older people is still mainly sightseeing and recreation, regardless of the pandemic situation. The rate was 82.8, 83.8, 83.2, and 80.1% in 2017, 2018, 2019 and 2020, respectively (**Figure 3**). Therefore, it is recommended that the relevant operators launch sightseeing and recreational itineraries to meet the demand.
4. The main reason older people tourists choose tourist attractions is about 40% for the convenience of transportation before the pandemic (**Figure 4**). After the pandemic, it dropped to ∼30%, the factor of fewer crowds accounted for ∼6%, and the factor of leisure and health care also reached ∼16% (**Table 5**). Therefore, the government and the industry should fully plan the transportation network of tourist attractions to provide greater convenience, and improve leisure and health care facilities to attract tourists. Healthcare providers should consider strategies for improving preventive behaviors among the older people to help ease their worries and fears concerning COVID-19 (17).
5. The reasons the older people did not participate in tourism were mainly influenced by health factors before

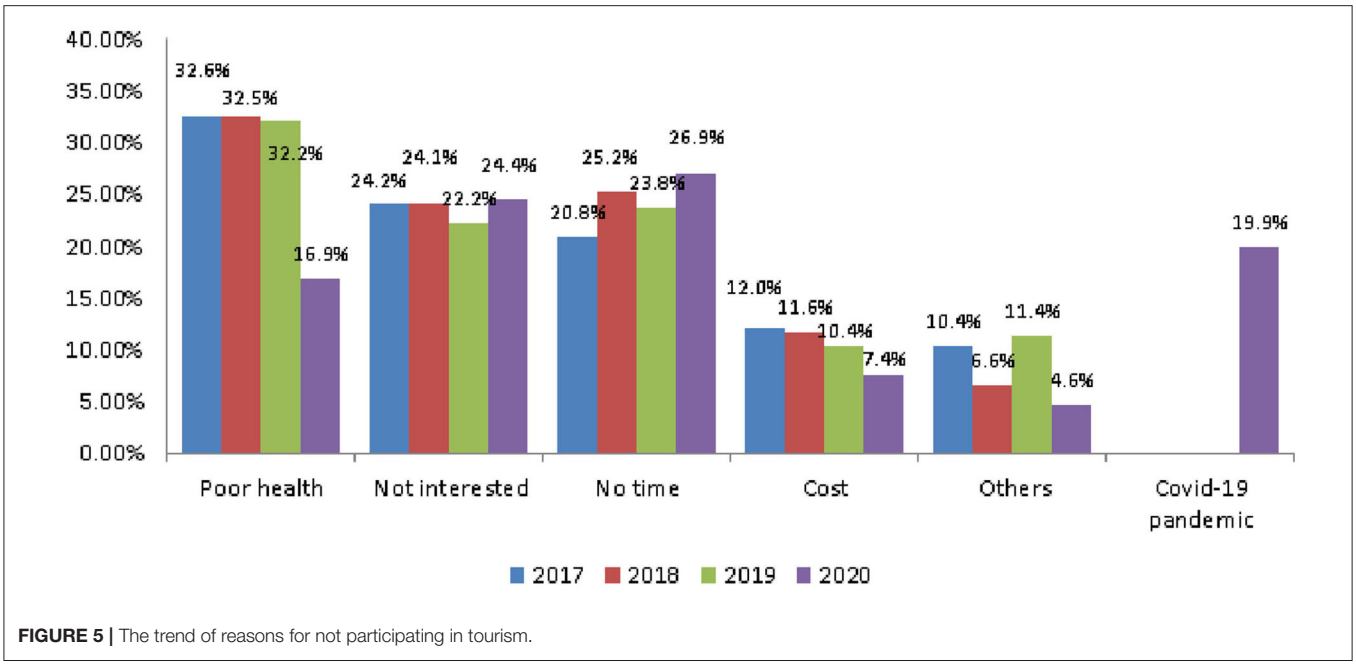

FIGURE 5 | The trend of reasons for not participating in tourism.

TABLE 6 | Reasons for not participating in tourism.

Year	Poor health	Not interested	No time	Cost	Others	COVID-19 pandemic
2017	32.60%	24.20%	20.80%	12.00%	10.40%	NA
2018	32.50%	24.10%	25.20%	11.60%	6.60%	NA
2019	32.20%	22.20%	23.80%	10.40%	11.40%	NA
2020	16.90%	24.40%	26.90%	7.40%	4.60%	19.90%
Before the pandemic (3-year average)	32.43%	23.50%	23.27%	11.33%	9.47%	NA
Post-pandemic change	−15.53%	0.90%	3.63%	−3.93%	−4.87%	19.90%

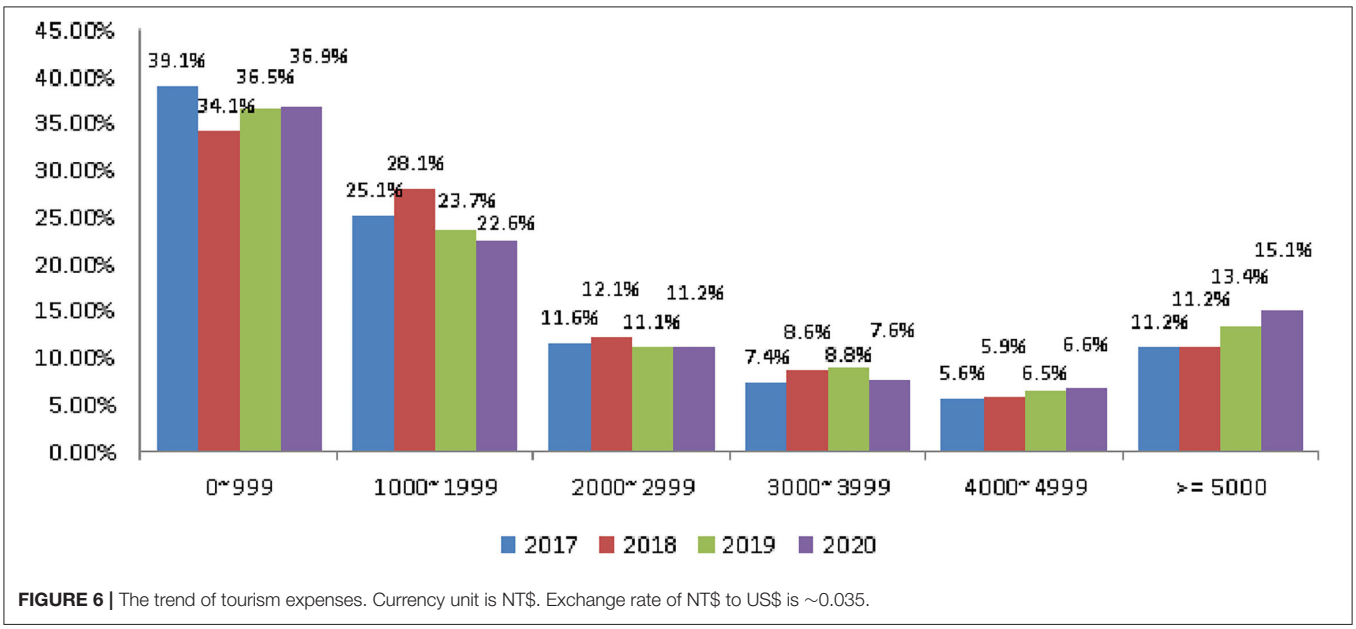

FIGURE 6 | The trend of tourism expenses. Currency unit is NT$. Exchange rate of NT$ to US$ is ~0.035.

TABLE 7 | Tourism expenses.

Year	0–999	1000–1999	2000–2999	3000–3999	4000–4999	≥5000
2017	39.10%	25.10%	11.60%	7.40%	5.60%	11.20%
2018	34.10%	28.10%	12.10%	8.60%	5.90%	11.20%
2019	36.50%	23.70%	11.10%	8.80%	6.50%	13.40%
2020	36.90%	22.60%	11.20%	7.60%	6.60%	15.10%
Before the pandemic (3-year average)	36.57%	25.63%	11.60%	8.27%	6.00%	11.93%
Post-pandemic change	0.33%	−3.03%	−0.40%	−0.67%	0.60%	3.17%

Currency unit is NT$. Exchange rate of NT$ to US$ is ∼0.035.

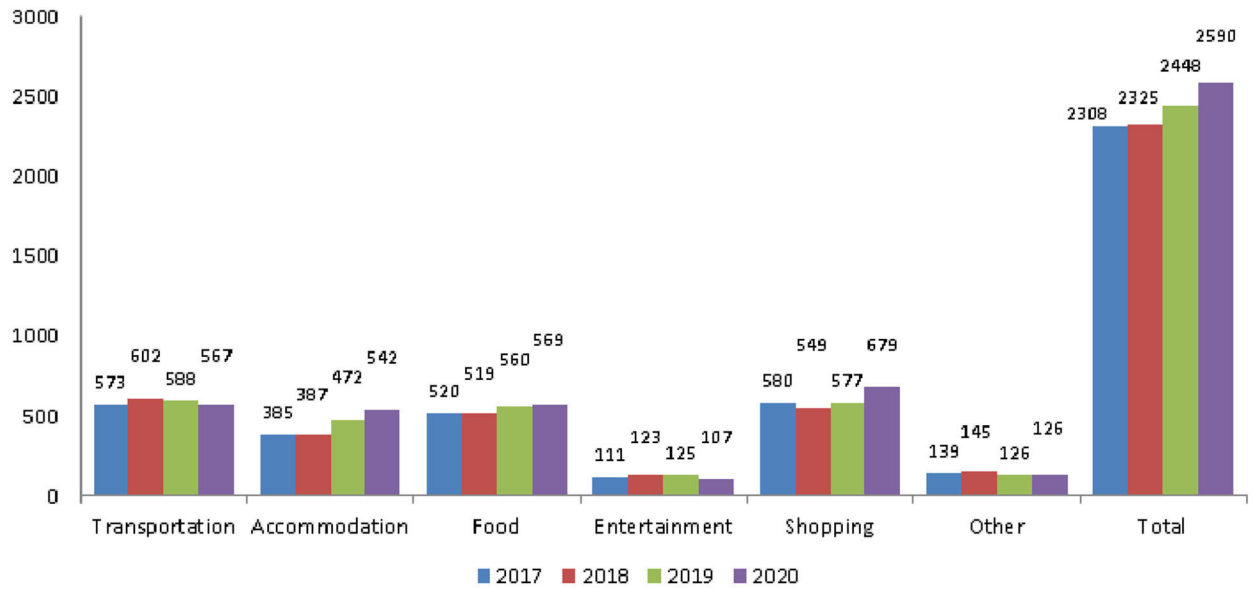

FIGURE 7 | The trend of expenses items. Currency unit is NT$. Exchange rate of NT$ to US$ is ∼0.035.

TABLE 8 | Expenses items.

Year	Transportation	Accommodation	Food	Entertainment	Shopping	Other	Total
2017	573	385	520	111	580	139	2,308
2018	602	387	519	123	549	145	2,325
2019	588	472	560	125	577	126	2,448
2020	567	542	569	107	679	126	2,590
Before the pandemic (3-year average)	587.67	414.67	533.00	119.67	568.67	136.67	2,360.33
Post-pandemic change	−20.67	127.33	36.00	−12.67	110.33	−10.67	229.67

the pandemic. The rate was 32.6, 32.5, and 32.2% in 2017, 2018, and 2019, respectively (**Figure 5**). In addition to health factors, there are also COVID-19 pandemic factors after the pandemic. The COVID-19 pandemic factor was 19.9% in 2020 (**Table 6**). Especially recently, some countries have been advocating coexistence with the pandemic and have been relaxing pandemic prevention control (30). Therefore, we suggest that the government and the industry should improve and properly plan health and medical care in travel itinerary, so that they can travel with peace of mind and more healthily. Healthcare providers should consider strategies for improving preventive behaviors among the older people to help ease their worries and fears concerning COVID-19 (17).

6. Tourism spending by the older people has increased each year and has not been affected by the COVID-19 pandemic. The average total amounts was NT$2,308, NT$2,325, NT$2,448, and NT$2,590 in 2017, 2018, 2019, and 2020, respectively (**Figure 7**). Through PCA analysis, we established that the first components were food, accommodation, shopping, and other expenses. The factor loadings were 0.989, 0.931, 0.641, and −0.948, respectively. The second components were entertainment and transportation expenses. The factor

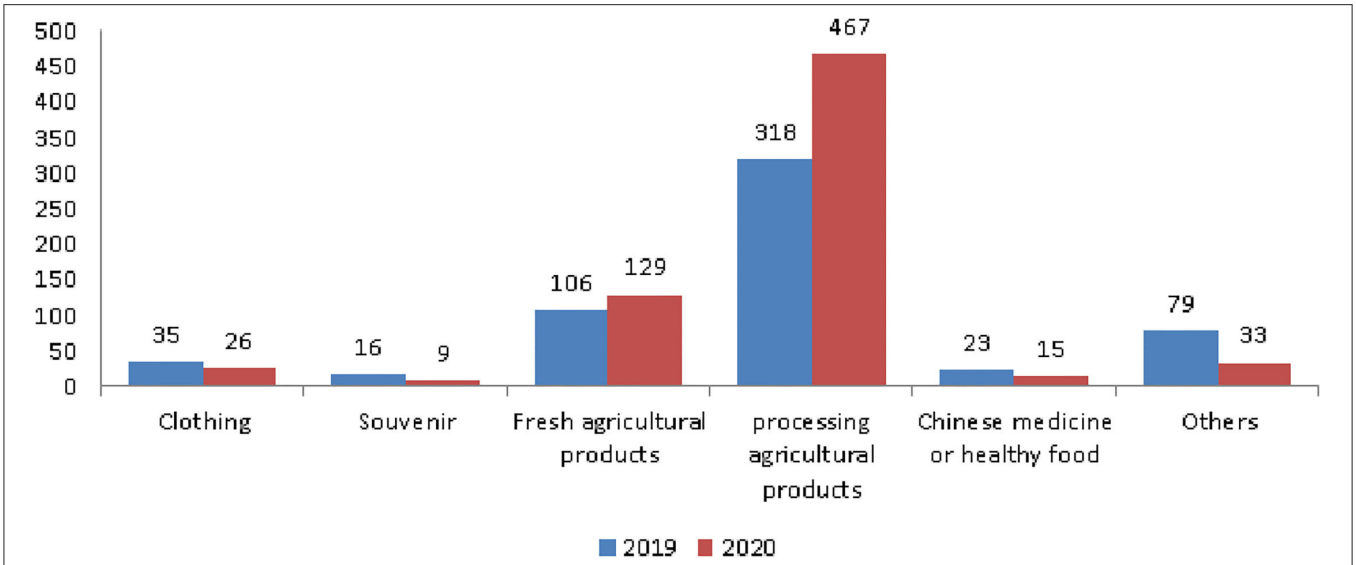

FIGURE 8 | The trend of shopping items. Currency unit is NT$. Exchange rate of NT$ to US$ is ~0.035.

TABLE 9 | Shopping items.

Year	Clothing	Souvenirs	Fresh agricultural products	processing agricultural products	Chinese medicine or healthy food	Other
2019	35	16	106	318	23	79
2020	26	9	129	467	15	33
Post-pandemic changes	−9	−7	23	149	−8	−46

Currency unit is NT$. Exchange rate of NT$ to US$ is ~0.035.

TABLE 10 | PCA total variance explained.

Component	Initial eigenvalues			Extraction sums of squared loadings			Rotation sums of squared loadings		
	Total	% of variance	Cumulative %	Total	% of variance	Cumulative %	Total	% of variance	Cumulative %
1	4.349	72.49	72.49	4.349	72.49	72.49	3.265	54.414	54.414
2	1.41	23.495	95.985	1.41	23.495	95.985	2.494	41.572	95.985
3	0.241	4.015	100						
4	6.08E-18	1.01E-16	100						
5	−1.43E-16	−2.38E-15	100						
6	−4.70E-16	−7.83E-15	100						

loadings were 0.997 and 0.902, respectively (**Figure 9**). If the industry planned the relevant consumption mix it could achieve the maximum benefit. The shopping items surveyed since 2019 show that processed agricultural products is the most important expenditure, and it also helps businesses plan related products (**Table 9**).

CONCLUSION

The older population in Taiwan reached ~3.95 million at the end of January 2022, accounting for around 16.9% of the country's total population. As the fertility rate declines and life expectancy increases, the older population will continue to increase toward a super-aged society. Therefore, the tourism demand of the older people will gradually increase and receive attention. At present, the COVID-19 pandemic is not completely under due to variants of the virus. This article explores how older people tourism have been affected by this major international public health event since early 2020. This study compares the differences and changes in the behavior of older people tourism before and after the pandemic through relevant statistical analysis such as quantitative and PCA methods. The study results found the frequency of tourism declined: the number was 5.32, a

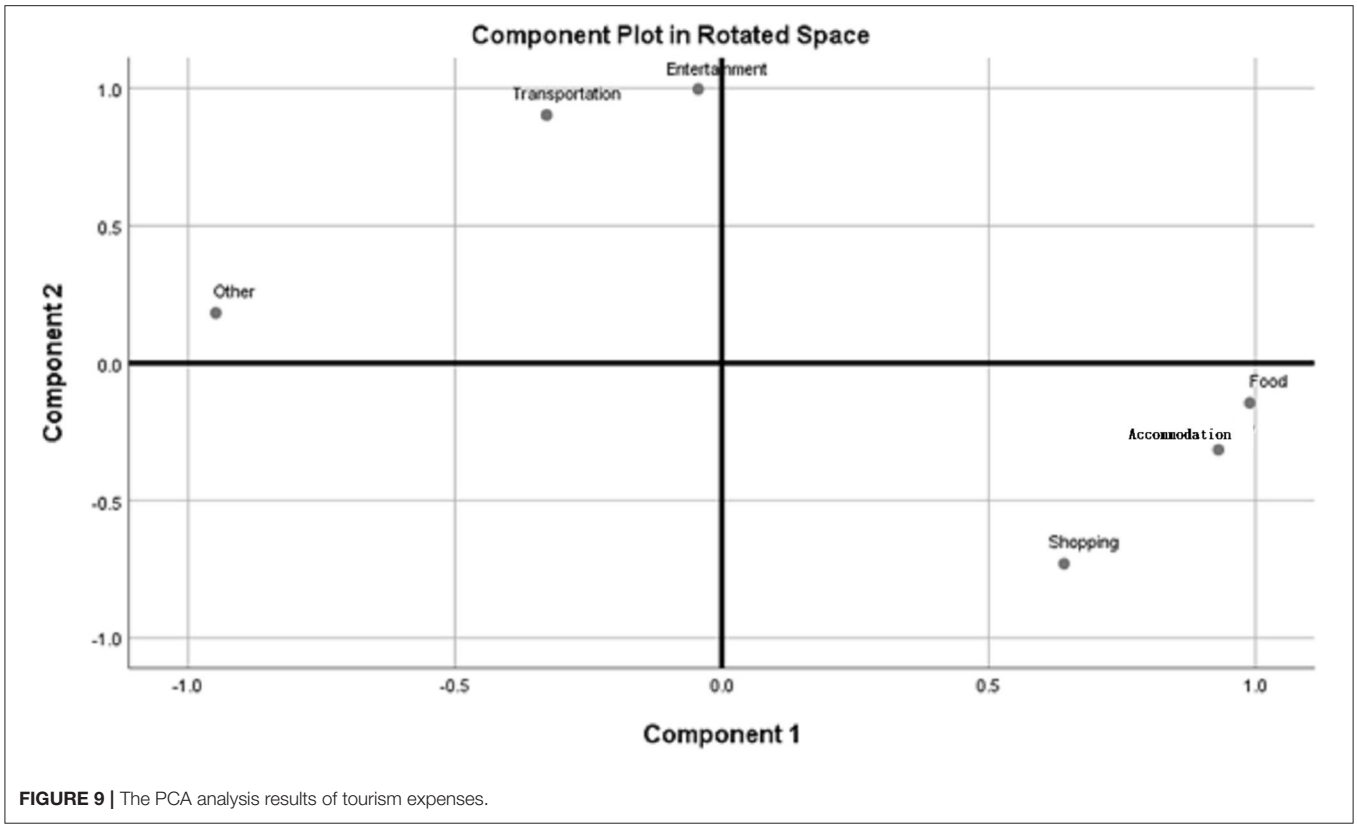

FIGURE 9 | The PCA analysis results of tourism expenses.

decrease of 0.77, and instances of people undertaking at least 1 tourist trip decreased by 3.87% after the pandemic. The duration of tourism day was mainly 1 day; at 68.1%, it decreased by 2.43% after the pandemic. The purpose of tourism was mainly sightseeing and recreation; it was 80.1%, a decrease of 3.17% after the pandemic. The convenient transportation is the main reason for choosing the attractions; it was 32.2%, a decrease of 13.47% after the pandemic. The reasons of not participate tourism; in COVID-19 pandemic factor was 19.9%. The total travel expenses was NT$2,590, an increase of NT$229.67, was not affected by the pandemic. We found that the frequency of travel, the number of days, the purpose, the reasons for choosing the attractions, and the reasons for not participating in the tour did change as a result of the impact of the pandemic. However, older people tourists were spending more year by year. Through PCA analysis, we examined the relationships between the items on which older people tourists spent money. The first component was food, accommodation, shopping and other expenses. The factor loadings were 0.989, 0.931, 0.641, and −0.948, respectively. The second component was entertainment and transportation expenses. The factor loadings were 0.997 and 0.902, respectively. Through PCA analysis, we established that it could help the industry to plan the relevant consumption mix to achieve maximum benefit. Finally, the paper puts forward relevant discussions and suggestions on the research results. If the pandemic could be controlled, it would help to increase the frequency of travel. The pandemic control factors are mainly based on the vaccination rate and pandemic prevention measures. The number of days spent on tourism by the older people, regardless of the pandemic situation, was still predominantly 1 day, accounting for about 70%. Therefore, we suggest that the tourism industry could launch 1-day travel itineraries to meet the demand. The purpose of tourism for older people is still mainly sightseeing and recreation; so we recommend that the relevant operators launch sightseeing and recreational itineraries to meet the demand. Convenient transportation is the main reason for choosing the attractions, so the government and the industry should fully plan the transportation network of tourist attractions to promote convenience, and should improve leisure and health care facilities to attract tourists, and make tourism for the older people more healthy and sustainable. In particular, the consideration of health factors is the main reason older people do not participate in tourism. In addition, the health status of the older people is not as good as that of young and middle-aged people, and they are more prone to sudden illness or injury. Therefore, the government and the tourism industry must properly plan the relevant health and medical care in travel itineraries to ensure their safety and health.

Whether the COVID-19 pandemic can be completely controlled in the future is not yet clear. The research in this paper includes analysis before and after the pandemic, it will help relevant units and operators to respond and consider different situations. The proportion of the older population in most countries in the world is also gradually increasing. However, at present, there are few studies on the impact of major public health events, such as COVID-19, on older people tourism. Therefore,

this article could also contribute to the research on tourism related to the older people in various countries around the world.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

AUTHOR CONTRIBUTIONS

C-TC designs the study and drafted the manuscript.

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Poor Physical Capacity Combined With High Body Fat Percentage as an Independent Risk Factor for Incident Hypertension in Chinese Suburb-Dwelling Older Adults

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Background: This study examined the effects of poor physical capacity and high body fat percentage (BF%) on the incidence of hypertension in Chinese suburb-dwelling older adults.

Methods: This study was conducted on 368 Chinese suburb-dwelling participants aged ≥ 60 years without hypertension (mean age: 66.74 ± 5.59 years, 48.9% men). Poor physical capacity is defined by the Asian Working Group for Sarcopenia (AWGS) criteria as grip strength < 26 kg for men and < 18 kg for women or walking speed <0.8 m/s. High BF% was defined as values that are greater than the upper tertile for BF% as stratified by sex. The outcome was the incidence of hypertension.

Results: Overall, 5.7% of subjects had both poor physical capacity and high BF%. After the average follow-up duration of 2 years, the incidence of hypertension was 39.7%, and those experiencing both poor physical capacity and high BF% had the highest incidence (81.0%). After multivariate adjustments, the incidence of hypertension was associated with the combination of poor physical capacity and high BF% [odds ratio (OR) = 6.43, 95% CI = 1.91–21.64] but not solely with poor physical capacity (OR = 1.11, 95% CI = 0.55–2.25) or only high BF% (OR = 1.37, 95% CI = 0.80–2.34).

Conclusion: The combination of poor physical capacity and high BF% can significantly increase the incidence of hypertension in Chinese suburb-dwelling older adults. For hypertension prevention, ideally, we should strive toward decreasing body fat mass while simultaneously improving physical capacity.

Keywords: older adults, physical capacity, body fat percentage (BF%), incident hypertension, Chinese

INTRODUCTION

As the aging population increases, hypertension has become one of the most prevalent diseases, affecting more than 70% of older people and contributing to the burden of cardiovascular disease, stroke, premature mortality, and disability (1–3). In addition, aging is also associated with a dramatic change in body composition and physical performance, such as an increase in the percentage of fat mass and a decrease in physical capacity, both of which are actively involved in metabolic regulation. Therefore, it is important to promptly and accurately identify and prevent these risk factors of hypertension in older adults.

Physical limitations can impair an independent lifestyle and quality of life. In fact, it is expected that the older population will experience declines in physical function and disability (4). Poor physical capability, as assessed by simple objective measures of muscle strength (grip strength) and physical performance (4-m walk test), has been shown to predict the onset of disability, loss of independence, and survival in older community-dwelling individuals (5). Several factors, such as endothelial dysfunction, oxidative stress, and inflammation, have been related to both arterial stiffness and muscular fitness (6–8). Muscle contraction-induced factors have an anti-inflammatory effect, but physical disability may cause a reduction in these factors, which in turn may increase the risk for cardiovascular disease, such as hypertension (9). Previous studies have emphasized the importance of preventing poor physical capacity when addressing hypertension, while other studies have suggested that poor physical capacity is not associated with hypertension (10). Given that the impact of poor physical capacity on hypertension is not fully understood, further research is needed to explore the association.

Aging is associated with significant changes in body composition. A recent large meta-analysis of nearly 200,000 individuals aged 65 and older showed a U-shaped relationship between body mass index (BMI) and mortality, with the lowest risk seen in those with a BMI between 24.0 and 30.0 kg/m (2). The risk began to increase when BMI exceeded 33 kg/m^2 (11). A possible explanation involves the functions of adipose tissue. Adipose tissue produces leptin which may have protective effects on heart failure and decrease the risks of adiponectin in obesity. Similarly, in our previous study based on the Adult Physical Fitness and Health Cohort Study (APFHCS, ChiCTR 1900024880), we found that a high BMI is protective against sarcopenia (12). In contrast, some studies have shown a clear association between an increase in blood pressure (BP) and BMI. A systematic review and dose-response meta-analysis of more than 2.3 million participants found that the relative risk of hypertension was 1.49 for a five-unit increment in BMI (13). Because BMI and other abdominal obesity indicators may not adequately reflect the amount of body fat in some cases (14), we focused on the influence of high body fat percentage (BF%) on hypertension. A cross-sectional study found that dynapenia (grip strength) and abdominal obesity (waist circumference) were associated with a high prevalence of lipid and glucose metabolism disorders and metabolic syndrome (15). Therefore, it is necessary to investigate the effect of the combination of poor physical capacity and high BF% on the incidence of hypertension in Chinese older adults.

In this study, our purpose was to determine both the separate and combined effects of poor physical capacity and high BF% on the new-onset hypertension. We hypothesized that two pathological conditions would synergistically increase the risk of incident hypertension more than poor physical capacity alone or high BF% alone in Chinese suburb-dwelling older adults. This is a particularly significant study population, which is more likely to be healthy and have fewer activity limitations than those residing in care facilities (16). From a public health perspective, it is essential to identify hypertension-related risk factors to improve healthcare management and inform lifestyle intervention programs.

MATERIALS AND METHODS

Study Participants

The APFHCS is a large prospective dynamic cohort study that mainly investigated the association between physical fitness and health status in a general adult population living in Tianjin, China. Participants were recruited for annual comprehensive health examinations and completed detailed questionnaires regarding their lifestyle and disease history. Our study population included 840 older individuals (age $\geq$ 60 years) from three areas of Tianjin, China, who joined the national free physical examination program from 2013 to 2014 at baseline. The inclusion criteria consisted of the following: (1) having undiagnosed hypertension; (2) having normal cognition (i.e., subjects who can communicate with interviewers or grant informed consent); and (3) subjects without disability or cardio-cerebrovascular diseases that affect the basic activities of daily living and geriatric assessments. A total of 453 subjects were excluded, i.e., 369 people with hypertension, 76 people with cardio-cerebrovascular diseases, three people with cancer, and five people who failed to undergo a physical examination. In total, 387 subjects enrolled in this study.

The cohort was invited to attend repeat questionnaire interviews and physical measurements after the 2 years from 2015 to 2016. During the follow-up duration, we excluded participants who died ($n = 2$), were bedridden ($n = 2$), and had those missing data ($n = 15$). Therefore, 368 participants were included. All participants provided informed consent prior to participation. The study was approved by the Ethics Committee of Tianjin Medical University.

Definition of Hypertension

Blood pressure was measured two times from the upper left arm using a sphygmomanometer after 10 min of sitting, and the mean of these two measurements was taken as the BP value. Based on the eighth report of the Joint National Committee on Prevention, Detection, Evaluation, and Treatment of High Blood Pressure (JNC 8) (17), participants were defined as having hypertension with systolic blood pressure (SBP) $\geq$140 mmHg or diastolic blood pressure (DBP) $\geq$90 mmHg and/or the self-reported current treatment for hypertension with antihypertensive medication.

TABLE 1 | Baseline characteristics of all patients following classification according to the incidence of hypertension during follow-up.

Characteristic	All ($n = 368$)	Hypertension event		*P*-value
		No event ($n = 222$)	Even ($n = 146$)	
Age (y)	66.74 ± 5.59	66.34 ± 5.47	67.36 ± 5.75	0.088
Male (%)	180 (48.9)	105 (47.3)	75 (51.4)	0.255
BMI (kg/m^2)	24.50 ± 3.32	23.84 ± 3.10	25.50 ± 3.39	<0.001
BF% (%)	29.71 ± 8.01	28.77 ± 8.14	31.14 ± 7.62	0.005
ASM/height^2 (kg/m^2)	7.04 ± 0.97	6.92 ± 0.98	7.21 ± 0.94	0.006
Grip strength (kg)	27.88 ± 9.05	27.83 ± 8.69	27.95 ± 9.60	0.895
Walking speed (m/s)	1.04 ± 0.17	1.06 ± 0.17	1.00 ± 0.17	0.002
IPAQ (Mets/wk)	2,110 (1,059–4,284)	2,099 (891–3,942)	2,184 (1,386–5,019)	0.289
Widowed (%)	37 (10.1)	24 (10.8)	13 (8.9)	0.599
Living alone (%)	41 (11.1)	22 (9.9)	19 (13.0)	0.398
Illiteracy (%)	97 (26.4)	57 (25.7)	40 (27.4)	0.718
Farming (%)	318 (86.4)	200 (90.1)	118 (80.8)	0.013
Smoking (%)	127 (34.5)	79 (35.6)	48 (32.9)	0.654
Drinking (%)	120 (32.6)	65 (29.3)	55 (47.7)	0.111
Fall history (%)	41 (11.1)	16 (7.2)	25 (17.1)	0.004
Diabetes (%)	33 (9.0)	15 (6.8)	18 (12.3)	0.092
Dyslipidemia (%)	147 (39.9)	79 (35.6)	68 (46.6)	0.039
Osteoporosis (%)	278 (75.5)	172 (77.5)	106 (72.6)	0.322

The continuous variables are presented as mean ± standard deviation or median (25th−75th percentiles), the categorical variables are reported as percentages. ASM, appendicular skeletal muscle mass; BF%, body fat percentage; BMI, body mass index; IPAQ, international physical activity questionnaire; Mets/wk, metabolic equivalent task minutes per week.

Definition of Poor Physical Capacity and High BF%

All body composition indicators were measured using a direct segmental multifrequency bioelectrical impedance analysis (BIA) (InBody720; Biospace Co., Ltd, Seoul, Korea). According to the Asian Working Group for Sarcopenia (AWGS) criteria (18), poor physical capacity is defined as grip strength <26 kg for men and <18 kg for women or usual walking speed <0.8 m/s. Grip strength was measured using a dynamometer (GRIP-D; Takei Ltd, Niigata, Japan). Participants were asked to exert maximum effort two times using their dominant hand (19), and the result from the strongest hand was used for analysis. Usual walking speed (m/s) on a 4-meter course was used as an objective measure of physical performance (19).

Body fat percentage was assessed by the means of BF% (fat mass/weight). Because no consensus definition has yet been adopted (20), high BF% is defined by the highest tertile for BF%. The cutoff point by sex was ≥27.43% for men and was ≥37.00% for women.

Assessment of Covariates

Data regarding sociodemographic variables, behavioral characteristics, and medical conditions were obtained *via* face-to-face questions. Sociodemographic variables included age, sex, marital status, educational level, and occupation. Marital status was classified as married (living together, divorced, separated, or widowed) or never married/single. Behavioral characteristics included smoking habits (current smoker or not), drinking habits (current drinker or not), and fall history. We have also described the methods of the International Physical Activity Questionnaire (IPAQ) and chronic conditions (such as diabetes, dyslipidemia, and osteoporosis). Details of the survey methods have been described in our previous study (12, 21).

Statistical Analysis

All continuous variables with a normal distribution are expressed as the mean and standard deviation (SD), whereas data with an abnormal distribution are expressed as the median, with the 25–75% interquartile range given in parentheses. Categorical variables are expressed as percentages. Differences in the characteristics according to poor physical capacity and high BF% status were analyzed using analysis of variance (ANOVA), χ^2 tests, and Kruskal-Wallis rank tests. Bonferroni corrected *p*-values ($k = 6$) were used for comparisons between poor physical capacity and high BF% categories. Logistic regression analysis was used to analyze the association between poor physical capacity and/or high BF% and incident hypertension. Crude was not adjusted. Model 1 was adjusted for age and sex. Model 2 was adjusted for Model 1 variables in addition to farming, illiteracy, widowed, living alone, smoking, drinking, appendicular skeletal muscle mass (ASM)/height^2, IPAQ (binary categorical variables based on the median), fall history, diabetes, dyslipidemia, and osteoporosis. All statistical analyses were performed using SPSS version 25.0, and a p-value <0.05 was considered statistically significant.

TABLE 2 | Basic characteristics according to poor physical capacity and high BF% status.

Characteristic	Normal (n = 189)	High BF% only (n = 102)	PPC only (n = 56)	PPC with high BF% (n = 21)	P-value
Age (y)	66.02 ± 5.10	65.89 ± 5.19	69.04 ± 6.43[a,b]	71.24 ± 5.97[a,b]	<0.001
Male (%)	102 (54.0)	54 (52.9)	18 (32.1)[a]	6 (28.6)	0.006
BMI (kg/m^2)	23.29 ± 2.50	27.34 ± 2.67[a,c]	22.34 ± 2.93	27.29 ± 2.69[a,c]	<0.001
BF% (%)	26.05 ± 6.89	35.81 ± 5.75[a,c]	27.54 ± 6.73	38.87 ± 4.96[a,c]	<0.001
ASM/height^2 (kg/m^2)	7.09 ± 0.93	7.31 ± 0.91	6.45 ± 1.06[a,b]	6.79 ± 0.77	<0.001
Grip strength (kg)	30.37 ± 7.68	30.62 ± 8.44	18.29 ± 5.67[a,b]	17.72 ± 6.14[a,b]	<0.001
Walking speed (m/s)	1.07 ± 0.16	1.07 ± 0.15	0.93 ± 0.17[a,b]	0.86 ± 0.17[a,b]	<0.001
IPAQ (Mets/wk)	2,324 (1,386–5,040)	2,184 (1,021–5,371)	1,897 (953–3,287)	1,386 (297–2,772)	0.037
Widowed (%)	13 (6.9)	9 (8.8)	12 (21.4)[a]	3 (14.3)	0.017
Living alone (%)	14 (7.4)	12 (11.8)	10 (17.9)	5 (23.8)	0.029
Illiteracy (%)	51 (27.0)	20 (19.6)	18 (32.1)	8 (38.1)	0.180
Farming (%)	166 (87.8)	82 (80.4)	52 (92.9)	18 (85.7)	0.144
Smoking (%)	73 (38.6)	26 (25.5)	22 (39.3)	6 (28.6)	0.113
Drinking (%)	69 (36.5)	34 (33.3)	13 (23.2)	4 (19.0)	0.149
Fall history (%)	16 (8.5)	13 (12.7)	7 (12.5)	5 (23.8)	0.148
Diabetes (%)	14 (7.4)	9 (8.8)	6 (10.7)	4 (19.0)	0.293
Dyslipidemia (%)	65 (34.4)	53 (52.0)[a]	17 (30.4)	12 (57.1)	0.004
Osteoporosis (%)	146 (77.2)	72 (70.6)	44 (78.6)	16 (76.2)	0.586

The continuous variables are presented as mean ± standard deviation or median (25th−75th percentiles), the categorical variables are reported as percentages. ASM, appendicular skeletal muscle mass; BF%, body fat percentage; BMI, body mass index; IPAQ, international physical activity questionnaire; Mets/wk, metabolic equivalent task minutes per week; PPC, poor physical capacity.

[a]P (bonferroni correction) < 0.05 vs. normal.

[b]P (bonferroni correction) < 0.05 vs. high BF% only.

[c]P (bonferroni correction) < 0.05 vs. PPC only.

TABLE 3 | Multivariable logistic regression analyses for the incidence of hypertension according to poor physical capacity and high BF% status.

Status	Normal	High BF% only	PPC only	PPC with high BF%	P-value
Incidence of hypertension (%)	64 (33.9)	47 (46.1)	18 (32.1)	17 (81.0)[a,b,c]	<0.001
Logistic regression analyses Odds Ratio (95% CI)					
Unadjusted	1.00 (Referent)	1.67 (1.02–2.73)[a]	0.93 (0.49–1.75)	8.30 (2.68–25.70)[a,b,c]	0.001
Adjusted Model 1	1.00 (Referent)	1.68 (1.03–2.76)[a]	0.91 (0.47–1.76)	7.96 (2.49–25.37)[a,b,c]	0.001
Adjusted Model 2	1.00 (Referent)	1.37 (0.80–2.34)	1.11 (0.55–2.25)	6.43 (1.91–21.64)[a,b,c]	0.023

ASM, appendicular skeletal muscle mass; BF%, body fat percentage; CI, confidence interval; IPAQ, international physical activity questionnaire; PPC, poor physical capacity. Model 1 was adjusted for age and gender. Model 2 was adjusted for Model 1 variables in addition to farming, illiteracy, widowed, living alone, smoking, drinking, ASM/height^2, IPAQ, fall history, diabetes, dyslipidemia and osteoporosis.

[a]P < 0.05 vs. normal.

[b]P < 0.05 vs. high BF% only.

[c]P < 0.05 vs. PPC only.

RESULTS

Characteristics of Subjects

Table 1 presents the baseline characteristics of all patients according to the incidence of hypertension during follow-up. The final study included 368 participants (48.9% men) with a mean age of 66.74 ± 5.59 years. According to the outcome of the average 2-year follow-up survey, 146 (39.7%) of the subjects (75 men and 71 women) with non-hypertension have developed hypertension. Subjects who had suffered from a hypertension event had a statistically significant higher BMI, BF%, and ASM/height^2, and a lower walking speed than subjects without hypertension ($p < 0.05$). In addition, those with new-onset hypertension were more likely to be farming and had a higher prevalence of fall history and dyslipidemia ($p < 0.05$).

The baseline characteristics of subjects according to poor physical capacity and high BF% status are shown in **Table 2**. Overall, 102 (27.7%) subjects had only high BF%, 56 (15.2%) subjects had only poor physical capacity, and 21 (5.7%) subjects had both poor physical capacity and high BF%. Subjects who had suffered from poor physical capacity with high BF% or poor physical capacity alone were older (71.24 ± 5.97/69.04 ± 6.43 vs. 66.02 ± 5.10/65.89 ± 5.19, $p < 0.001$), had a weaker grip strength (17.72 ± 6.14/18.29 ± 5.67 vs. 30.37 ± 7.68/30.62 ± 8.44, $p <$

0.001), and a slower walking speed (0.86 ± 0.17/0.93 ± 0.17 vs. 1.07 ± 0.16/1.07 ± 0.15, $p < 0.001$). Those with poor physical capacity with a high BF% or high BF% alone had a higher BMI (27.29 ± 2.69/27.34 ± 2.67 vs. 23.29 ± 2.50/22.34 ± 2.93, $p < 0.001$) and BF% (38.87 ± 4.96/35.81 ± 5.75 vs. 26.05 ± 6.89/27.54 ± 6.73, $p < 0.001$) than other groups. Among these groups, the only poor physical capacity group had more female proportions (67.9 vs. 46.0%, Bonferroni $p = 0.004$), widowed (21.4 vs. 6.9%, Bonferroni $p = 0.002$), and had the lower ASM/height^2 (6.45 ± 1.06 vs. 7.09 ± 0.93/7.31 ± 0.91, Bonferroni $p < 0.001$). The only high BF% group had a higher prevalence of dyslipidemia (52.0 vs. 34.4%, Bonferroni $p = 0.004$).

Poor Physical Capacity and High BF% on Incident Hypertension

Table 3 presents the multivariable logistic regression analyses for the incidence of hypertension according to poor physical capacity and high BF% status. Compared to other groups, participants who had both poor physical capacity and high BF% had the highest incidence of hypertension. In the unadjusted model, the risk of the incidence of hypertension was progressively greater in the high BF% alone group [odds ratio (OR) = 1.67, 95% CI = 1.02–2.73] and the high BF% group than in the poor physical capacity group (OR = 8.30, 95% CI = 2.68–25.70). Adjusting for potential confounders of Model 2, high BF% when compared with poor physical capacity (OR = 6.43, 95% CI = 1.91–21.64) was still associated with a significantly higher risk for incident hypertension. However, this association was not observed in the high BF% alone group.

DISCUSSION

In this study, we estimated the separate and combined effects of poor physical capacity and high BF% on new-onset hypertension in Chinese suburb-dwelling older adults. We found that the highest incidence of hypertension occurred among those with both poor physical capacity and high BF%. Furthermore, our results suggest that poor physical capacity alone or high BF% alone did not have a significant effect on the incidence of hypertension, while the combination of these two pathological conditions can independently predict the risk of developing hypertension after adjusting for potential confounders.

In our analysis, the incidence of hypertension was 39.7% after the average follow-up duration of 2 years, which is similar to a previous study (22). A large-scale longitudinal study had shown that 29.6% of suburb-dwelling older adults developed hypertension (23). The main possible reason for these differences is that the incidence of hypertension increases with age, and the average age of the above study (64.28 years) was lower than that of our study (66.74 years). Moreover, such variability to some extent can be attributed to differences in the characteristics, gender, and living conditions of the study sample.

Although there were significant differences in the grip strength (18.29 ± 5.67 vs. 30.37 ± 7.68, Bonferroni $p < 0.001$) and walking speed (0.93 ± 0.17 vs. 1.07 ± 0.16, Bonferroni $p < 0.001$) between the group of subjects who suffered from poor physical capacity alone and the group of normal individuals, our regression analyses revealed that poor physical capacity alone could not predict incident hypertension. A previous cross-sectional study supported our results, which suggested that hypertension is not associated with poor physical capacity (10). Furthermore, other researchers also found that a normotensive status rather than hypertension is associated with mobility limitations in those participants who aged ≥60 years (24). Indeed, recent reviews in the literature have described a possible association between high BP levels and poor physical capacity in older people (25, 26). This topic has been extensively discussed in the areas of geriatrics and gerontology, and a proposed theory is that a low and controlled hypertension phenotype can catalyze the development of frailty syndrome (25). The discrepancy between the results may be due to a difference in the sensitivity and specificity of the employed diagnostic tools and the characteristics of the participants. One major consideration is the age of the participants. Our study sample was approximately 10 years younger than those of previous longitudinal multicenter studies (27), which indicates that this condition may be time dependent. The other consideration is that poor physical capacity may increase the risk of incident hypertension due to the lack of physical activity. However, in our study, our population was relatively active and independent, and there were no significant differences in physical activity between the normal group and the poor physical capacity group [2,324 (1,386–5,040) vs. 1,897 (953–3,287), Bonferroni $p > 0.05$]. To date, studies on the causal relationships between poor physical capacity and incident hypertension are very few and limited, more future cohort studies are required to elucidate this relationship.

Obesity is increasing globally among Chinese older adults. Our results showed that high BF% alone can precipitate new-onset hypertension in a crude analysis but there was no difference after adjusting for potential confounders, which agrees with previous findings (28). On the one hand, the different outcomes may be due to the impact of the adjusted confounders, such as diabetes and dyslipidemia. Excessive intra-abdominal fat can be associated with type II diabetes, hypertension, dyslipidemia, coronary heart disease, and stroke. Despite having a normal BMI, those with an increased BF% are at increased risk of developing cardiometabolic diseases (29). On the other hand, because no consensus definition has yet been adopted, the cutoff values for BF% also have the potential to influence our results. Currently, the relationship between high BF% and hypertension has mostly been demonstrated based on cross-sectional studies, and more extensive longitudinal evidence is needed to clarify this relationship.

The present study results confirmed our primary hypothesis that the combination of poor physical capacity and high BF% can be an independent risk factor for incident hypertension. The results of our study show that the combination of poor physical capacity and high BF% had an incidence of hypertension of 81%, which was more than a 6-fold higher risk than those without poor physical capacity and high BF%. Although poor physical capacity alone or high BF% alone did not show significant effects on the morbidity of hypertension, their influence became obvious after superimposing. There are some reasons that may

explain the joint effect of poor physical capacity and high BF% on hypertension. There was a clear negative relationship between fat mass and physical performance. Previous studies have shown a clear negative relationship between fat mass and physical performance. Poor physical capacity may cause physical inactivity, thereby leading to a reduction in energy expenditure, fat accumulation, and subsequent hypertension (30). Conversely, the activation of inflammatory pathways is mediated by adipose tissue. These inflammatory markers, such as tumor necrosis factor alpha (TNF-a), interleukin 6 (IL-6), C-reactive protein, and leptin, influence insulin resistance and growth hormone and cause an imbalance in protein synthesis, and lead to poor physical capacity (14). Furthermore, the additional weight resulting from body fat mass accumulation on the knee joints is associated with musculoskeletal impairments and physical disability. Therefore, it is possible to postulate that poor physical capacity and high BF% may potentiate each other to induce hypertension.

This study has a number of strengths. This was the first longitudinal prospective study to examine the separate and joint effects of poor physical capacity and high BF% on new-onset hypertension in Chinese suburb-dwelling older adults. In addition, it was also the first one to examine a uniquely defined group of suburb-dwelling older adults living in a discrete geographical area. Our participants were leading a more physically active lifestyle, which might differ from that of subjects in other geographical areas. Despite extensive efforts to curb the limits of our study, some limitations did exist. In our study, all participants in the present study were relatively healthy, as we did not include participants who were unable to participate in the free annual national physical examination, which inevitably led to selection bias. Due to this limitation, our results might in fact underestimate the prevalence of the combination of poor physical capacity and high BF% and its health impact. Despite this limitation, significant differences were still observed, implying that statistical power should not be a serious problem. In addition, the use of BIA to assess body composition presents a drawback, but it is well-correlated with magnetic resonance imaging (MRI) predictions and dual-energy X-ray absorptiometry (DXA). Furthermore, high BF% was identified as the highest tertile for BF% in our study, which is a lack of generally accepted reference values in the Chinese older adults. Despite controlling a considerable number of confounding factors, we cannot exclude all the possible confounders that may affect the results, such as endothelial dysfunction, oxidative stress, and inflammation, which correlate with BP. In the future, we will add relevant data to our subsequent study. In future research, we will enlarge the sample sizes and extend the follow-up years to determine the cut-off values for BF% and explore other lifestyle behaviors that might contribute to hypertension.

In our study, we found that poor physical capacity alone or high BF% alone did not have a significant effect on the incidence of hypertension, while the combination of poor physical capacity and high BF% may be an independent risk factor for incident hypertension in Chinese community-dwelling older adults. For older individuals with these two pathological conditions, ideally, we should pay attention to decreasing body fat mass while simultaneously improving physical capacity. Considering current findings, public health efforts should continue to promote regular physical activity and balanced nutrition to assist with the maintenance of optimal physical fitness.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Ethics Committee of Tianjin Medical University. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

PH wrote the main manuscript text. YZheng, ZZ, ML, and QG conceived and designed research. WC, JLi, and YC analyzed the data. XC discussed the results. ZL, XY, YL, SS, JM, and JLiu did the most research. YZhang made constructive comments during the review process. All authors contributed to the article and approved the submitted version.

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Effects of Social Participation by Middle-Aged and Elderly Residents on the Utilization of Medical Services: Evidence From China

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Objectives: Aim to evaluate the effect of social participation on utilization of medical services among middle-aged and elderly residents in China.

Methods: We used data from the 2018 wave of the China Health and Retirement Longitudinal Study. Social participation is classified into three types. Furthermore, to control for confounding factors, our study computed propensity score matching (PSM) to evaluate the effect of social participation on the utilization of medical services.

Result: The result of PSM indicates that social participation significantly positively affects the utilization of outpatient services, the average treatment effect on the treated (ATT = 0.038***) and the utilization of inpatient services (ATT = 0.015**) by middle-aged and elderly residents. Furthermore, the utilization of outpatient health care services was significantly positively associated with leisure activities (ATT = 0.035***), social activities to help others (ATT = 0.031***), and learning activities to gain new knowledge (ATT = 0.034***) among middle-aged and elderly residents. The utilization of inpatient health care was significantly positively associated with leisure activities (ATT = 0.015***) but had no significant association with social deeds that help others and increased new knowledge among middle-aged and elderly residents.

Conclusion: Thus, social participation significantly positively affects healthcare utilization by middle-aged and elderly residents. Hence, the government and society should provide more conveniences and promote social participation among middle-aged and elderly residents.

Keywords: social participation, utilization of medical services, propensity score matching, elderly residents, middle-aged residents

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INTRODUCTION

Population aging is a global problem, and China has the most rapidly aging population in the world (1). With the aging of the people in China, diseases among older adults, such as chronic non-communicable diseases and mental health disorders, have gained increasing attention (2), resulting in an emerging demand for health services by middle-aged and elderly residents (3).

The Andersen Health Services Utilization Initial Model, which includes predisposing, enabling, and need factors, is one of the most widespread research frameworks to indicate the influence

of a healthcare utilization factor (4). Among the middle-aged and elderly residents, physical, and mental health had a negative connection with the utilization of medical services (5, 6), and social variables, such as regular involvement in activities of clubs, societies, and religious organizations, increase the odds of health service utilization (7).

Social participation was defined as participation in social activities, including engagement as volunteers and social groups interacting with the community (8). It is common knowledge that middle-aged and elderly residents have a relatively lower social participation rate. In addition, social participation is positively associated with improved overall health, which increases with age (9, 10). Besides providing better health, social participation improves the social bonds of middle-aged and elderly residents, and older people stay active by participating in voluntary work (11).

Although social participation is meaningful, few studies have examined its influence on the utilization of health services. Research reveals that the association between social participation and health services is complex. The results were affected by other factors, including health factors (12, 13). One study that used a nationally representative sample of older adults found that people with high social participation were significantly less likely to utilize health care services (visit their family doctor and district nurse last month). When controlling for demographic factors, physical and mental health, and physical activity, the longitudinal data indicated that social participation was positively associated with contacting home help services (13). Another researcher noted that social participation was significantly connected with low inpatient visits by controlling initial health variables (12).

The association between social participation and healthcare utilization due to confounding factors is unclear. Therefore, this study used the propensity score method (PSM) to control for confounding factors and explore the effect of social participation on the utilization of health care services among middle-aged and elderly residents. PSM is a statistical technique that can effectively reduce selection bias due to confounding variables between two different groups, such as the number of social participants and unsociable participants among middle-aged and elderly residents (14). PSM is widely used in social participation or medical service utilization. Yean Wang divided the middle-aged and elderly into two groups: internet users and non-internet users, and used the PSM method to analyze the connection between Internet use and levels of depression. The results show that older adults who reported internet use have lower depression levels than did those who did not use the internet, with adjustments made for Confounding factors (15). Jong-Yi Wang found that mortality and total medical expenditures per capita were significantly higher in psychiatric patients than in non-psychiatric patients by 1:1 dual propensity score matching (16).

METHODS

Data Sources and Sample Selection

The data from the 2018 wave of the China Health and Retirement Longitudinal Study (CHARLS) was a nationally representative longitudinal study conducted by the China Center for Economic Research (CCER), Peking University (17). The baseline survey of CHARLS was performed in 2011, and samples were surveyed every 2 years. Four national study waves of national study until 2018, analyzing 17,543 Chinese residents over 45 years old. Participants were selected from 450 villages and urban communities of 28 provinces in China, through probability-proportional-to-size sampling, using a multistage stratified sampling technique. They were interviewed through a high-quality questionnaire, which required detailed information about demographic backgrounds, health care and status, cognition, depression, work retirement, and property ownership (18).

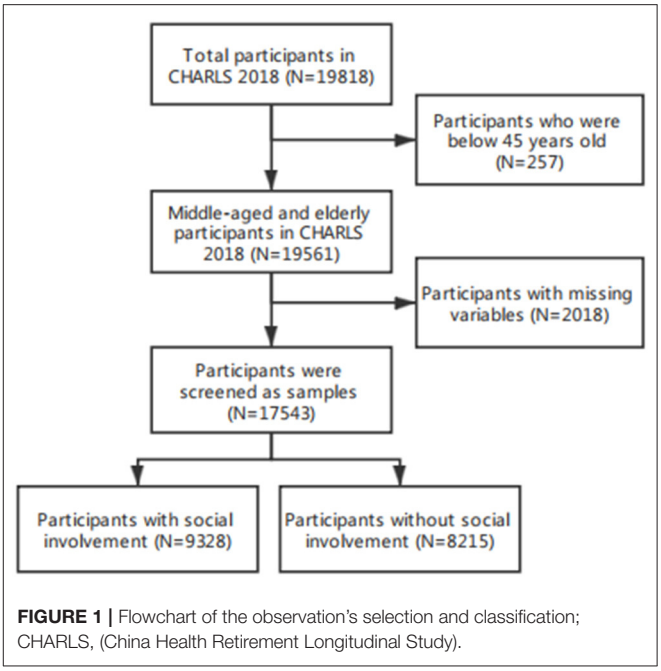

FIGURE 1 | Flowchart of the observation's selection and classification; CHARLS, (China Health Retirement Longitudinal Study).

The Biomedical Ethics Review Committee approved the CHARLS Study at Peking University in January 2011. All enrollees were notified, and informed consent was obtained before the interviews. We applied to the CHARLS team for data for this study and received anonymous enrollees (19).

To comply with the research purpose, the invalid samples from 2018 comprised 257 participants aged 45 years, and 2018 participants with missing variables were eliminated. The final sample consisted of 17,543 enrollees, including 9,328 enrollees who participated socially and 8,215 participants who did not. The effective sample rate was 88.5% (**Figure 1**).

Measurements

Social Participation

To measure current social participation, we asked participants 10 multiple-choice questions about their involvement in the following activities, in the previous month: (1) interacting with friends; (2) playing Mahjong, playing chess, playing cards, or going to a community club; (3) providing help to family, friends, or neighbors who do not live with you; (4) went to the sport, social, or other kind of the club; (5) took part in a community-related organization; (6) voluntary or charity work; (7) cared

for a sick or disabled adult who does not live with you; (8) attended an educational or training course; (9) stock investment; and (10) using the internet. If respondents answered at least one "yes" to the above questions, they were defined as "social participants." The other respondents were defined as unsociable participants (20).

We classified social activities into three types to explore the associations between various categories of social participation and the utilization of medical services. The labels of training, 1, 2, 4, and 5, were regarded as leisure activities; the classifications of action, which were 3, 6, and 7, were considered as social activities to help others; the categorization of training, consisting of 8, 9, and 10, were regarded as learning activities to acquire new knowledge (21). Among 17,543 middle-aged and elderly residents, 7,797 (44.5%) enrollees engaged in leisure activities, 2,831(16.1%) partook in social activities to help others, and 2,286 (13.0%) joined learning activities for new knowledge.

Utilization of Medicine Services

This research included two types of services for medicine utilization: (1) outpatient visits: we asked participants whether they had visited a hospital, public health center, clinic, or were seen by health workers or doctors for outpatient care, last month; (2) inpatient visits: participants who had received inpatient care in the past year (22). The variables of outpatient and inpatient utilization was the classification variable (1 = yes, 0 = no).

Covariables

According to the Andersen Health Services Utilization Initial Model framework, we classified the covariates that were comprehensively arranged and screened from the CHARLS questionnaire into three elements with some effect on the utilization of health services (23).

The parts included:(1) Propensity characteristics; age, gender, education level (no formal education, primary school, middle school, high school, and above), marriage (married and currently living with a spouse or others), household register (urban, rural), number of family members: (2) Capacity resources; income (household income in the past year), insurance (had at least one type of insurance or others), receive from child (financial support received from children, last year), provide to children (financial aid provided to children, last year): (3) Health needs; smoke (smoking currently, never smoked, stopped smoking), drink (drink alcohol now, never drank, stooped drinking), health status (perfect, good, poor, very poor), chronic disease (had at least one type of chronic illness or others), the activities of daily living (ADL) (the capacity of daily living activity, had 20 questions and a total of 80 points. The higher the score, the lower the ADL score). Covariables, including "income," "receive from the child," and "provide to the child" were natural logarithm transformed, as the original data were skewed to the right.

Statistical Analysis

The *t*-test and Pearson chi-square test were used for the social participation survey to analyse the differences in demographic characteristics between the social and unsociable participation groups.

The primary statistical analysis method used was the propensity score matching (PSM) model computed through psmatch2 of Stata 15.0. The PSM model was a non-parametric statistical method to reduce the selective bias between treatment and control units (18, 24). The confounding factors were balanced, based on the propensity score by matching two groups, reflecting the selective probability of receiving treatment. The average treatment effect on the treated (ATT) was estimated after the PSM method reduced the influence of confounding variables in matched groups, which was the mean of the individual causal effect in the treated unit (25).

PSM analysis was classified into three steps. The first was calculating the propensity score according to the logistic model, including the abovementioned covariates. Second, the treatment and control groups were matched based on the propensity score, where matching methods varied in PSM, including the *k*-nearest neighbor matching method, radius matching method, and kernel matching method (15). Third, the ATT was evaluated. If the value of ATT is positive and statistically significant, it represents that social participation has increased the healthcare utilization rate. Suppose the value of ATT is negative and statistically significant. In that case, it means that social participation has decreased the health care utilization rate, such as ATT of social participation was 0.061 to inpatient visits, showing that the social participation had increased the inpatient visit rate within 1 year by approximately six percent points (26). The kernel matching method at a bandwidth of 0.06 was used, as frequently computed in the literature (27, 28). The *k*-nearest neighbor matching method (one to four), and the radius matching method (Caliper = 0.03) confirmed the robustness of the results.

The PSM method resulted in erroneous standard errors owing to the high correlation between matched samples and the error between the estimated propensity score and the actual value. The current approach is to substitute the standard empirical mistake with the empirical standard error. Our research used the bootstrap method to obtain the empirical standard error (15).

Patient and Public Involvement

The data used in this study were derived from the CHARLS database, so patients and the public were not involved in the design or conduct of this research.

RESULTS

Characteristics of Study Samples

Samples regarding social activity were selected in two groups and descriptive analyses were conducted for the differences between the groups (*t*-test was computed for continuous variables, and chi-square test was computed for classification variables). For outcome variables, social participants were more likely to visit outpatients ($p < 0.001$), and unsociable participants were likelier to visit inpatients ($p < 0.001$). There were statistically significant social participation differences between the two groups of middle-aged and elderly residents on 11 covariates: middle-aged and older residents who were younger ($p < 0.001$), had a higher education level ($p < 0.001$), had a spouse ($p < 0.001$), provided for children more ($p < 0.001$), had higher income ($p < 0.001$),

had insurance ($p < 0.001$), smoked ($p < 0.001$), drank ($p < 0.001$), had better health ($p < 0.001$), had lower ADL ($p < 0.001$), were urban residents ($p < 0.001$), had a higher incidence of social participation. This finding suggests that the effect of social participation on the utilization of medical services is complicated to calculate (**Table 1**).

Association Between Social Participation and the Utilization of Medicine Services

Table 2 shows results for the overall balance *t*-test for 15 covariates. After kernel matching the propensity score, the final sample size in this analysis was 9,325 social participation enrollees and 8,199 unsociable participation enrollees. The bias of overall covariates was lower than 5% (mean bias = 1.7%, median bias = 1.4%) and no longer significant between the two groups ($p = 0.294 > 0.05$); the covariates of the two groups were significantly balanced, and PSM improved the comparability of social participation enrollees and unsociable participation enrollees.

The ATT of the raw sample and the sample after kernel matching can be estimated. The estimates reveal that middle-aged and elderly residents who participated socially in the last month had significantly higher outpatient visit rates than those who had not attended socially in the previous month in both the unmatched sample and the kernel matched sample (ATT = 0.029***; 0.038***). Furthermore, the inpatient visits showed a higher rate in middle-aged and elderly residents who did not participate socially in the last month than those who had, before kernel matching (ATT = −0.023***). However, after kernel matching, the middle-aged and elderly residents who participated socially in the last month showed a higher inpatient visit rate than those enrollees who had not (ATT = 0.015**) (**Table 2**).

Effects of Three Types of Social Participation on the Utilization of Medical Services

Table 3 describes the impact of diverse kinds of social participation on the utilization of medical services. The treatment group and control group's overall balance for each type displayed excellent results for covariate balances after kernel matching. The mean and median biases were jointly lower than 5% (mean bias = 1.1%; 1.9%; 1.7%, median bias = 0.7%; 1.5%; 1.1%), and no longer significant between the two groups in the three types of social participation ($p = 0.910$, 0.979, and 0.979, 0.05).

Among middle-aged and elderly residents, social participation (leisure activities, social activities helping others, and learning activities) significantly improved the outpatient visit rate in both raw samples and matched samples after kernel matching (ATT = 0.035***; 0.031***; 0.034***). For inpatient visits, all types of social participation had a significantly negative role before matching (ATT = −0.012**; −0.033***; −0.054***), and after kernel matching, the results changed. The inpatient visit rates were positively and significantly different between the treatment unit and control unit for leisure activities (ATT = 0.015***), and there was no significant difference between the two groups in the two other types of social participation (ATT = 0.002, 0.003). **Table 4** showed the combined effect of different types of social participation on utilization of medical services. Compared with those who did not participate in any social participation, participants who attended one type of social participation (any one of leisure activities, social activities helping others, or learning activities) had a significantly higher outpatient visit rate and inpatient visit rate after kernel matching (ATT = 0.029***, ATT = 0.014**). The effect was even more significant in the participants who attended two or three types of social participation (ATT = 0.057***, ATT = 0.017**).

Robustness Check

Our research compared the results of the kernel matching method with radius and *k*-nearest neighbor matching methods (one to four) and Logistic regression to explore the robustness of the kernel matching method in propensity score matching. **Table 5** indicates that the significance of the average treatment effect for the matching methods was the same. The propensity score-matching results were robust.

DISCUSSION

To the best of our knowledge, this is the first study that used PSM to assess the association between social participation and healthcare utilization. Our research explored the association between social participation and healthcare utilization by PSM among residents aged 45 years and above based on the 2018 CHARLS statistics. By adjustment for 15 confounding variates through PSM, this study demonstrated a significant positive effect of social participation on healthcare service utilization by middle-aged and elderly residents. All the treatment groups; leisure activities, social helping activities, and learning activities, had a higher rate of outpatient visits than their corresponding control groups. Moreover, leisure activities enrollees had a healthy level of inpatient visits in contrast with the team that had not.

In China, there were about 249.49 million residents aged 60 and over at the end of 2018 (29). Severe population aging is a burden on health care utilization; health is a significant relevant intermediary element; and unmet health care needs is deleterious for older adults (30, 31). The association between health care utilization and unmet health care needs was remarkably negative, and the promoted utilization of medical services met health care needs (32).

We found that older men had less social participation than younger men, and the rate of residents over 45 years who participated socially was 53.17%. The incident odds of social participation in prior studies paralleled those in our study. The number of residents participating socially was not high (33, 34). In contrast, the elderly in developed countries usually had high social participation rates (29).

Moreover, regardless of outpatient and inpatient services, residents with greater social participation, utilized health care services more. There are many possible reasons for this finding. First, social activities improved relationships with relatives and friends, which confirmed the optimism associated with the utilization of medical services and preventive health care (35, 36). Improving relationships with friends and relatives may reduce

TABLE 1 | Characteristics of social and unsociable groups before matching.

Variables	Social participants (*N* = 9,328)	Unsociable participants (*N* = 8,215)	*p*-value
Outcome variables			
Outpatient visit (last month)			<0.001
Yes	1,683 (18.04)	1,242 (15.12)	
No	7,645 (81.96)	6,973 (84.88)	
Inpatient visit (last year)			<0.001
Yes	1,480 (15.87)	1,496 (18.21)	
No	7,848 (84.13)	6,719 (81.79)	
Covariate			
Gender			
Male	4,481 (48.04)	3,865 (47.05)	0.190
Female	4,847 (51.96)	4,350 (52.95)	
Age	60.74 ± 0.10	63.78 ± 0.11	<0.001
Education level			<0.001
No formal education	1,587 (17.01)	2,415 (29.40)	
Primary school	3,888 (41.68)	3,753 (45.68)	
Middle school	2,335 (25.03)	1,485 (18.08)	
High school and above	1,518 (16.27)	562 (6.84)	
Marriage			<0.001
Having spouse	8,083 (86.49)	6,941 (84.49)	
No spouse	1,245 (13.35)	1,274 (15.51)	
Receive form child	5.98 ± 3.66	5.99 ± 3.49	0.836
Provide to child	2.85 ± 3.64	1.84 ± 3.09	<0.001
Income	9.18 ± 2.58	8.59 ± 2.66	<0.001
Health insurance			<0.001
Yes	9,099 (97.55)	7,931 (96.54)	
No	299 (2.45)	284 (3.46)	
Drink			<0.001
Yes	3,595 (38.54)	2,336 (28.44)	
No	5,733 (61.46)	5,879 (71.56)	
Smoke			<0.001
Yes	2,670 (28.62)	2,077 (25.28)	
No	6,658 (71.38)	6,138 (74.72)	
Number of family members	2.66 ± 1.15	2.68 ± 1.22	0.471
Health status			<0.001
Very good	1,193 (12.79)	842 (10.25)	
Good	1,335 (14.31)	872 (10.61)	
Pair	4,629 (49.62)	3,828 (46.48)	
Poor	1,684 (18.05)	2,002 (24.37)	
Very poor	487 (5.22)	681 (8.29)	
Chronic disease			0.119
Yes	7,451 (78.88)	6,639 (80.82)	
No	1,877 (20.12)	1,576 (19.18)	
ADL	20.89 ± 8.89	25.13 ± 12.55	<0.001
Household register			<0.001
Urban	4,041 (43.32)	2,695 (32.81)	
Rural	5,287 (56.68)	5,520 (67.19)	

t-test was computed for continuous variables, and chi-square test was computed for classification variables.
ADL, activities of daily living.

TABLE 2 | Overall balance *t*-test and the average treatment effect on the treated of social participation.

	Overall balance					Match result							
						Outpatient visits				Inpatient visits			
						ATT	Bootstrap result			ATT	Bootstrap result		
	Pseudo R^2	LR CHI^2	*p*-value	Mean bias	Median bias		Bootstrap SE	*z*	*p*-value		Bootstrap SE	*z*	*p*-value
Unmatched	0.067	1,626.06	<0.001	16.9	20.7	0.029***				−0.023***			
Matched	0.001	17.43	0.294	1.7	1.4	0.038***	0.006	6.36	<0.001	0.015**	0.005	2.82	0.005

ATT, the average treatment effect on the treated.
**p < 0.10, **p < 0.05, ***p < 0.01.*

TABLE 3 | Overall balance *t*-test and propensity score matched results and effect of each type of social participation.

Variables	Overall balance					Match result							
						Outpatient visits				Inpatient visits			
						ATT	Bootstrap result			ATT	Bootstrap result		
	Pseudo R^2	LR CHI^2	*p*-value	Mean bias	Median bias		Bootstrap SE	*z*	*p*-value		Bootstrap SE	*z*	*p*-value
Leisure activities													
Unmatched	0.041	993.47	0.001	12.3	16.3	0.027***				−0.012**			
Matched	0.001	8.32	0.910	1.1	0.7	0.035***	0.006	6.29	<0.001	0.015***	0.005	2.90	0.004
Social activities helping others													
Unmatched	0.052	811.00	0.001	17.8	13.3	0.025***				−0.033***			
Matched	0.001	6.05	0.979	1.9	1.5	0.031***	0.008	4.06	<0.001	0.002	0.007	0.30	0.765
Learning activities													
Unmatched	0.266	3,611.83	0.001	42.1	40.6	0.021**				−0.054***			
Matched	0.001	6.06	0.979	1.7	1.1	0.034***	0.01	3.26	<0.001	0.003	0.009	0.36	0.719

ATT, the average treatment effect on the treated.
**p < 0.10, **p < 0.05, ***p < 0.001.*

the psychological pressure and financial support of middle-aged and older adults facing medical treatment. Second, previous research shows that socially isolated older adults used health care services less, and there was a significant association between loneliness and lower odds of physician visits, social isolation and loneliness will lead to the weakening of mobility and the obstruction of social communication in middle-aged and older adults (37, 38). Social participation reduces social isolation and helps the elderly to integrate socially. Furthermore, our findings revealed that social participation had a negative connection to the incidence of inpatient visits before matching, similar to previous research that indicates that higher social participation meant lower odds of inpatient visits (12). However, the result changed after matching the factors, possibly because of the covariates for health needs, which most significantly affected the utilization of medical services in the Andersen model.

In Previous researches, the relationship between social participation and medical service utilization was unclear. It was often mixed with other factors, such as health factors. Since health factors were a relatively crucial confounding factor, the opposite result may be obtained after the balance of health factors (12, 13). The same pattern was present in our study, social participants had higher health status, and those with solid health had lower healthcare utilization, utilization of medical services will increase with the balance of health-related variables (23, 39). If the elderly healthy balance to the same level to participate in social activities of the high degree of the elderly, the possibility of medical service utilization will increase. The reasons for the changes in the results before and after the propensity score matching was balancing confounding factors and reducing the influence of confounding factors. The PSM method eliminated the effect of covariates, including health need factors and evaluated the natural result of the connection between social participation and health care utilization.

Our study showed a significantly positive association between diverse types of social participation and outpatient service utilization, and that social participation for leisure, affects inpatient service utilization. Various kinds of social participation revealed diverse characteristics and functions of health care utilization. Leisure activities, such as interacting with friends

TABLE 4 | Overall balance *t*-test and propensity score matched results and combined effect of each type of social participation.

Variables	Overall balance					Match result							
						Outpatient visits				Inpatient visits			
						ATT	Bootstrap result			ATT	Bootstrap result		
	Pseudo R^2	LR CHI^2	*p*-value	Mean bias	Median bias		Bootstrap SE	*z*	*p*-value		Bootstrap SE	*z*	*p*-value
Social participation (Ref: none)													
One type													
Unmatched	0.032	632.92	0.001	10.7	13.2	0.022***				−0.013**			
Matched	0.001	9.44	0.853	1.1	0.8	0.029***	0.006	4.71	<0.001	0.014**	0.006	2.41	0.016
Two or three types													
Unmatched	0.188	2,479.74	0.001	32.3	36.5	0.043***				−0.047***			
Matched	0.001	7.81	0.931	1.7	1.4	0.057***	0.009	6.00	<0.001	0.017**	0.008	2.17	0.030

ATT, the average treatment effect on the treated.
$^*p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.001$.

TABLE 5 | The average treatment effect of propensity score matching among three matching methods and logistic regression.

Variables	Outpatient visits				Inpatient visits			
	Model 1 ATT	Model 2 ATT	Model 3 ATT	Model 4 OR	Model 1 ATT	Model 2 ATT	Model 3 ATT	Model 4 OR
Social participation	0.038***	0.038***	0.039***	1.356***	0.015**	0.016**	0.015**	1.121**
(1) Leisure activities	0.035***	0.035***	0.037***	1.314***	0.015**	0.015**	0.012**	1.140***
(2) Social activitieshelping others	0.031***	0.031***	0.037***	1.266***	0.002	0.004	0.008	1.046
(3) Learningactivities	0.034***	0.034***	0.030***	1.283***	0.003	0.004	0.005	1.011

ATT, the average treatment effect on the treated; Model 1: Kernel matching method in PSM, Model 2: Radius matching method in PSM, Model 3: k-nearest neighbor matching method in PSM, Model 4: Logistic regression.
$^*p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$.

and playing Mahjong, could enhance relatives' and friends' relationships and relax older adults (40, 41). Social activities to help others, such as voluntary or charity work, generates social integration and fulfillment among older people (21, 42). Learning activities, such as internet use, improved communication and social connections across geographic distances at comparably low consumption (43), and could provide new information about medical services for the elderly. Enhancing the social participation of older adults was a critical factor in successful aging that many older adults value. The government and society should increase the convenience of and promote social participation by providing public spaces to encourage increased social participation in middle-aged and elderly residents.

There are some limitations to our study. First, the 11 covariates in this study may not cover all essential confounding factors for medical service utilization and social participation among middle-aged and elderly residents. Unobservable covariates increase selection bias, influencing PSM results between the treatment and control groups. Second, our study has one indicator that determines social participation in the last month; instead the frequency of current social participation could be examined. The study may ignore the effects of different degrees of social participation on health service utilization. These limitations deserve further scrutiny.

CONCLUSIONS

Our research indicated that residents in middle-age and at a later life stage in China who participated socially, had a significantly higher incidence of utilizing health services than those who did not participate socially. Diverse social activities positively affected outpatient service utilization, and leisure activities were positively associated with inpatient service utilization. Considering our conclusion, the government and society should increase the convenience of and promote social participation by providing public spaces to encourage increased social participation in middle-aged and elderly residents.

DATA AVAILABILITY STATEMENT

The datasets presented in this study can be found in online repositories. The names of the repository/repositories and accession number(s) can be found below: (http://charls.pku.edu.cn) China Health and Retirement Longitudinal Study.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the Biomedical Ethics Review Committee. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

T-YL, TC, and D-CQ contributed to the development of the research ideas and obtained the dataset. T-YL cleaned the dataset. T-YL and TC performed data analyses and drafted the manuscript. All authors commented on the manuscript. All authors contributed to the article and approved the submitted version.

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Changes and Trend Disparities in Life Expectancy and Health-Adjusted Life Expectancy Attributed to Disability and Mortality From 1990 to 2019 in China

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Objective: This study aims to investigate sex, age, and cause-specific contributions to changes and trend disparities in life expectancy (LE) and health-adjusted life expectancy (HALE) attributed to disability and mortality from 1990 to 2019 in China, which provides insight into policy-making, health systems planning, and resource allocation.

Methods: Contributions of disability and mortality to changes and trend disparities in LE and HALE were estimated with standard abridged life table, Sullivan's method, and decomposition method, using retrospective demographic analysis based on mortality and years lived with disability (YLD) rates extracted from Global Burden of Disease Study 2019 (GBD 2019).

Results: From 1990 to 2019, LE and HALE increased by 10.49 and 8.71 years for both sexes, mainly due to noncommunicable diseases (NCDs) (5.83 years, 55.58% for LE and 6.28 years, 72.10% for HALE). However, HIV/AIDS and sexually transmitted infections had negative effects on changes in LE (−0.03 years, −0.29%) and HALE (−0.05 years, −0.57%). Lung cancer and ischemic heart disease caused the biggest reduction in LE (−0.14 years, −1.33%) and HALE (−0.42 years, −4.82%). Also, cardiovascular diseases (−0.08 years, −0.92%), neurological disorders (−0.08 years, −0.92%), diabetes and kidney diseases (−0.06 years, −0.69%), and transport injuries (−0.06 years, −0.69%) had main negative disability effects in HALE. Moreover, life expectancy lived with disability (LED) increased by 1.78 years, mainly attributed to respiratory infections and tuberculosis (1.04 years, 58.43%) and maternal and neonatal disorders (0.78 years, 43.82%).

Conclusion: The LE and HALE in China have grown rapidly over the past few decades, mainly attributed to NCDs. It is necessary to further reduce the negative mortality effect of HIV/AIDS, lung cancer, colon and rectum cancer, pancreatic cancer, and ischemic heart disease and the negative disability effect of stroke, diabetes mellitus, and road injuries. In addition, the signs of disparities in mortality and disability of different sexes and ages call for targeted and precise interventions for key groups such as males and the elderly. According to the decomposition results, we may better determine the key objects of health policies that take into account substantial cause-specific variations to facilitate the realization of "healthy China 2030" plan.

Keywords: life expectancy, health-adjusted life expectancy, disability effect, mortality effect, decomposition

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INTRODUCTION

Life expectancy (LE) is one of the most commonly used population health summary indicators, which is based on a set of observed age-specific mortalities (1). Unlike LE, health-adjusted life expectancy (HALE) is more comprehensive and captures both the length and the quality of life (2, 3). LE and HALE are important indicators of socioeconomic and medical development, which had increased steadily in the past several years in China due to improvements in living conditions, education, and healthcare practices (4, 5). However, HALE has grown at a slower rate than LE, resulting in longer LE for patients with disabilities (LED) (6, 7).

Due to population aging and urbanization, the leading causes of death in China have undergone an epidemiological transition from communicable, maternal, neonatal, and nutritional diseases (CMNNs) to noncommunicable diseases (NCDs) (8, 9). China is rapidly catching up with this epidemic, like most developed countries (10). Despite China's progress in improving health, NCDs were still responsible for 1.65 million (88%) of China's total deaths in 2019, including leading contributors to mortality and disability such as cardiovascular diseases (0.88 million, 46%) and cancer (0.45 million, 24%) (11). In addition, far less is known about cause-specific trends in mortality and disability, and detailed information on sex, age, and cause-specific LE obtained in LE and HALE is not yet well characterized. The question of whether some population groups or causes remain disadvantaged and left behind as LE and HALE grow should be focused on.

While cause-eliminated life tables are often used to evaluate the impact of different causes on LE and HALE (12, 13), this approach only focuses on the cross-sectional study and is unable to access the impact on changes. Thus, we used a decomposition method, which was more comparative and allowed assigned contributions of mortality and disability variation to specific age groups or causes of death (14). Additionally, the advantages of using data from the Global Burden of Disease (GBD) study, which involved comprehensive data sources and methods, were obvious.

The Chinese government has attached great importance to population health. The Healthy China 2030 plan was implemented as a national health policy in 2016 (15). Two of the goals are to improve LE and HALE. At present, a comprehensive and comparable assessment of cause-specific effects on LE and HALE and how they change over time is not available. Understanding changes and trend disparities in LE and HALE at the national level is crucial to tracking progress toward the goals and promoting population wellbeing. Thus, this study aimed to investigate sex, age, and cause-specific contributions to changes and trend disparities in LE and HALE attributed to disability and mortality in China from 1990 to 2019, thereby providing insights into policy-making, health systems planning, and resource allocation.

MATERIALS AND METHODS

Data Sources

All the data for the period 1990–2019 in China, as tabulated in different causes, sexes, and age groups (<1 year, 1–4 years, 5–9 years, ..., 95+ years), were retrieved from the Global Burden of Disease Study 2019 (GBD 2019) (10), including mortality and years lived with disability (YLD) rates. The main data sources are the China Disease Surveillance Points (DSP) system, Maternal and Child Surveillance System, Cause of Death Reporting System of Chinese Center for Disease Control and Prevention (CDC), and Cancer Registry data. The methods for data collecting, processing, and analyzing are briefly described below, and the details can be found in the GBD 2019 (16, 17). A crucial step in data processing is correcting for known bias by redistributing deaths from unspecified codes to more specific disease categories, and by adjusting data with alternative case definitions or measurement methods to the reference method. Another important aspect is that cause-specific estimates are modeled using standardized tools such as the Cause of Death Ensemble model (CODEm), spatiotemporal Gaussian process regression (ST-GPR), and DisMod-MR to generate estimates of each quantity of interest by age, sex, location, and year.

Causes of death are organized in a hierarchical list containing 3 levels. At the highest level (Level 1), all causes are divided into three mutually exclusive and collectively exhaustive categories, namely, CMNNs, NCDs, and injuries. Level 2 contains 22 cause groups, such as cardiovascular diseases, neoplasms, and transport injuries. Level 3 disaggregates these causes further, including 168 more specific causes. The corresponding International Classification of Diseases (ICD9 and ICD10) codes are detailed in **Supplementary Table S1**.

Statistical Analysis

The LE at birth was computed with a standard abridged life table (18), using mortality in the infant age group (<1 year) and 19 non-infant age groups starting with age 1–4 years, then proceeding in 5-year age groups (5–9 years, 10–14 years, ...) until the terminal age group of 95+ years. Next, the probability of dying, the number of individuals alive, and the number of person-years lived in each age group were computed. HALE refers to the number of years that a person can expect to live in good health, taking into account both mortality and disability, which were computed with Sullivan's method based on the standard abridged life table (19). YLD rates were used to represent the disability prevalence.

$$LE(x) = \frac{\sum_{i=x}^{n} \times L_x}{l_x}$$

$$HALE(x) = \frac{\sum_{i=x}^{n} (1 - YLD_x) \times L_x}{l_x}$$

where n is the last age group in the life table; l_x is the number of individuals alive at age x; L_x is the number of person-years lived in age group; YLD_x is all-cause disability prevalence in age group.

Contributions to the changes in LE were estimated with Arriaga's decomposition method (20, 21), while contributions to

the changes in HALE were estimated with an extended method based on Arriaga (22). LE and HALE changes in the period of 1990–2019 and 10-year intervals (1990–1999, 2000–2009, and 2010–2019) were both decomposed. All the analyses were carried out with R version 3.4.1 (R Foundation for Statistical Computing, Vienna, Austria). Detailed procedures and formulas are described below.

Step 1: To decompose LE by age group. The total contribution of an age group to the LE gap (in years) is the sum of two mathematical terms. The first term represents the direct effect of age group, which consists of the years an age group contributes to LE changes. The second term represents indirect and interaction effect. For example, higher mortality in the 30–34 years age group may leave fewer survivors at the age of 35 years.

$$\Delta LE_x = TE_x = \left[\frac{l_x^A}{l_0} \times \left(\frac{L_x^B}{l_x^B} - \frac{L_x^A}{l_x^A}\right)\right] + \left[\frac{T_{x+n}^B}{l_0} \times \left(\frac{l_x^A}{l_x^B} - \frac{l_{x+n}^A}{l_{x+n}^B}\right)\right]$$

Step 2: To decompose HALE by age group. The total contribution of an age group to the HALE gap (in years) is also the sum of two mathematical terms. The first term represents the mortality effect of age group (ME), which is the changes in HALE caused by the changes in person-years lived in age group. The second term represents the disability effect (DE), which is the changes in HALE caused by the changes in YLD rates in age group.

$$\Delta HALE_x = TE_x = \left[\frac{YLD_x^A + YLD_x^B}{2 \times l_0} \times \left(L_x^B - L_x^A\right)\right] + \left[\frac{L_x^A + L_x^B}{2 \times l_0} \times \left(YLD_x^B - YLD_x^A\right)\right]$$

Step 3: To decompose LE by cause-specific death within an age group. The total contribution of a given age group to the LE gap (in years) is further partitioned into the years contributed by each cause. The total contribution of each cause to the LE gap is obtained by summing cause-specific contributions across all age groups.

$$\Delta LE_x^i = TE_x^i = TE_x \times \left[\frac{R_x^{i,B} - R_x^{i,A}}{S_x^B - S_x^A}\right]$$

Step 4: To decompose HALE by cause-specific death within an age group. The mortality and disability effect of a given age group to the HALE gap (in years) is further partitioned into the years contributed by each cause based on the specific percentage of gap of mortality or YLD rates in the total change. The total contribution of each cause to the HALE gap is also obtained by summing cause-specific mortality and disability effect across all age groups.

$$\Delta HALE_x^i = TE_x^i = ME_x^i + DE_x^i$$
$$ME_x^i = \left[\frac{YLD_x^A + YLD_x^B}{2 \times l_0} \times \left(L_x^B - L_x^A\right)\right] \times \left[\frac{R_x^{i,B} - R_x^{i,A}}{S_x^B - S_x^A}\right]$$
$$DE_x^i = \left[\frac{L_x^A + L_x^B}{2 \times l_0} \times \left(YLD_x^B - YLD_x^A\right)\right] \times \left[\frac{YLD_x^{i,B} - YLD_x^{i,A}}{V_x^B - V_x^A}\right]$$

where TE_x is the total contribution between ages x and $x+n$, l_x is the number of individuals alive at age x, $l_0$is the cohort size at the start, L_x is the number of person-years lived between ages x and $x+n$, and T_{x+n} is the total number of person-years lived above age x+n. l_{x+n} is the number of individuals alive at age $x+n$. YLD_x is the disability prevalence at age x. TE_x^i is the total contribution between ages x and $x+n$ due to cause i, R_x^i is the specific mortality rate between ages x and $x+n$ due to cause i. S_x is the all-cause mortality rate between ages x and $x+n$. YLD_x^i is the specific disability prevalence between ages x and $x+n$ due to cause i. V_x is the all-cause YLD rate between ages x and $x+n$. "A" and "B" represent different years.

TABLE 1 | Effects of mortality and disability on changes in life expectancy (LE) and health-adjusted life expectancy (HALE) (years) from 1990 to 2019.

Population	ΔLE	ΔHALE			ΔLED
	TE	ME	DE	TE	
Both sexes	10.49	8.30	0.41	8.71	1.78
Males	8.92	7.42	0.23	7.65	1.27
Females	12.63	9.53	0.60	10.13	2.51

TE, total effect; ME, mortality effect; DE, disability effect.

RESULTS

Changes in LE and HALE

From 1990 to 2019, LE increased by 10.49 years for both sexes, while HALE increased by 8.71 years as a result of reduced mortality (8.30 years, 95.29%) and disability (0.41 years, 4.71%). LED was the difference between LE and HALE, with an average increase of 1.78 years for both sexes (**Table 1**). The total effect on the change in LE and HALE was greater for females than for males with higher LEDs. LE and HALE showed an increasing trend every year, varying significantly from year to year, with the overall effect being positive (**Figure 1**). For changes in HALE, the disability effects of all causes were at a low level, with both males and females showing a negative effect after 2011. In addition, from 1990 to 1999, LE and HALE increased by 3.20 and 2.85 years for males and females. Starting in 2000, LE and HALE further increased by 3.65 and 3.16 years for both sexes. However, the growth rate has decreased since 2010, resulting in 3.24 and 2.30 years for both sexes, respectively, until 2019, especially in terms of the total effect of HALE changes. From 2010 to 2019, a negative effect of disability was observed. Thus, LED increased from 0.35

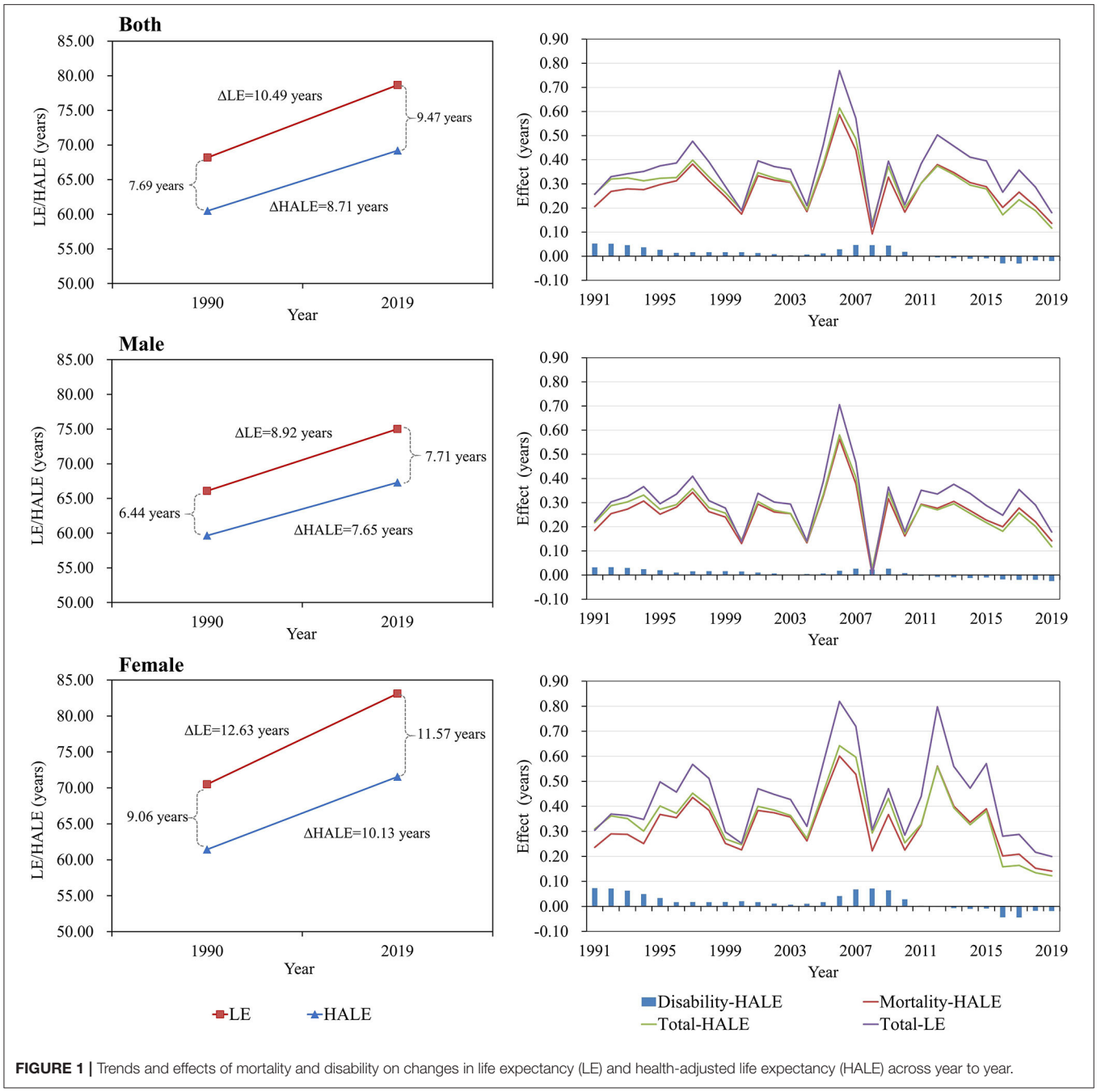

FIGURE 1 | Trends and effects of mortality and disability on changes in life expectancy (LE) and health-adjusted life expectancy (HALE) across year to year.

to 0.94 years for both sexes in the past three decades, and females also had a higher total effect of changes in LE and HALE than males with a higher LED in each decade (**Table 2**).

Mortality and Disability Effect on Changes in LE and HALE

From 1990 to 2019, better control of NCDs contributed most to changes in LE (5.83 years, 55.58%) and HALE (6.28 years, 72.10%) for both sexes, followed by control of CMNNs (3.46 years, 32.98% for LE and 1.32 years, 15.15% for HALE) and injuries (1.20 years, 11.44% for LE and 1.11 years, 12.74% for HALE) (**Table 3**). For level 2 causes of CMNNs, respiratory infections and tuberculosis contributed most to the changes in LE (1.86 years, 17.73%) and HALE (0.82 years, 9.41%). Only HIV/AIDS and sexually transmitted infections had negative total effects both on changes in LE (−0.03 years, −0.29%) and HALE (−0.05 years, −0.57%) because of the negative effect of mortality. HALE also decreased by 0.09 years (1.03%) owing to a reduction in the disability of maternal and neonatal disorders. For level 2 causes of NCDs, chronic respiratory diseases contributed most to the changes in LE (2.02 years, 19.26%) and HALE (2.83 years, 32.49%), followed by cardiovascular diseases (1.77 years,

16.87% for LE and 1.82 years, 20.90% for HALE). Moreover, 5 causes had negative disability effects on changes in HALE such as cardiovascular diseases (−0.08 years, −0.92%), neurological disorders (−0.08 years, −0.92%), and diabetes and kidney diseases (−0.06 years, −0.69%). For level 2 causes of injuries, unintentional injuries contributed the most to changes in LE (0.57 years, 5.43%), and self-harm injuries and interpersonal violence contributed most to the changes in HALE (0.59 years, 6.77%). Among them, transport injuries (−0.06 years, −0.69%) and unintentional injuries (−0.01 years, −0.11%) had negative disability effects on changes in HALE.

Figure 2 shows the top 10 level 3 causes that positively/negatively influenced the changes in LE and HALE. Chronic obstructive pulmonary disease contributed the most to changes in LE (1.93 years, 18.40%) and HALE (2.71 years, 31.11%). More than 70% of improvement in both LE and HALE was attributed to better control of these top 10 level 3 causes, and 7 of them were shown simultaneously in both lists, including chronic obstructive pulmonary disease, stroke, lower respiratory infections, tuberculosis, stomach cancer, liver cancer, and drowning. But it is worth noting that stroke (−0.07 years, −0.80%) had a negative disability effect on changes in HALE. Lung cancer and ischemic heart disease caused the biggest reduction in LE (−0.14 years, −1.33%) and HALE (−0.42 years, −4.82%). More than 10% of the decline in HALE was attributed to poorer control of these top 10 level 3 causes with a negative effect. More details are summarized in **Supplementary Table S2**.

TABLE 2 | Effects of mortality and disability on changes in life expectancy (LE) and health-adjusted life expectancy (HALE) (years) for 10-year interval.

Intervals	Population	ΔLE	ΔHALE			ΔLED
		TE	ME	DE	TE	
1990–1999	Both sexes	3.20	2.57	0.28	2.85	0.35
	Males	2.84	2.39	0.20	2.59	0.25
	Females	3.72	2.85	0.37	3.22	0.50
2000–2009	Both sexes	3.65	2.96	0.20	3.16	0.49
	Males	3.00	2.53	0.12	2.65	0.35
	Females	4.56	3.54	0.30	3.84	0.72
2010–2019	Both sexes	3.24	2.43	−0.13	2.30	0.94
	Males	2.76	2.21	−0.12	2.09	0.67
	Females	3.83	2.71	−0.14	2.57	1.26

TE, total effect; ME, mortality effect; DE, disability effect.

TABLE 3 | Cause-specific effects on changes in life expectancy (LE) and health-adjusted life expectancy (HALE) from 1990 to 2019 (years, levels 1–2).

Causes	Level	ΔHALE			ΔLE	ΔLED
		ME	TE	TE	TE	
Communicable, maternal, neonatal, and nutritional diseases	A	1.09	0.23	1.32	3.46	2.14
HIV/AIDS and sexually transmitted infections	A.1	−0.05	< 0.01	−0.05	−0.03	0.02
Respiratory infections and tuberculosis	A.2	0.78	0.04	0.82	1.86	1.04
Enteric infections	A.3	0.07	< 0.01	0.07	0.29	0.21
Neglected tropical diseases and malaria	A.4	0.01	0.10	0.11	0.01	−0.10
Other infectious diseases	A.5	0.17	0.02	0.19	0.45	0.26
Maternal and neonatal disorders	A.6	0.07	−0.09	−0.02	0.76	0.78
Nutritional deficiencies	A.7	0.03	0.16	0.20	0.11	−0.08
Non-communicable diseases	B	6.05	0.23	6.28	5.83	−0.45
Neoplasms	B.1	0.71	−0.04	0.66	0.83	0.17
Cardiovascular diseases	B.2	1.84	−0.08	1.77	1.82	0.06
Chronic respiratory diseases	B.3	2.72	0.11	2.83	2.02	−0.81
Digestive diseases	B.4	0.50	0.05	0.54	0.49	−0.06
Neurological disorders	B.5	0.05	−0.08	−0.03	0.05	0.08
Mental disorders	B.6	< 0.01	0.04	0.04	< 0.01	−0.04
Substance use disorders	B.7	0.06	0.01	0.07	0.04	−0.02
Diabetes and kidney diseases	B.8	0.08	−0.06	0.02	0.09	0.07
Skin and subcutaneous diseases	B.9	0.01	−0.01	< 0.01	0.01	0.01
Sense organ diseases	B.10	< 0.01	0.05	0.05	< 0.01	−0.05
Musculoskeletal disorders	B.11	< 0.01	0.11	0.10	< 0.01	−0.11
Other non-communicable diseases	B.12	0.08	0.14	0.22	0.48	0.26
Injuries	C	1.16	−0.05	1.11	1.20	0.09
Transport injuries	C.1	0.21	−0.06	0.15	0.21	0.05
Unintentional injuries	C.2	0.37	−0.01	0.36	0.57	0.21
Self-harm and interpersonal violence	C.3	0.58	0.01	0.59	0.42	−0.17

TE, total effect; ME, mortality effect; DE, disability effect.

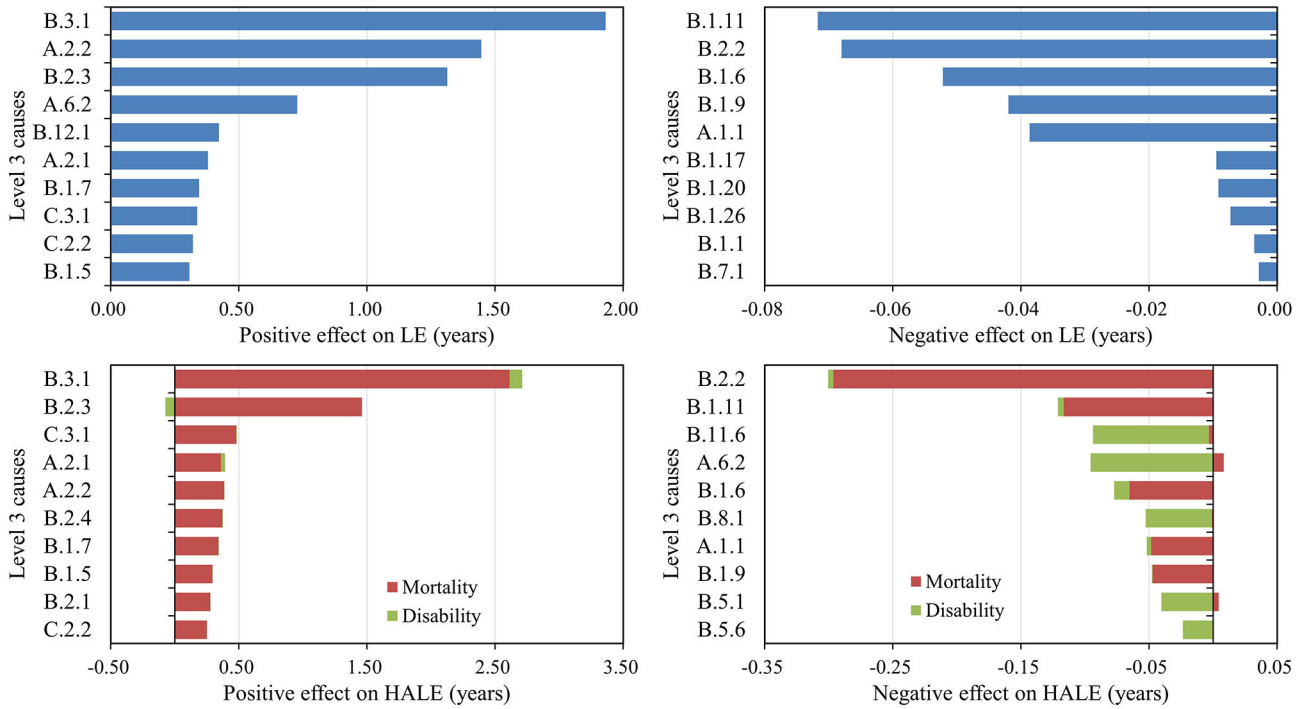

FIGURE 2 | Leading causes with positive/negative effects on changes in life expectancy (LE) and health-adjusted life expectancy (HALE) from 1990 to 2019 (level 3).

In the past three decades, the most prominent causes of the increases in LE between 1990 and 1999 were NCDs (1.59 years, 49.66%) and CMNNs (1.29 years, 40.32%), including cardiovascular diseases (0.63 years, 19.86%), chronic respiratory diseases (0.55 years, 17.27%), and respiratory infections and tuberculosis (0.76 years, 23.92%). The most prominent cause of the increases in HALE was also NCDs (1.58 years, 55.35%), followed by CMNNs (0.89 years, 31.24%). Subsequently, the positive total effects of NCDs on changes in LE increased, reaching 2.25 years between 2010 and 2019, mainly attributed to a reduction in mortality of neoplasms (0.37 years, 11.47%) and cardiovascular diseases (0.95 years, 29.27%). However, the positive total effects of NCDs on changes in HALE decreased since 2010 to 1.93 years, mainly attributed to an increase in disability rate of neoplasms (0.26 years, 11.20%), chronic respiratory diseases (0.63 years, 27.48%), and digestive diseases (0.10 years, 4.51%). For CMNNs, the positive total effects both on changes in LE and HALE decreased to a low level (0.49 years, 15.02%) from 2010 to 2019, which was mainly due to HIV/AIDS and sexually transmitted infections (−0.02 years, −0.62%) and maternal and neonatal disorders (−0.03 years, −0.93%) with negative effects. For injuries (0.50 years, 15.50%), which mainly attributed to transport injuries (−0.04 years, −1.24%) and unintentional injuries (−0.11 years, −3.40%) with negative disability effects. More details are summarized in **Supplementary Tables S3–S5**.

Sex and Age-Specific Effect on Changes in LE and HALE

From 1990 to 2019, better control of NCDs contributed most to the changes in LE (4.50 years, 50.45% for males; 7.68 years, 60.81% for females) and HALE (5.24 years, 68.50% for males; 7.65 years, 75.52% for females). **Figure 3** shows level 2 causes with total effect on changes in LE and HALE. For males, more than 60% (5.89 years) of improvement in LE was attributed to better control of the following 5 diseases: respiratory infections and tuberculosis (1.71 years), chronic respiratory diseases (1.49 years), cardiovascular diseases (1.19 years), neoplasms (0.76 years), and maternal and neonatal disorders (0.74 years). More than 70% (5.79 years) of improvement in HALE was attributed to better control of the following 5 diseases: chronic respiratory diseases (2.53 years), cardiovascular diseases (1.21 years), respiratory infections and tuberculosis (0.83 years), neoplasms (0.62 years), and digestive diseases (0.60 years). Similarly, for females, more than 70% (9.24 years) was due to cardiovascular diseases (2.77 years), chronic respiratory diseases (2.68 years), respiratory infections and tuberculosis (2.04 years), neoplasms (0.96 years), and maternal and neonatal disorders (0.79 years). More than 75% (7.97 years) of improvement in HALE was attributed to better control of the following 5 diseases: chronic respiratory diseases (3.31 years), cardiovascular diseases (2.41 years), respiratory infections and tuberculosis (0.85 years), neoplasms (0.74 years), and self-harm and

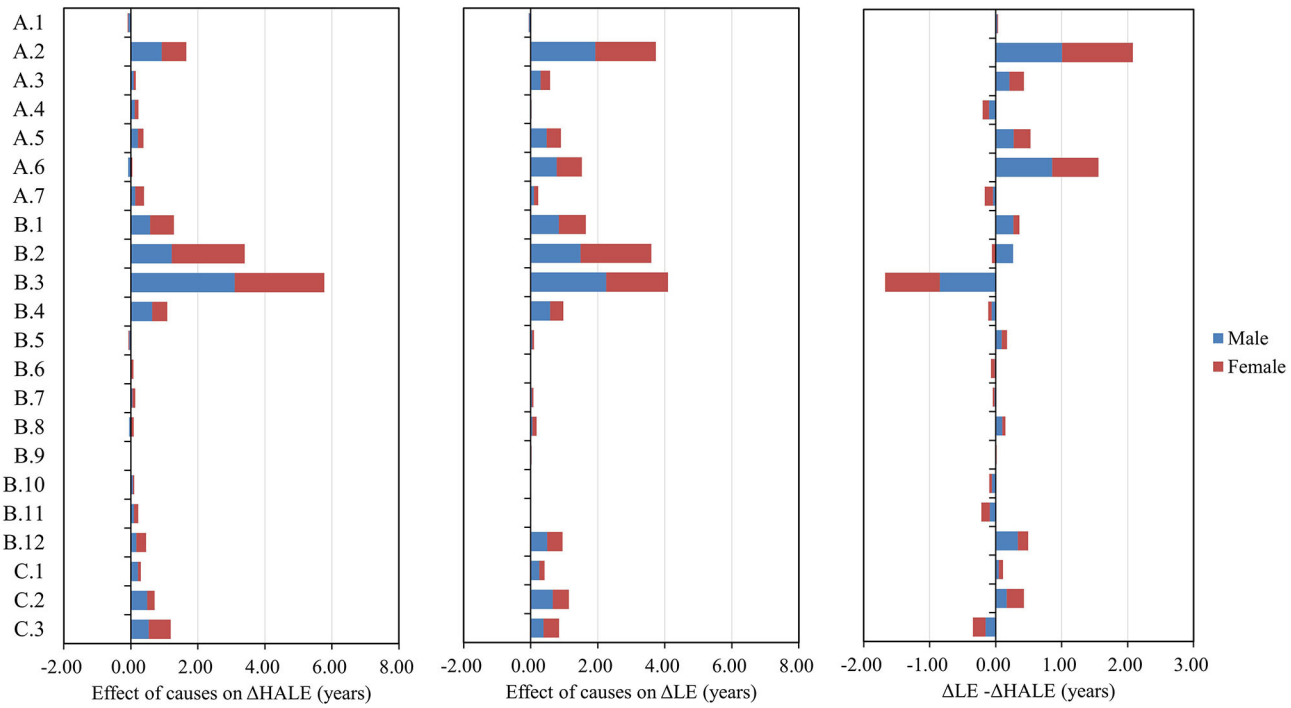

FIGURE 3 | Cause-specific effects on changes in life expectancy (LE) and health-adjusted life expectancy (HALE) (levels 1–2) for males and females from 1990 to 2019.

interpersonal violence (0.66 years). More details are summarized in **Supplementary Table S6**.

From 1990 to 2019, better control of NCDs in elderly aged more than 65 years old contributed most to the changes in HALE (3.68 years, 42.25%) (**Figure 4**). Better control of CMNNs in children aged under 14 years old had the greatest impact on LE (2.80 years, 26.69%). For injuries, more attention should be paid to older adults over 65 years of age, which had a smaller effect on changes in LE and a negative effect on changes in HALE. For children under 14 years old, LE improvements of more than 20% (2.53 years) were attributed to better control of the following 3 diseases: respiratory infections and tuberculosis (1.34 years), maternal and neonatal disorders (0.73 years), and unintentional injuries (0.46 years). But the total effect on improvement in HALE was very small (0.74 years, 8.50%). For youth aged 15–44 years, 10.10% (1.06 years) of improvement in LE and 21.47% (1.87 years) of improvement in HALE were attributed to all causes. For adults aged 45–64 years, the top level 2 cause with a positive effect on changes in LE and HALE was cardiovascular diseases (0.72 years, 6.86% and 0.57 years, 6.54%). Among older adults aged 65 years or older, the top 3 level 2 causes with a positive effect on changes in LE and HALE were chronic respiratory diseases (1.55 years, 14.78% and 2.37 years, 27.21%), cardiovascular diseases (0.91 years, 8.67% and 0.98 years, 11.25%), and respiratory infections and tuberculosis (0.27 years, 2.57% and 0.41 years, 4.71%). More details are summarized in **Supplementary Table S7**.

Changes in LED

The LED, which refers to the difference between LE and HALE, increased by 1.78 years, mainly attributed to respiratory infections and tuberculosis (1.04 years, 58.43%) and maternal and neonatal disorders (0.78 years, 43.82%). The slow reduction in disability resulted in a longer LED. Additionally, LED increased by 1.27 years for males, through respiratory infections and tuberculosis (0.88 years, 69.29%) and maternal and neonatal disorders (0.82 years, 64.57%). LED increased by 2.51 years for females due to respiratory infections and tuberculosis (1.19 years, 47.41%) and maternal and neonatal disorders (0.76 years, 30.28%). Compared with the other level 2 causes and age groups, respiratory infections and tuberculosis (1.23 years, 69.10%) and maternal and neonatal disorders (0.74 years, 41.57%) in children aged <14 years contributed the most to increased LED, while chronic respiratory diseases in elderly aged more than 65 years old showed a negative effect (−0.82 years, −46.07%) on LED. For level 3 causes and both sexes, lower respiratory infections (1.06 years, 59.55%) and neonatal disorders (0.82 years, 46.07%,) contributed the most to increased LED. More details are summarized in **Supplementary Tables S2**, **S6**, **S7**.

DISCUSSION

This study was based on the largest epidemiological dataset to date in the 30-year history of GBD 2019 and continued to provide representative, comprehensive, and updated national

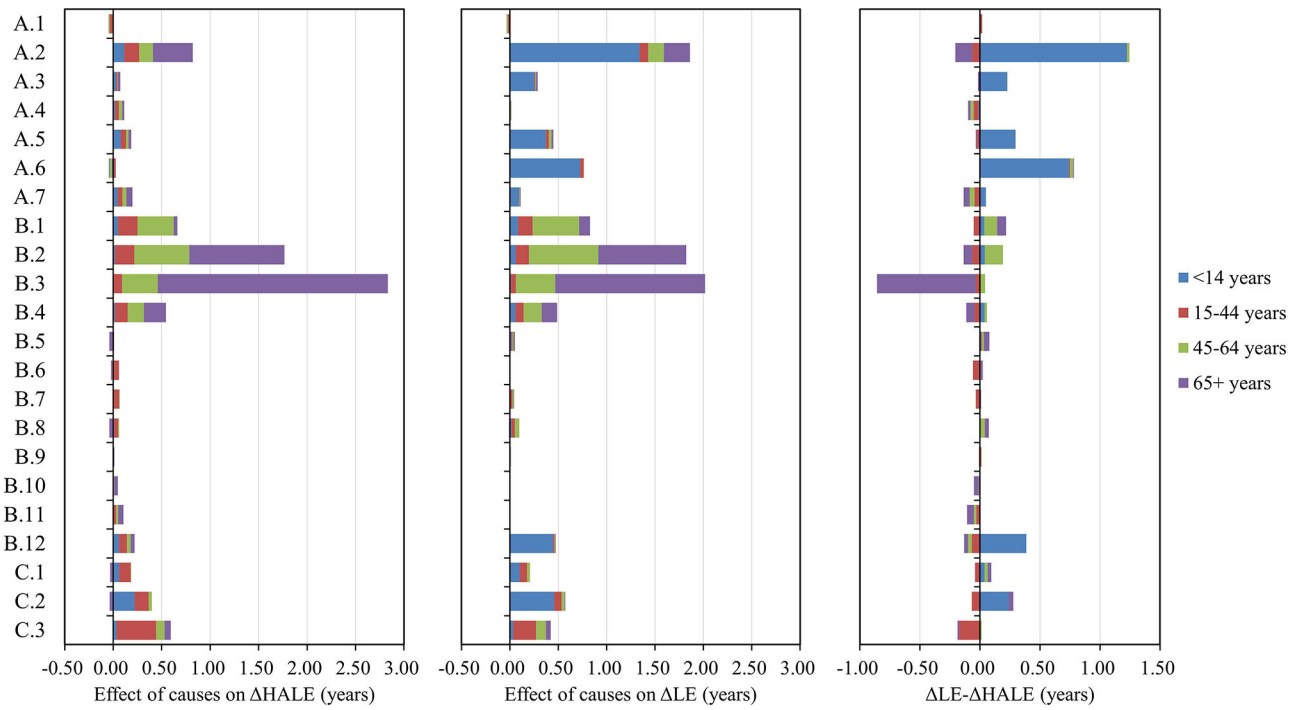

FIGURE 4 | Cause-specific effects on changes in life expectancy (LE) and health-adjusted life expectancy (HALE) (levels 1–2) for different age groups from 1990 to 2019.

estimates of the burden of diseases and injuries by integrating all available data. LE is a population health indicator of overall population health, and HALE is a more comprehensive indicator that incorporates mortality and disability into a single statistic (23). Arriaga's decomposition method was used to investigate sex-, age-, and cause-specific contributions in changes in LE and HALE across time in China, which is ideal for determining whether seemingly positive disparities are associated with large differences in cause-specific mortality or disability.

With improvement in the national economy and healthcare system, LE and HALE in China increased by 10.49 years and 8.71 years from 1990 to 2019, largely due to better control of NCDs (5.83 years, 55.58% for LE and 6.28 years, 72.10% for HALE) and, to a lesser extent, CMNNs (3.46 years, 32.98% for LE and 1.32 years, 15.15% for HALE) and injuries (1.20 years, 11.44% for LE and 1.11 years, 12.74% for HALE). According to the global research (24), NCDs were the main positive factor for HALE changes in high-income countries, while low-income countries experienced the most improvement from CMNNs. The results in China were more similar to those for high-income countries. Moreover, for level 3 causes, the top 10 positive factors leading to changes in LE were chronic obstructive pulmonary disease, lower respiratory infections, stroke, neonatal disorders, congenital birth defects, tuberculosis, liver cancer, self-harm, drowning, and stomach cancer; the top 10 positive factors leading to changes in HALE were chronic obstructive pulmonary disease, stroke, self-harm, tuberculosis, lower respiratory infections, hypertensive heart disease, liver cancer, stomach cancer, rheumatic heart disease, and drowning. According to previous studies (25–28), mortality from the above causes has decreased globally in the last decades, as it has in China, although they may have different effects on LE and HALE.

However, negative mortality and disability effects persist, especially in the period of 2010 to 2019. Both HIV/AIDS and sexually transmitted infections had negative mortality effects on changes in LE and HALE. According to GBD 2019, HIV/AIDS has become the leading cause of death in infectious diseases in China since 2009, with increasing mortality (29), as in other western countries (17). Theoretically, with the advent of antiretroviral treatment, the mortality rate would decrease significantly. However, those patients who did not meet the treatment criteria or had poor compliance may have higher mortality rates (30). For NCDs, level 3 causes of lung cancer, colon and rectum cancer, pancreatic cancer, and ischemic heart disease caused the main reduction in LE and HALE due to increased mortality, as has been proved in previous studies (31–35). For lung cancer, more emphasis should be placed on early screening, and tobacco control, and improving air pollution by reducing industrial energy consumption and dust (36, 37). For colon and rectum cancer, screening also has been shown to reduce their incidence and mortality, and in the longer term, primary prevention should be promoted (38). For pancreatic cancer, a timely and accurate diagnosis can improve the current poor prognosis of this disease (39). Improved dietary quality is associated with a reduced risk of pancreatic cancer (40). For ischemic heart disease, interventions

should be expanded to control risk factors such as hypertension, hyperlipidemia, diabetes, and smoking, and eating more fresh fruit helps reduce the incidence of ischemic heart disease (41, 42). In addition, cardiovascular diseases (stroke), neonatal and neurological disorders, diabetes mellitus, and transport injuries (road injuries) had negative disability effects on changes in HALE as a result of increased disability rates. Consistent with previous studies (43–46), main causes such as stroke, diabetes mellitus, and road injuries are associated with an increased risk of disability. How well these diseases are rehabilitated is very important and more effective measures should be developed to decline the mortality of specific diseases, along with disability rates.

In addition, LEDs have increased in both sexes over the past three decades, which was mainly attributed to CMNNs, including lower respiratory infections and neonatal disorders. This is because the rate of mortality reduction has been much faster than the rate of disability reduction. The slow reduction in disability resulted in a longer LED. For most diseases and injuries, the mortality effect was dominant in influencing changes in HALE. It is noteworthy that the decline in mortality contributes more than 95% to the change of HALE in China, while disability reduction contributed <5%. HALE could not catch up with the growth rate of LE, which increased the additional personal, family, and social costs of medical services and long-term care for the elderly.

For different populations, more than 38% of improvement in LE was attributable to children under 14 years due to decreased mortality (47, 48). As the population ages, those over 65 years of age are coming to dominate the changes in LE and HALE. China is encountering formidable healthcare challenges brought about by the problem of aging (49, 50). Major diseases that need more attention in the elderly include cancer, cardiovascular diseases, diabetes, and injuries such as falls (13, 51). The increases in LE and HALE for females were higher than for males. More than 50% of improvement in LE and HALE for males and females was attributed to better control of the following 4 diseases: cardiovascular diseases, chronic respiratory diseases, respiratory infections and tuberculosis, and neoplasms. Similar to other studies worldwide (24), Chinese women had higher LED than men, along with higher incremental LED.

The rapid rise in NCDs driven by urbanization, income growth, and aging, as well as the transition to chronic disability, has brought major challenges to China's health system. Changes in cause-specific mortality and disability will require an integrated government response to improve primary healthcare and take necessary action to address key risks, especially for those diseases that are increasing with negative effects such as lung cancer, colon and rectum cancer, pancreatic cancer, stroke, ischemic heart disease, diabetes mellitus, and road injury. Analyses of changes and trend disparities in LE and HALE attributed to disability and mortality provide a useful framework to guide evidence-based policy responses to the changing disease spectrum in China, including timely adjustments to health programs and interventions. In the future, more studies should be implemented to investigate the drivers of heterogeneity observed in the changes and trend disparities in China, which may help guide more cost-effective and precise policies in China and other developing countries.

Nevertheless, there are several limitations in this study. First, the quality of mortality and disability data varied across years, which may affect the accuracy of the estimated changes in LE and HALE. We may overlook the cause-specific contributions between smaller time intervals. In the future, cause-specific contributions between each year will be explored. Second, data comparability over time should be considered. Different surveillance scope and completeness, diagnostic technology, and healthcare accessibility of diseases may affect the data quality. Third, this study shared the same limitations as the GBD 2019 study in the process of collecting and analyzing data on mortality and disability in China. Finally, this study only included levels 1–3 causes. Different diseases may have an opposite effect even in the same cause. More comprehensive studies will be required.

CONCLUSION

The LE and HALE in China have grown rapidly over the past few decades, mainly attributed to NCDs. It is necessary to further reduce the negative mortality effect of HIV/AIDS, lung cancer, colon and rectum cancer, pancreatic cancer, and ischemic heart disease and the negative disability effect of stroke, diabetes mellitus, and road injuries. In addition, the signs of disparities in mortality and disability of different sexes and ages call for targeted and precise interventions for key groups such as males and the elderly. According to the decomposition results, we may better determine the key objects of health policies that take into account substantial cause-specific variations to facilitate the realization of "healthy China 2030" plan.

As a next step, to further improve LE and HALE, the construction of national demonstration areas for comprehensive prevention and control of NCDs should be expanded, including the national healthy lifestyle action and the project for early diagnosis and treatment of cancer. At the same time, we should not neglect to strengthen the prevention and control of HIV/AIDS and anti-virus treatment, as well as the rehabilitation after various diseases and injuries.

DATA AVAILABILITY STATEMENT

Publicly available datasets were analyzed in this study. This data can be found here: http://ghdx.healthdata.org/gbd-results-tool.

AUTHOR CONTRIBUTIONS

HC: conceptualization, visualization, and writing review and editing. LC: literature research, statistical analysis, and writing original draft preparation. YQ: methodology, data interpretation, and curation. LW: supervision and validation. All authors contributed to the article and approved the submitted version.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpubh.2022.925114/full#supplementary-material

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Impact of intergenerational support and medical expenditures on depression: Evidence from rural older adults in China

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Objective: Globally, depression has become a major health issue among older adults, who experience poor physical health and high medical expenditures. In Asian countries, older adults are greatly dependent on their children. This study assessed the impact of different types of intergenerational support and medical expenditures on depression among older adults in rural China.

Method: A three-phase balanced panel was constructed based on data from 1,838 rural older adults with comparable scores on the Center for Epidemiologic Studies Depression Scale (CES-D) from the China Family Panel Studies in 2012, 2016, and 2018. A fixed-effects model was used to analyze the impact of intergenerational support and medical expenditures on CES-D score and of intergenerational support on medical expenditures. The propensity score-matching model was used to test the regression results' robustness.

Results: The findings were as follows. First, different types of intergenerational support had a heterogeneous impact on depression among rural older adults. Emotional support had a significantly negative impact on CES-D score, although too much care-based support had a positive impact on CES-D score. Low-level economic support had no significant effect on CES-D score. Second, medical expenditures impacted depression; among these, non-inpatient medical expenditure had a significant and positive impact on CES-D score. Third, CES-D scores among rural older adults were associated with chronic diseases and per capita family income. Fourth, care-based support was associated with reduced non-inpatient medical expenditures, and the sub-sample regression results indicated that the impact was significant for older adults with no chronic diseases and those younger than 75 years.

Conclusion: Intergenerational emotional support and non-inpatient medical expenditures directly affected rural older adults' CES-D scores. The mediating role of medical expenditures between intergenerational support and CES-D score was not significant. Measures should be taken to

encourage intergenerational emotional support and reduce the pressure on children's economic and care-based support. Further, the medical insurance reimbursement policy, as formal support, should be improved to alleviate depression among rural older adults when children's support is limited.

KEYWORDS

older adults, depression, intergenerational support, medical expenditures, rural

Introduction

Based on data from China's seventh census, approximately 23.81% of rural residents are older adults, which is 7.99% higher than for residents of cities and towns. As aging is a constant process, the prevalence of psychological diseases such as dementia, depression, and anxiety among older adults is also rising (1). According to the World Health Organization's statistics, 15% of older adults have a mental disorder, the most common of which are depression and anxiety (2). Of the total suicides among Chinese older adults, 36% of cases involve psychological issues. Geriatric depression has also emerged as a serious health problem, particularly in low- and-middle-income countries and regions (3). For instance, in some rural areas of India, the prevalence of depression among older adults is over 60% (4). In China, almost half of rural older adults have depressive symptoms (5), and the suicide rate among older adults in rural areas owing to psychological problems is approximately 1.83 times higher than that in urban areas (6). In this regard, psychological health issues among rural older adults require urgent social attention.

Social support exerts a significant influence on older parents' psychological well-being, particularly in East Asian societies that are under the influence of traditional norms such as filial piety; these include China (7), South Korea (8), and Thailand (9). Children are the core actors in family support, especially in rural areas, where social services for older adults are still in the nascent stage. Older adults are generally unlikely to accept institutional care (10); thus, intergenerational support has a great impact on older adults in rural areas. The need for medical services for older adults also increases as physical health worsens with age (11); catastrophic health payments are common in low-income regions (12), increasing the financial and psychological burden. Owing to a loss of labor ability and lack of income sources, older adults are more likely to drop out of treatment (13). Additionally, while China's New Rural Cooperative Medical System (NRCMS) has reduced immediate outpatient expenses, they remain expensive (14). Thus, older adults still rely on their children for care, company, and financial support.

Existing studies have indicated that a deteriorating physical condition aggravates depression in older adults (15). This raises an interesting question: would an increase in medical service expenditures, which closely correspond to physical health, also aggravate depression in older adults? As adult children are at the core of family support, would different types of intergenerational support provided by children help improve mental health among rural older adults? Additionally, would intergenerational support impact older adults' mental health by eliminating concerns regarding medical expenditures? To answer these questions, the current study proposes that three factors—intergenerational support, medical expenditures, and depression among older adults—be combined into one research framework. Specifically, in this study of rural older adults, we analyze the impact of intergenerational support and medical expenditures on depression among rural older adults and the impact of intergenerational support on medical expenditures. We further examine sample heterogeneity through a sub-sample regression based on different health conditions and age groups among older adults. Overall, this study explores the role of intergenerational support while actively addressing aging.

Literature review and hypotheses

Intergenerational support and mental health among older adults

With age, physical health problems and social isolation become increasingly prominent, and mental health is affected by intergenerational and social support, among other factors (16). In the context of China, as adult children and spouses are the primary caregivers (17), the relationship between depression and family support becomes particularly significant for older adults (18). Intergenerational support manifests as economic, care-based, and emotional support from children (19, 20). Economic support refers to financial or material support, care-based support refers to the support provided in housework and daily life, and emotional support refers to the intimate relationships generated through communication. Children bear the main responsibility of support, and intergenerational support inevitably impacts health among older adults. However, no consensus exists as to whether intergenerational support can promote mental health in older adults.

The literature posits that intergenerational support helps promote older adults' mental health (21). Some scholars have

proven that children's economic support can alleviate the pressure on older adults, provide a sense of security, and promote their mental health (22). Life care helps enhance older adults' life satisfaction and mental health (23) and reduces the incidence of depression by increasing opportunities to participate in social activities and exercise (24). Emotional interaction can reduce loneliness among older adults and improve their life satisfaction and mental health (25, 26). In this regard, the emotional comfort that children offer older adults within a household is irreplaceable.

Other studies have reported contradictory findings, such as that while economic support is related to life satisfaction, it does not have a significant impact on depression (27). Certain scholars have posited that intergenerational support improves older adults' physical and mental health. Children's economic and care-related support has been reported to lead to a decline in older adults' self-care ability (28), in that daily care becomes a burden for older adults and reduces their self-efficacy, thus further aggravating depression (29). Continuous care can create discontent that leads to intergenerational conflicts, reducing children's willingness to provide care and diminishing the effects of that care, which is not conducive to improving mental health among older adults (30).

Based on the above discussion, whether intergenerational support promotes or inhibits depression among older adults largely depends on what older adults actually need. Rural socialized services for older adults and medical resources are still developing (31), and rural older adults are generally weak in terms of social security and pensions. Additionally, owing to the stigma associated with living in care homes in most Asian countries (32), nearly all (93%) older parents expect their children to take care of them (33), and children's support has a great impact on older adults' health. Therefore, the current study proposes the following hypotheses:

H1: Intergenerational support has a negative impact on depression among rural older adults.

As intergenerational support is divided into three types, it is proposed that:

H1a: Economic support has a negative impact on depression among rural older adults.

H1b: Care-based support has a negative impact on depression among rural older adults.

H1c: Emotional support has a negative impact on depression among rural older adults.

Medical expenditure and mental health among older adults

Aging degrades physical function, increasing older adults' vulnerability to diseases. Their deteriorating physical health and increased medical burden can also unfavorably influence their mental health (34). Research has demonstrated that among older adults with disabilities, negative emotions are significantly more serious than among those without disabilities (35). The deterioration of physical health inevitably leads to the increased utilization of medical services and additional medical expenditures (36). Moreover, chronic diseases or an increase in the types of chronic diseases significantly relate to high medical expenditures (37, 38). Health expenditures improve universal healthcare service coverage and life expectancy, but the association with the overall achievement of health outcomes is weak (39).

Some studies have noted that medical expenses are an important factor leading to patients' psychological stress. The amount of medical expenditure reflects changes in patients' physical health, utilization of medical services, and economic burden from medical treatment. On the one hand, medical insurance can significantly enhance older adults' use of medical services, thus improving physical and mental health and life satisfaction (40). On the other hand, most older adults in rural areas have no source of income, are vulnerable to the impacts of catastrophic medical expenditures, and can further experience poverty due to illness (41). Aging is an important element in households' catastrophic health payments in developing countries (12). Long-term medical treatments can cause patients to lose confidence in remaining healthy or alive, reduce their subjective well-being, and result in depression and anxiety, potentially even leading to suicide (42, 43). Hence, it is necessary to analyze whether medical expenditures significantly positively affected depression among rural older adults, specifically in terms of improving their physical health and reducing their medical burden.

Existing studies typically divide medical expenditures into "inpatient" and "outpatient" (44). First, theoretically, outpatient and inpatient medical treatments include different levels of medical behavior that correspond to different levels of disease severity. Second, the NRCMS provides a higher proportion of inpatient reimbursement to its participants. However, the data from four national health service surveys (45) reveal that the proportion of patients who should be hospitalized but are not increases significantly with age. Rural older adults also have economic constraints, with most choosing to receive outpatient medical services or purchase medicines not prescribed by a doctor, rarely utilizing inpatient medical services. Collectively, inpatient and non-inpatient medical expenditures include all medical service expenditures, and their impact on depression among older adults vary given different physical and family financial conditions. Therefore, this study further proposes the following hypotheses:

H2: Medical expenditures are associated with severe depression among rural older adults.

As medical expenditures are divided into two aspects, the

following hypotheses are proposed:

H2a: Inpatient expenditures are associated with severe depression among rural older adults.

H2b: Non-inpatient expenditures are associated with severe depression among rural older adults.

Intergenerational support and medical expenditure

Anderson's (46) behavioral model of health service use and its index system demonstrate that medical expenditures are affected by demographic characteristics such as income, gender, age, education, and various other factors including medical insurance, disease severity, and medical service pricing (47). Regarding older adults in particular, their participation in intra-household decision-making declines with age (48), and medical expenditures also relate to such factors as their social support and living arrangements (49). The theory of intergenerational support indicates that children's support impacts older adults' utilization of medical services and, consequently, their medical expenditures.

The effect of intergenerational support on medical expenditures is uncertain, with two opposing views, including substitution and complementary effects. Intergenerational support can improve older adults' health and shorten treatment times, partially replacing the use of medical services to reduce medical expenditures through a substitution relationship (50). Moreover, it can mitigate the demand for medical services among older adults by reducing access barriers and increasing inpatient medical expenditures through a supplementary relationship (51, 52). Nonetheless, the literature reveals that emotional comfort has no significant association with older adults' physical health (21) and no significant impact on their medical expenditures (53).

Generally, rural older adults are socioeconomically weak, and a high proportion refuse to seek medical treatment because they cannot afford it (54). A certain amount of economic support may improve their treatment rate, but more medical services will be replaced if their health improves under their children's care (53). Therefore, this study proposes the following hypotheses:

H3: Economic support has a positive impact on medical expenditures among rural older adults.

H4: Care-based support has a negative impact on medical expenditures among rural older adults.

Similarly, because medical expenditures include two aspects, the following assumptions are made:

H3a: Economic support has a positive impact on inpatient expenditures among rural older adults.

H3b: Economic support has a positive impact on non-inpatient expenditures among rural older adults.

H4a: Care-based support has a negative impact on inpatient expenditures among rural older adults.

H4b: Care-based support has a negative impact on non-inpatient expenditures among rural older adults.

The data for this study are sourced from the China Family Panel Studies (CFPS) data bank, during the years 2012, 2016, and 2018. The theory of intergenerational support and the behavioral model of health service use are drawn upon to explore the following objectives in the context of rural older adults: the impact of different types of intergenerational support and medical expenditures on depression; the impact of intergenerational support on medical expenditures; and the mediating role of medical expenditures in the relationship between intergenerational support and depression.

Methods

Sample selection

Data were obtained from the CFPS database, which is a long-term social survey of 25 provinces in China tracked every 2 years. Depression was measured by the Center for Epidemiologic Studies Depression Scale (CES-D) in 2012, 2016, and 2018 and by the Kessler Psychological Distress Scale (K6) in 2014. Thus, data from 2012, 2016, and 2018 were combined into a panel to facilitate comparisons and reduce any errors caused by different indicators. We selected rural older adults aged 60 and older as research subjects. After eliminating subjects who lacked key variables, we used a three-year balanced panel of 1,838 older adults who were surveyed in all three waves for a total of 5,514 observations.

Variable description

Dependent variable

The dependent variable was depression assessed by CES-D score among rural older adults. There are a number of exhaustive diagnostic instruments for depression, such as the Composite International Diagnostic Interview, Diagnostic Interview Schedule and the CES-D (55). However, compared with instruments concerning clinical investigation, the CES-D created by Radloff is one of the most common instruments used for assessing depression in general populations globally (56–58); this tool measures the frequency of depressive events and ideas over the past week (59).

The original CES-D contains 20 items, of which 16 assess negative symptoms (e.g., "I felt lonely") and four measure positive affect (e.g., "I was happy") (60). Each item is rated on a four-point scale, with 0 representing "rarely or none (less than a day)," 1 indicating "unusual (1–2 days)," 2 indicating "often (3–4 days)," and 3 representing "most of the time (5–7 days)." The

four positive items are reverse-scored. Total scores range from 0 to 60 points.

The CFPS used the 20-item CES-D to conduct a detailed survey on depression in 2012. Few respondents completed the survey in 2016 owing to its many questions: only 20% of adults answered all questions, and the other 80% answered the shorter version—only eight items. The same short version was adopted for all adults in 2018. According to the official CFPS database, an equi-percentile equating method was used in 2016 and 2018 to generate CES-D-20 score comparable to those in 2012. Therefore, the dependent variable is assessed by CES-D-20.

Independent variables

The explanatory variables were intergenerational support and medical expenditures (1) Based on the social support theory, scholars typically measure the aforementioned three types of intergenerational support: economic, care-based, and emotional (20). We constructed core variables according to items from the questionnaire module examining the relationship between children and parents: "Have your children provided economic support for you in the past 6 months?" "Have your children done housework or provided life care for you in the past 6 months?" and "How has the relationship between you and your children been in the past 6 months?" (2) Only one-third of the sample had inpatient medical expenditures. Based on existing research and according to the questionnaire—specifically, the items "How much was spent on medical treatment for hospitalization in the past year?" and "How much was the cost of disease, besides hospitalization, in the past year?"—medical expenditures were divided into inpatient and non-inpatient. Further, the total medical expenditures represent expenditure regardless of whether they were self-paid, and medical expenditures in the CFPS database include medical, treatment, or examination expenses, among others; preventive medical services are not included.

Covariates

According to existing research, older adults with depression are primarily women and characterized by their old age, low education, poor family income, and poor physical health. The number of children influences the intergenerational support older adults receive and can even directly impact their mood. The type of medical insurance is also expected to influence older adults who seek medical treatment. Therefore, this study controls for individual differences through demographic indicators (gender, age, and educational level), health status (self-rated health or the existence of chronic diseases), type of medical insurance, per capita family income, and number of children (61–64). Self-rated health in the CFPS questionnaire were measured by asking patients, "How would you rate your current health status?" with five possible responses: "very healthy," "healthy," "relatively healthy," "general" or "unhealthy." Regarding the type of medical insurance, the CFPS questionnaire has five categories with six options: "public medical insurance," "urban employee medical insurance," "urban residential medical insurance," "NRCMS insurance," "supplementary medical insurance," and "none." The description and assignment of variables are shown in Table 1.

The sample's average age was 68.75 years. In terms of gender, 53.84% were men, and 46.16% were women. Regarding education, 86.84% had an educational level of primary school or below, and those with junior high school education and above accounted for only about 13.16%; overall, the respondents' educational level was low. In terms of depression, the mean CES-D score was 22, meaning that the majority of older adults experienced depressive symptoms. Regarding intergenerational support from children, 83.33% received economic support, 75.61% received care-based support, and the mean value for emotional support was 4.19, indicating generally close relationships between older adults and their children. Regarding medical expenditures, the mean values of inpatient and non-inpatient costs were 4,207.151 yuan and 1,417.643 yuan, respectively. In terms of per capita family income, the average value was 12,293.35 yuan. In regard to the type of medical insurance, the vast majority (95.64%) had medical insurance, and most (88.67%) had NRCMS insurance. Finally, regarding self-rated health, 6.69% reported being very healthy, 10.21% reported being healthy, nearly half reported being relatively healthy, and 33.73% reported being unhealthy.

Statistical analysis

The panel data model can address the endogeneity caused by unobservable individual heterogeneity and correctly interpret the relationship between variables; we use this approach to investigate the effect of intergenerational support and medical expenditures on depression among the older adults. We estimated the following model using three-wave panel data:

$$\begin{aligned} D_{it} &= \alpha_0 + \beta_1 S_{it} + \lambda_1 Control_{it} + \lambda_2 Year_{it} \\ &\quad + \lambda_3 Region_{it} + \varepsilon_{it} \quad (1) \\ D_{it} &= \alpha_0 + \beta_2 IME_{it} + \beta_3 NME_{it} + \lambda_4 Control_{it} \\ &\quad + \lambda_5 Year + \lambda_6 Region + \varepsilon_{it} \quad (2) \\ IME_{it} &= \alpha_0 + \beta_4 S_{it} + \lambda_7 Control_{it} + \lambda_8 Year \\ &\quad + \lambda_9 Region + \varepsilon_{it} \quad (3) \\ NME_{it} &= \alpha_0 + \beta_5 S_{it} + \lambda_{10} Control_{it} + \lambda_{11} Year \\ &\quad + \lambda_{12} Region + \varepsilon_{it} \quad (4) \end{aligned}$$

TABLE 1 Variable definitions and statistical analysis.

Variables	Description of variable settings	Mean (SD)	Percentage	References
Depression (points)	The score of CES-D	22.00 (9.60)		(56)
Inpatient medical expenditure (yuan)	Inpatient medical expenditure	4,207.151 (14,085.21)		(14)
Non-inpatient medical expenditure (yuan)	Non-inpatient medical expenditure	1,417.643 (3,005.974)		(14)
Per capita family income (yuan)	Per capita family income	12,293.35 (85,624.09)		(65)
Number of children	Number of children	2.75 (1.48)		(66)
Age (years)	Age	68.75 (5.22)		(67)
Emotional support	The mean value of the emotional close degree with all children (very distant = 1; distant = 2; normal = 3; close = 4; very close = 5)	4.19 (0.71)		(68)
Economic support	Receiving children's economic support = 1 Not receiving = 0		83.33 16.67	(20)
Care support	Receiving children's economic support = 1 Not receiving = 0		75.61 24.39	(20)
Gender	Male = 1 Female = 0		53.84 46.16	(69)
Education level	Illiteracy = 1 Primary school = 2 junior high school or above = 3		60.50 26.34 13.16	(66, 69)
Type of medical insurance	None = 0 New rural cooperative medical insurance = 1 Urban resident medical insurance = 2 Urban employee medical insurance = 3 supplementary medical insurance = 4 public medical insurance = 5		4.36 88.67 1.93 3.36 0.30 1.38	(22)
Chronic diseases	Yes = 1 No = 0		27.04 72.96	(65)
Self-rated health level	Very healthy = 1 Health = 2 Relatively healthy = 3 General = 4 Unhealthy = 5		6.69 10.21 30.01 19.35 33.73	(69)

$$D_{it} = \alpha_0 + \beta_6 S_{it} + \beta_7 IME_{it} + \beta_8 NME_{it} + \lambda_{13} Control_{it} + \lambda_{14} Year + \lambda_{15} Region + \varepsilon_{it} \quad (5)$$

where D_{it}represents depression among older adults that measured by the CES-D; S_i is the key independent variable representing intergenerational support, which includes economic, care-based, and emotional support;IME_{it} represents inpatient medical expenditures, andNME_{it} represents non-inpatient medical expenditures;$Control_{it}$ represents all of the control variables, including demographic indicators (gender, age, and educational level), health status (self-rated health changes and existence of chronic diseases), type of medical insurance, per capita family income, and the respondent's number of children. Additionally, *Year* and *Region* are virtual control variables; ε_{it} represents the random error term of the mixed difference between respondents and time; i, t represents data from the i^{th} older adult respondent in year t.

In general, panel data models include random effects (RE) models and fixed effects (FE) models, and the Hausman test is used to determine which model to apply. The data were analyzed using Stata/SE version 15.0 for Windows (StataCorp, College Station, TX, USA).

Results

Statistical inference

Table 2 indicates the results of analysis of variance concerning depression and medical expenditures in the context of whether or not older adults received intergenerational support. In terms of depression, the mean CES-D score among older adults who received children's economic support was 9.77 points higher than the mean score of those who did not receive such support. Further, the mean CES-D score among older adults who received care-based support was 11.77 points higher than among their counterparts. Regarding emotional support, the mean CES-D score of recipients was lower than that of older adults who did not receive such support. In terms of medical expenditures, the inpatient costs of those who received economic or care-based support were higher than the costs of those who did not receive such support. However, there were no significant differences in

TABLE 2 Analysis of variance results of depression and medical expenditures among the rural elderly in the context of whether or not older adults received intergenerational support.

Variables	Sample size	Mean	Sample size	Mean	Difference
	Not receiving children's economic support		Receiving children's economic support		Difference test
Ln (inpatient medical expenditure)	842	0.79	1,469	5.11	4.32***
Ln (non-inpatient medical expenditure)	743	5.32	4,018	5.29	0.03
CES-D score	842	14.55	4,210	24.32	9.77***
	Not receiving children's care support		Receiving children's care support		Difference test
Ln (inpatient medical expenditure)	1,232	0.79	1,079	6.67	5.88***
Ln (non-inpatient medical expenditure)	1,085	5.41	3,676	5.26	−0.15
CES-D score	1,232	14.25	3,820	25.42	11.17***
	Not receiving children's emotional support		Receiving children's emotional support		Difference test
Ln (inpatient medical expenditure)	40	3.31	2,634	3.28	−0.03
Ln (non-inpatient medical expenditure)	69	5.06	5,086	5.29	0.23
CES-D score	78	27.40	5,436	22.33	−5.07***

*, **, *** represent the significance level of 10, 5, and 1%, respectively.

inpatient medical expenditures based on the presence or absence of emotional support. Moreover, non-inpatient medical expenditures among older adults who received intergenerational support were not significantly different from those who did not receive intergenerational support. Thus, intergenerational support may have an impact on inpatient medical expenditures and depression.

Impact of intergenerational support and medical expenditure on depression

Table 3 presents the impacts of not only intergenerational support and medical expenditures on depression among rural older adults but also of intergenerational support on medical expenditures. The findings of the Hausman test support the fixed-effect model in the benchmark regression (prob > chi^2 = 0.001); the virtual variables "year" and "region" were controlled for. Model 1 presents the regression results of the impact of different types of intergenerational support on depression among rural older adults. The results reveal that intergenerational support was significantly associated with CES-D score, and older adults who received economic support ($\beta = -0.854$, $p < 0.05$) or had closer intergenerational relationships ($\beta = -0.890$, $p < 0.01$) were likely to experience lower CES-D score; thus, H1a and H1c were supported. In contrast, receiving care-based support was significantly positively associated with CES-D score at a 1% significance level ($\beta = 2.003$, $p < 0.01$); thus, H1b was disproved. Additionally, the number of children was negatively associated with CES-D score among older adults at a 5% significance level, implying that the concept of "more children, more happiness" is still prevalent in rural areas.

Model 2 presents the regression results of the impacts of medical expenditures on depression among rural older adults, in which non-inpatient medical expenditures were significantly positively associated with CES-D score ($\beta = 0.304$, $p < 0.01$). As inpatient medical expenditures did not produce a significant influence ($\beta = -0.270$, $p > 0.1$), H2b was proven, but H2a was not verified. Further, rural older adults may report higher CES-D score when experiencing chronic diseases or when their self-rated health is poor, as demonstrated by the results from Models 1 and 2. Moreover, per capita family income was significantly negatively associated with CES-D score at the 1% significance level. However, age, gender, education, and the type of medical insurance were not significantly related to CES-D score.

TABLE 3 Regression analysis for intergenerational support and medical expenditures on depression among the rural older adults.

Variables	Model 1	Model 2	Model 3	Model 4	Model 5
	CES-D score	CES-D score	Inpatient	Non-inpatient	CES-D score
Economic support (ref: not receiving)	−0.854**		0.564**	−0.074	−0.542
	(0.398)		(0.280)	(0.187)	(0.853)
Care support (ref: not receiving)	2.003***		0.665**	−0.453*	2.555***
	(0.498)		(0.338)	(0.238)	(1.058)
Emotional support	−0.890***		−0.004	0.051	−1.191***
	(0.173)		(0.149)	(0.079)	(0.438)
Ln (inpatient medical expenditure)		0.278			−0.168
		(0.255)			(0.284)
Ln (non-inpatient medical expenditure)		0.304***			0.365***
		(0.101)			(0.107)
Number of children	−0.492**	0.368	−0.354	0.080	0.418
	(0.266)	(0.372)	(0.227)	(0.120)	(0.651)
Chronic diseases (ref: no)	0.806***	1.011*	0.273	0.761***	1.119*
	(0.259)	(0.564)	(0.197)	(0.118)	(0.582)
Self-rated health level = 2 (ref: very healthy)	0.307	−0.390	−0.917	0.332	0.601**
	(0.533)	(1.527)	(0.596)	(0.237)	(0.284)
Self-rated health level = 3 (ref: very healthy)	1.034**	0.619	0.616***	0.692***	0.803
	(0.485)	(1.458)	(0.554)	(0.217)	(1.267)
Self-rated health level = 4 (ref: very healthy)	1.402***	−0.855	0.191	0.973***	1.285
	(0.518)	(1.496)	(0.560)	(0.233)	(0.887)
Self-rated health level = 5 (ref: very healthy)	3.498***	2.035	0.441***	1.486***	2.037**
	(0.523)	(1.454)	(0.126)	(0.236)	(0.686)
Type of medical insurance = 1 (ref: none)	−0.691	2.841	−0.808	0.522**	3.289
	(0.549)	(1.934)	(0.705)	(0.248)	(2.115)
Type of medical insurance = 2 (ref: none)	−1.554	1.927	0.085	0.467	0.763
	(1.074)	(3.221)	(1.162)	(0.493)	(3.378)
Type of medical insurance = 3 (ref: none)	−2.391**	−0.983	0.365	1.389***	−1.750
	(1.129)	(2.538)	(0.955)	(0.505)	(2.733)
Type of medical insurance = 4 (ref: none)	−1.419	−3.622	−1.112	0.973	−0.979
	(1.877)	(4.470)	(1.571)	(0.882)	(5.007)
Type of medical insurance = 5 (ref: none)	−1.579	0.341	−0.726	0.710	−1.481
	(1.316)	(2.738)	(1.083)	0.590	(3.021)
Age	0.352	−0.260	0.138	0.141	−0.346
	(0.260)	(0.609)	(0.216)	(0.120)	(0.599)
Gender (ref: female)	−1.075	3.947	−1.553	4.951**	2.371
	(4.892)	(8.493)	(3.093)	(2.122)	(8.434)
Education level 2 (ref: Education level 1)	−1.446	1.253	0.996	0.397	1.309
	(1.341)	(2.764)	(0.950)	(0.616)	(2.897)
Education level 3 (ref: Education level 1)	2.572	2.363	0.016	−0.012	1.353
	(3.117)	(3.011)	(1.235)	(1.353)	(2.214)
Ln (per capita family income)	−0.385***	−0.847***	0.031	0.165***	−0.695**
	(0.130)	(0.270)	(0.095)	(0.060)	(0.287)
Constant	−0.596	30.419	−6.295	−9.903	39.199
	(17.307)	(40.286)	(14.396)	(7.938)	(40.045)

(Continued)

TABLE 3 Continued

Variables	Model 1	Model 2	Model 3	Model 4	Model 5
	CES-D score	CES-D score	Inpatient	Non-inpatient	CES-D score
Regional fixed effect	Yes	Yes	Yes	Yes	Yes
Time fixed effect	Yes	Yes	Yes	Yes	Yes
R-squared	0.546	0.631	0.825	0.055	0.628

Standard errors in parentheses, *, **, *** represent the significance level of 10%, 5%, and 1%, respectively.

Models 3 and 4 denote the regression results of the impact of intergenerational support on medical expenditures among rural older adults, and the explained variables are inpatient and non-inpatient medical expenditures. Economic support has a positive impact on inpatient medical expenditures ($\beta = 0.564$, $p < 0.05$); hence, H3a was verified. However, an insignificant influence on non-inpatient medical expenditures existed; thus, H3b was not supported. This is possibly because Chinese older adults, especially those living in rural areas, have a stronger traditional notion of saving their money for untimely needs rather than investing in health in daily life (70). Care-related support significantly affected medical expenditures, as respondents who received care-based support had more inpatient medical expenditures ($\beta = 0.665$, $p < 0.05$) and lower non-inpatient medical expenditures ($\beta = -0.453$, $p < 0.1$), disproving H4a and proving H4b. However, emotional support had no significant impact on medical expenditures.

In contrast, non-inpatient medical expenditures were significantly positively associated with worse self-rated health, existence of chronic disease, type of medical insurance, per capita family income, and gender. Older adults diagnosed with chronic diseases in the past 6 months had higher non-inpatient medical expenditures ($\beta = 0.761$, $p < 0.01$). Older adults who participated in medical insurance programs—such as NRCMS ($\beta = 0.522$, $p < 0.05$) or urban employees' basic medical insurance ($\beta = 1.389$, $p < 0.01$)—were more likely to have more non-inpatient medical expenditures. Additionally, per capita family income was positively correlated with the use of health services and non-inpatient medical expenditures by decreasing the medical burden. Finally, gender was associated with non-inpatient medical expenditures; men were more likely to have higher such expenditures. However, the number of children and age were not significantly correlated with non-inpatient medical expenditures.

Model 5 displays the regression result of adding all independent variables. Economic support had a negative influence on CES-D score in older adults after adding medical expenditures as a variable, but it was not significant. Care-based support was positively associated with higher CES-D score in older adults ($\beta = 2.555$, $p < 0.01$), and those with more emotional support reported lower CES-D score ($\beta = -1.191$, $p < 0.01$), consistent with the results of Model 1. Non-inpatient medical expenditures were significantly and positively correlated with higher CES-D score ($\beta = 0.365$, $p < 0.01$), consistent with the results of Model 2. Moreover, the mediating roles of inpatient and non-inpatient medical expenditures in the relationship between intergenerational support and depression were examined and reported in the Supplementary Materials, which indicated that the mediating role of medical expenditures between intergenerational support and depression was not significant.

Robustness test based on propensity score matching

The benchmark regression analysis indicated that the effects of care-based and emotional support and non-inpatient medical expenditures on depression were significant, while the impact of economic and care-based support on medical expenditures was significant. However, individual differences in factors can determine whether older adults are supported by their children or incur medical expenditures. Some respondents did not report medical expenditures, causing the problem of a missing variable; the covariates were associated not only with depression but also potentially with intergenerational support, causing endogeneity problems. Therefore, the propensity score matching (PSM) method was used to conduct counterfactual analysis to reduce sample selection bias and resolve the issues of missing data and endogeneity, thus improving the regression results' reliability (66, 71).

The core variables that significantly impacted the outcome variables were regarded as the treatment variables. The k-nearest neighbor-matching method ($n = 4$) was used to test the average treatment effect on the treated (ATT) of intergenerational support and medical expenditures on CES-D score as well as the ATT of intergenerational support on medical expenditures by comparing the two samples, which differ only in terms of the key processing variables and have similar resource endowment characteristics. As Table 4 indicates, the net effect of care-based support ($t = 2.02$, $p < 0.05$), emotional support ($t = -2.37$, $p < 0.05$), and non-inpatient medical expenditures (t

TABLE 4 The Propensity score matching (PSM) test for the treatment variable.

Treatment variables	Sample	ATT	S.E.	T
		CES-D score		
Economic support	Unmatched	0.04	0.54	0.08
	Matched	−0.23	0.67	−0.34
Care support	Unmatched	1.91	0.69	2.76
	Matched	1.72	0.85	2.02**
Emotional support	Unmatched	−6.70	1.17	−5.71
	Matched	−4.86	2.06	−2.37**
Non-inpatient medical expenditure	Unmatched	1.64	0.33	4.91
	Matched	1.76	0.50	3.50***
		Inpatient medical expenditure		
Economic support	Unmatched	0.22	0.15	1.50
	Matched	−0.09	0.18	−0.49
Care support	Unmatched	0.55	0.19	2.92
	Matched	0.35	0.24	1.47
		Non-inpatient medical expenditure		
Economic support	Unmatched	0.16	0.15	1.05
	Matched	0.12	0.18	0.63
Care support	Unmatched	−0.38	0.20	−1.92
	Matched	−0.52	0.24	−2.16**

*, **, *** represent the significance level of 10, 5, and 1%, respectively.

= 3.50, $p < 0.01$) on CES-D score was significant, indicating that the former regression analysis results were robust and disproving H1b. Furthermore, H1c and H2b endorsed the PSM test.

Regarding inpatient medical expenditures, the ATT of economic support and care-based support were lower than that of the regression coefficient in the fixed-effects Model 3, and the *t*-test was not significant. Thus, economic and care-based support had an insignificant net effect on inpatient medical expenditures after matching. Regarding the effect of intergenerational support on non-inpatient medical expenditures, the matched ATT of care support (ATT = −0.52) was close to the regression coefficient in Model 4 (β = −0.453). However, economic support had an insignificant effect on non-inpatient medical expenditures. Thus, care-based support had the potential to reduce non-inpatient medical expenditures but report higher CES-D scores; emotional support had a significantly negative net effect on CES-D score; and non-inpatient medical expenditures had a positive net effect on CES-D score. However, the effects of economic support on CES-D score and medical expenditures did not pass the PSM test, nor did care support's effect on inpatient medical expenditures.

Heterogeneity in impact of intergenerational support on medical expenditure and depression

The need for intergenerational support and medical services varies among older adults with different physical conditions and ages. First, the sample was divided to delineate whether the individual had experienced a chronic disease in the last half of the year. Second, the sample was divided into a "young" group, or those under age 75, and a "very old" group, or those aged 75 or older, according to the World Health Organization's age division criteria. The impact of intergenerational support and medical expenditures on depression among older adults and the impact of intergenerational support on medical expenditures were analyzed using a grouped ordinary least-squares regression in the different groups, including cases of chronic diseases (or none) as well as different ages. The Hausman test is used to decide the regression model either with or without fixed effects. Tables 5, 6 present the results.

The sample heterogeneity in Table 5 demonstrates that care-based support positively correlated with CES-D score among young older adults (β = 2.877, $p < 0.05$) and negatively correlated with CES-D scores in the very old (β = −2.494, p

TABLE 5 Sub-samples regression results regarding the effects of intergenerational support and medical expenditures on depression among the rural older adults.

Variables	CES-D score			
	Chronic = 0 *N* = 4,023	Chronic = 1 *N* = 1,491	Age<75 *N* = 4,711	Age≥75 *N* = 803
Ln (inpatient medical expenditure)	−0.094	0.114	−0.138	−0.025
	(0.257)	(0.314)	(0.318)	(0.454)
Ln (non-inpatient medical expenditure)	0.282***	0.215	0.326***	0.151
	(0.078)	(0.156)	(0.126)	(0.175)
Economic support (ref: not receiving)	−0.473	−0.529	−0.625	0.083
	(0.500)	(1.114)	(0.981)	(2.193)
Care support (ref: not receiving)	1.204*	2.507*	2.877**	−2.494
	(0.642)	(1.357)	(1.224)	(2.980)
Emotional support	−1.492***	−1.372***	−2.049***	−3.345***
	(0.301)	(0.460)	(0.475)	(0.764)
Covariates	Controlled	Controlled	Controlled	Controlled
Regional fixed effect	No	No	Yes	No
Time fixed effect	No	No	Yes	No
R-squared	0.507	0.441	0.619	0.622

Standard errors in parentheses, *, **, *** represent the significance level of 10, 5, and 1%, respectively.

> 0.1), although the association was not significant. Emotional support had negative influence on CES-D score in the full sample at the 1% level, and the coefficient was higher for the very old ($\beta = -3.345$). Similarly, the regression results regarding medical expenditures' impact on CES-D score revealed that non-inpatient medical expenditures were positively associated with CES-D score among the older adults. Moreover, those with no chronic diseases ($\beta = 0.282$, $p < 0.01$) and the young group ($\beta = 0.326$, $p < 0.01$) were more sensitive to medical expenditures.

The results in Table 6 indicate that emotional support had no significant impact on medical expenditures, while economic support positively impacted inpatient medical expenditures for those with no chronic diseases ($\beta = 0.321$, $p < 0.05$) and negatively impacted inpatient medical expenditures for those with chronic diseases ($\beta = -0.506$, $p < 0.1$). Care-based support had a positive influence on inpatient medical expenditures for those with chronic diseases ($\beta = 1.460$, $p < 0.01$) and the young group ($\beta = 0.939$, $p < 0.01$) and a negative influence on non-inpatient medical expenditures for those without chronic diseases ($\beta = -0.604$, $p < 0.05$) and the young group ($\beta = -0.473$, $p < 0.1$).

In conclusion, according to the regression analysis and robustness test results, there was heterogeneity in the impact of different types of intergenerational support on depression among rural older adults. All of the samples indicated that economic support was negatively correlated with CES-D score, but this was insignificant; thus, H1a could not be verified. Care-based support was significantly associated with CES-D score. Specifically, it had a significant and positive impact on CES-D score among the young group and a negative but insignificant correlation with CES-D score among the very old; hence, H1b was refuted. In contrast, emotional support significantly and negatively impacted CES-D score, verifying H1c. While medical expenditures—which represent both physical health and medical burden—had an adverse effect on CES-D score in older adults, only non-inpatient medical expenditures were significant; therefore, while H2a could not be verified, H2b was proved.

The regression results regarding the impact of intergenerational support on medical expenditures demonstrate that those with economic support may have more medical expenditures, but the net effect on inpatient medical expenditures did not pass the PSM test. Thus, H3a could not be verified, but H3b was verified. The results of the sub-sample regression show that economic support was positively associated with inpatient medical expenditures among older adults without chronic diseases and negatively associated with such expenditures among older adults with chronic diseases. Older adults with care-based support generated more inpatient medical expenditures and lower non-inpatient medical expenditures; however, non-inpatient medical expenditures' mediating role in care-based support's influence on depression was insignificant. Additionally, the robustness test results shown in the Supplementary Materials were obtained by replacing the explanatory variables, which revealed that the older adults who received higher-frequency care-based support reported higher inpatient medical expenditures; thus, H4b was supported, while H4a was not. The sub-sample regression results demonstrated

TABLE 6 Sub-samples regression results regarding the effect of intergenerational support on the medical expenditures of the rural older adults.

Variables	Chronic = 0 N = 4,023		Chronic = 1 N = 1,491		Age<75 N = 4,711		Age≥75 N = 803	
	Inpatient	Non-inpatient	Inpatient	Non-inpatient	Inpatient	Non-inpatient	Inpatient	Non-inpatient
Economic support (ref: not receiving)	0.321**	−0.032	−0.506*	0.357	0.598*	−0.025	0.692	−0.505
	(0.140)	(0.192)	(0.291)	(0.313)	(0.329)	(0.206)	(0.520)	(0.816)
Care support(ref: not receiving)	0.189	−0.604**	1.460***	−0.309	0.939**	−0.473*	0.765	−1.185
	(0.177)	(0.247)	(0.344)	(0.384)	(0.393)	(0.263)	(0.675)	(1.124)
Emotional support	−0.018	0.062	−0.034	−0.003	0.093	0.114	0.250	0.016
	(0.084)	(0.073)	(0.128)	(0.095)	(0.166)	(0.088)	(0.188)	(0.158)
Covariates	Controlled	Controlled	Controlled	Controlled	Controlled	Controlled	Controlled	Controlled
Regional fixed effect	No	No	No	No	Yes	Yes	No	No
Time fixed effect	No	No	No	No	Yes	Yes	No	No
R-squared	0.750	0.149	0.715	0.092	0.819	0.052	0.828	0.270

Standard errors in parentheses, *, **, *** represent the significance level of 10, 5, and 1%, respectively.

that receiving care-based support was positively correlated with the inpatient medical expenditures of older adults with chronic diseases and the younger group. In contrast, it was negatively correlated to non-inpatient medical expenditures among older adults without chronic diseases and those younger than 75.

In terms of covariates, respondents with chronic diseases or worse self-rated health were more likely to report higher CES-D scores, and higher per capita family income was correlated with lower CES-D scores in this population. Moreover, the family's economic level was also positively associated with non-inpatient medical expenditures for the younger group.

Discussion

Based on the CFPS balanced panel data from 2012, 2016, and 2018, the regression and robustness test results demonstrated the existence of heterogeneity in the impact of different types of intergenerational support on depression among rural older adults. Further, the impact of medical expenditures on depression and the impact of intergenerational support on medical expenditures differed among the indicators. The specific analysis is as follows.

As intergenerational support was partially associated with depression among rural older adults, H1 was partially proven. The regression results indicated that older adults experienced lower CES-D scores with economic support, but this was not significant; hence, H1a could not be verified. Most studies generally state that economic support acts as a buffer against the effects of life costs on depression among older adults (72). However, consistent with our conclusion, some scholars posit that economic support has no significant effect on older adults' physical and mental health (73). Based on the 2014 Chinese General Social Survey database, He et al. (21) classified all children's economic support in that year into three levels—low, medium, and high—according to the following ranges: < 1,000 yuan, 1,000 to 5,000 yuan, and more than 5000 yuan, respectively. For rural older adults, medium and high economic support was associated with significantly fewer depressive symptoms, but low economic support was insignificant in this regard. This study's statistical results showed that in the past 6 months, 921 older adults received low economic support (< 500 yuan) in 2016 and 774 in 2018; 508 and 591 received medium economic support (500 to 2,500 yuan) in 2016 and 2018, respectively; and 409 and 473 received high economic support (> 2,500 yuan) in 2016 and 2018, respectively. Half of the older adults received low economic support, or < 83 yuan per month. Among these, 842, 814, and 628 older adults did not receive economic support from their children in 2012, 2016, and 2018, respectively; thus, the economic support provided by children in rural China is generally limited (74). As it is difficult for older adults to reduce their life stress, this factor was insignificant with regard to lower CES-D scores.

As care-based support significantly and positively affected depression among rural older adults, H1b was disproved. Some scholars believe that family care can increase the interactions between older adults and their family members, thus alleviating depression and enhancing their life satisfaction (75), which contradicts this study. Specifically, most of the present respondents were younger than 75 ($n = 4{,}711$) or did not have chronic diseases ($n = 4{,}023$). First, this predisposes them to "excessive" care. Younger older adults have some self-care ability, and children's life care can easily interfere in their lives, producing psychological stress. It may also undermine their evaluations of self-perceived health and self-utility or lead to intergenerational conflict, thus producing severe depression (53, 76). Early studies based on older female adults also indicate that family care affects their privacy to some extent, consequently deteriorating their mental health (77). Second, as rural families commonly have a low socioeconomic status, most young migrants move to other areas to work. The opportunity cost incurred by children remaining in the countryside causes psychological stress for older adults, and long-term care generates guilt (78). Third, based on intergenerational reciprocity theory, special residential arrangements for older adults in rural China have led to lower expectations for nursing care from non-coresidential children. As children in rural areas become adults, older adults primarily live with their sons (79, 80), and any other children are relatively estranged, especially after a daughter is married. Parents invest heavily in the child they live with, thus expecting greater returns with regard to nursing care. As a result, care-based support from non-coresidential children, especially daughters, places a psychological burden on older adults.

The regression results revealed that compared with economic and care-based support, emotional support and close relationships had a negative impact on CES-D score among older adults, and this effect was stronger for those with chronic diseases or who were older than 75, verifying H1c. Intergenerational relationship intimacy potentially alleviated depression in rural older adults (25, 26). However, in other surveys, children in rural areas focused more on economically supporting their parents, followed by care-based support, and were least likely to offer emotional support (81). Family members should be encouraged to pay more attention to older adults' emotional needs and their intimate relationship to relieve their loneliness, isolation, and depression.

The impact of medical expenditures on depression among rural older adults was partially significant, and H2 was partly proven, with the regression results indicating that non-inpatient medical expenditures significantly and positively influenced CES-D score. Hence, H2a was verified. Existing studies have noted that poor physical health is detrimental to mental health (63, 82). However, older adults are vulnerable to disease shocks, and those in rural areas have multiple psychological burdens, such as life constraints, poor physical health, and high medical expenditures (83). Although some studies have suggested that higher medical expenditures are beneficial for improving older adults' life satisfaction, the family's economic status is also significantly associated with depression among older adults (84). High medical expenditures in rural areas can create anxiety among older adults, as they can perceive themselves as a burden to the family, leading to more serious phenomena such as depression or even suicide (85). Nevertheless, inpatient medical expenditures had no significant impact on CES-D score; thus, H2b could not be verified. The proportion of inpatient medical reimbursements under the NRCMS policy was high, while the proportion of inpatient services used by rural older adults was low owing to the reimbursement threshold. Thus, the amount of non-inpatient medical expenditures, as the primary medical expenditures, had a stronger positive impact on higher CES-D scores among older adults.

Economic support was partially associated with rural older adults' medical expenditures, partially verifying H3. The regression results revealed that economic support positively influenced inpatient medical expenditures for those with no chronic diseases, indicating that economic support was beneficial in reducing their economic burden and increasing medical expenditures (53). However, economic support's effect on medical expenditures did not pass the PSM test because economic support in rural areas is not sufficient. The robustness test conducted by replacing explanatory indicators demonstrated that increasing economic support had a positive impact on non-inpatient medical expenditures. In Chen et al.'s study (86) based on the CHARLS database, economic support was limited, which significantly affected middle-income older adults' physical health and weakly affected high- and low-income older adults. Hence, the effects of economic support were correlated with the amount of support and older adults' income.

Second, care-based support was partially associated with medical expenditures among rural older adults, partially verifying H4. The regression results showed that care-based support significantly and negatively affected older adults' non-inpatient medical expenditures, verifying H4b. This is consistent with existing studies wherein care-based support had an alternative effect on healthcare services by improving older adults' health through the provision of life care (53). However, care-based services have a limited effect on physical health (21); this explains the non-significant impact on non-inpatient medical expenditures among older adults with chronic diseases or who were older than 75. In the case of sudden illness or severe diseases, care services can reduce the barriers to medical treatment (51, 52), which exerts a complementary effect on medical services and elevates inpatient medical

expenditures. The sub-sample regression indicated that the impact was significant for older adults with chronic diseases, but the net effect did not pass the PSM test. Hence, H4a was disproved.

Moreover, intergenerational support directly affected older adults' mood, and the mediating role of medical expenditures between intergenerational support and depression was not significant. Therefore, as it is difficult to alleviate depression in older adults by reducing medical expenditures through intergenerational support from adult children, it is necessary to alleviate their medical burden *via* formal support.

Compared with previous studies, this study is novel in certain aspects. First, two factors—intergenerational support and medical expenditures—were considered to have the greatest influence on depression among rural older adults because social nursing and medical security in rural China still need improvement. Second, this work comprehensively explores the effects of intergenerational support in three dimensions: economic, care, and emotional support. The results revealed that the different types of intergenerational support had varying correlations with depression among rural older adults. Compared with economic and care-based support, emotional support had a significantly negative influence on depression among older adults, while excessive care support was positively associated with severe depression and low economic support had no significant effect. Third, the group differences in previous studies were primarily analyzed given various categories of gender or age, among other factors. In addition to considering different age groups, this study conducted a sub-sample regression given different health levels, specifically, whether older adults were diagnosed with chronic diseases in the past 6 months. This led to an analysis of differences in the impact of intergenerational support and medical expenditures on depression as well as the impact of intergenerational support on medical expenditures among older adults with different physical conditions. This work demonstrated that among respondents with care support, higher CES-D scores were reported for younger older adults, and care support partially replaced the use of non-inpatient medical services for those without chronic diseases or who were younger than 75.

This study has several limitations. First, we focused on rural older adults and primarily considered intergenerational support from adult children, which did not include intergenerational mutual support or support provided by grandchildren or spouses. Second, the study did not explore the interactions among different types of intergenerational support. Third, the examination was limited to the CFPS database, which had samples that were mostly younger than 75 years, resulting in a younger sample. Finally, while the fixed- effects model and PSM could solve the endogeneity problem to some extent, this problem cannot be completely resolved, and potential reverse causality should be considered in further studies.

Conclusions and implications

First, heterogeneity was observed in the impact of intergenerational support on depression among China's rural older adults in different dimensions. Emotional support had a negative impact on depression, and excessive care support had a positive impact on depression, except among older adults aged above 75. In contrast, low-level economic support had no significant impact on depression. Therefore, more attention should be paid to the mental health problems of older adults in rural areas, especially among those with chronic diseases. It is necessary to advocate for and motivate intergenerational intimacy and emotional support in contemporary society. Further, the stress from intergenerational support should be reduced by formulating incentives, such as financial allowances and nursing training, which encourage children to provide high-level economic support and effective care to older adults. This is especially essential for older adults in poor physical health or of advanced age, thus relieving depression.

Second, medical expenditures are an economic burden for rural older adults, among which there is a high proportion of individuals who should be hospitalized but are not. Therefore, non-inpatient medical expenditures had a greater emotional impact as the primary type of medical expenditure. Further, higher non-inpatient medical expenditures significantly aggravate depression. It is necessary to focus on chronic disease care to improve rural medical systems. This will reduce the problem of the difficulty and high cost of obtaining medical services among rural older adults. Moreover, a medical insurance reimbursement policy for chronic diseases should be implemented for rural residents. The reimbursement application process should also be simplified to reduce medical expenditures and alleviate the associated psychological stress.

Finally, the impact of intergenerational support on medical expenditures can be divided into two levels. First, the increase in economic support, which is accompanied by an increase in older adults' non-inpatient medical expenditures, has a supplementary effect. Second, receiving care-based support would produce lower non-inpatient medical expenditures as a substitution effect. The family security system should be fully implemented to capitalize on the traditional filial piety culture, and intergenerational support is encouraged to improve older adults' ability to pay for medical services. However, the fact that the mediating role of medical expenditures in the relationship between intergenerational support and depression was not significant implies that it is difficult to alleviate depression among older adults by reducing medical expenditures through children's support. Thus, subsidies for older adults, as formal support, should also be improved for low-income older adults, especially in rural areas and if their children's economic support is limited, to alleviate depression caused by life pressures and medical burdens.

Data availability statement

Publicly available datasets were analyzed in this study. This data can be found at: http://www.isss.pku.edu.cn/cfps/.

Author contributions

CL contributed to the study conception and research design. QH conducted the statistical analysis and contributed to the drafting of the manuscript. JH, ZH, and HY provided critical feedback and contributed to the discussion. CL and QH edited the manuscript for language. All authors contributed to the revision of the manuscript and have read and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpubh.2022.840864/full#supplementary-material

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Translating and Evaluating a Physical Activity Program for Aboriginal Elders on Noongar Boodjar (Country) — A Longitudinal Study

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Objective: The primary aim of the study was to translate and evaluate the impact of a Physical Activity (PA) program on the physical function of older Aboriginal Elders on Noongar Boodjar (Country).

Methods: A longitudinal design framed within an Indigenous methodology. Two groups, one metropolitan and one regional, of Aboriginal Elders, aged ≥45 years, participated in the Ironbark PA program. This comprised weekly strength and balance exercises followed by yarning circles. Physical function (primary outcome) and functional ability, cardiovascular risk factors (weight, waist circumference), falls efficacy and health-related quality of life were measured at baseline 6, 12 and 24 months. Data were analyzed using generalized linear mixed effects modeling.

Results: Fifty-two Elders initially enrolled and of those, $n = 23$ (44.2%) Elders participated regularly for 24 months. There was a 6-month gap in program delivery due to the COVID-19 pandemic. Participants made significant improvement in physical function at 12 months compared to baseline: [short physical performance battery (SPPB) at baseline, 8.85 points (95% CI 8.10, 9.61); 12 months 10.28 (95% CI 9.44, 11.13), $p = 0.001$: gait speed at baseline 0.81 ms^{-1} (95% CI 0.60, 0.93); 12 months 1.14 (95% CI 1.01, 1.27), $p < 0.001$]. Some sustained improvement compared to baseline was still evident at 24 months after the 6-month gap in attendance [SPPB 9.60 (8.59, 10.60) $p = 0.14$, gait speed 1.11 (0.95, 1.26) $p < 0.001$]. Cardiovascular risk factors showed a non-significant improvement at 12 and 24 months compared to baseline. All participants reported that they enjoyed the program, found it culturally appropriate and would recommend it to others.

Conclusion: Older Aboriginal people showed sustained improvements in physical function after engaging in a culturally appropriate PA program. Culturally appropriate PA programs provide safety, security and choice for older Aboriginal people to engage in evidence-based PA.

Keywords: Aboriginal and Torres Strait Islander, aged, physical activity, First Nations, Indigenous, Elder, evaluations

INTRODUCTION

Indigenous peoples worldwide have suffered through invasion and the impacts of colonization (1, 2). It has resulted in the loss of languages, customs, and the freedom to hunt and gather on their traditional lands leading to changes in dietary intake and a sedentary lifestyle (3, 4). These consequences of colonization have negatively impacted on the health status of Indigenous peoples (3), causing disparities between the Aboriginal and non-Aboriginal people and communities in Australia. This disparity must be addressed by hearing Indigenous voices and privileging Indigenous ways of working, rather than providing only Westernized health services (2, 4).

Physical activity (PA) guidelines recommend that older adults should be participating in at least 150 min of moderate-intensity physical activity per week (5). Physical activity improves older adults' strength, balance, functional ability, mental health, cardiovascular health and reduces the risk of falls and functional decline (5, 6). However, less than half of older adults in Australia, including 27% of Aboriginal and Torres Strait Islander older adults, meet PA guidelines (7, 8). Aboriginal and Torres Strait Islander older adults are disproportionately affected by physical disability, therefore may find it difficult to participate in moderate or high intensity levels of PA (9).

However, there have been few studies worldwide that have evaluated PA programs for older Indigenous peoples (10–14). While there are a broad range of PA programs designed or recommended for older populations (15, 16), very few programs are appropriately designed to attract and engage older Indigenous peoples (17–20). A recent systematic review that included 23 studies from four countries found that acknowledging social determinants of health, cultural safety and security and taking a decolonizing approach was needed to encourage older Indigenous peoples' leadership and participation in PA programs (21). However, a review of physical activity programs focused targeting Aboriginal and Torres Strait Islander people in Australia found only 24 programs that operated in WA, and of these only one was specifically designed for older Aboriginal and Torres Strait Islander people (22). Programs that are not designed with these considerations are unlikely to succeed (21).

Taking a decolonizing approach is to "unpack" or "undo" the privilege and power that "whiteness" has always dominated with over other cultures that are different to theirs (23). It is also about trust, cultural competencies, respectfulness, recognition and acknowledgment of diversity among Aboriginal Elders, protecting Aboriginal Elders' knowledge and information shared, importance of relationships and how that contributes to a whole of community happiness and good health (24). Coombes et al. (25) describes that using an Indigenous methodological approach can ensure that the First Nation people and communities' voices are heard (25). The Ironbark PA program followed this approach as it was designed by Aboriginal researchers partnering with Elders and their local community's leadership (10). The program sought to facilitate the engagement of older Aboriginal people in PA through exercise within a culturally secure setting. These settings provided a regular venue and ongoing weekly support for the group as part of their support for the local community. Elders made physical improvements from attending the program and the community response was highly positive (10). However, there were no similar programs provided for older Aboriginal people in WA. While the Ironbark PA program fitted the needs of the Aboriginal and Torres Strait Islander communities in NSW, the "one size fits all" (17), cannot be applied to geographically and culturally disparate Aboriginal and Torres Strait Islander communities. Cultural differences may create barriers that prevent successful engagement and sustainability (18, 21). Therefore, to evaluate the Ironbark PA program in WA the program needed to be delivered with local protocols that were guided by leadership of local Aboriginal Elders. The first adaptation for undertaking the program in WA was time. The Ironbark program in NSW ran for 6 months, but in WA it was considered important to operate the program for a longer period, so that Aboriginal Elders could have time to build confidence and trust to engage in the program. This would allow the program to be evaluated for its impact over a sustained time. Therefore, the researchers aimed to operate the program for at least 18 months.

The objective of the study was to evaluate the impact of a PA program (the Ironbark program) on physical function of Aboriginal Elders on Noongar Country in WA. Secondary aims were to evaluate the impact of the program on functional mobility, cardiovascular risk factors (weight, waist circumference), falls self-efficacy and health related quality of life. Participants' feedback about the program was also sought to understand whether Aboriginal Elders enjoyed the program and felt it could be translated widely among older Aboriginal peoples in WA. This study was part of a larger project that sought to understand how the Ironbark program could be translated into WA.

METHODS

Design

The study used a longitudinal design framed within an Indigenous methodology. This study formed part of a larger

project which aimed to understand how to translate the Ironbark program into WA. Some findings of this larger project have been published previously (21, 26). The methodology followed key principles of working with Aboriginal and Torres Strait Islander peoples, including being based on relationships and privileging Aboriginal leadership (23, 27). Relationship building forms an integral part of how Aboriginal and Torres Strait Islander people prefer to interact with health professionals and if based on mutual respect then the communication and conversation will be fruitful (23). Regarding Aboriginal leadership, the research team included culturally competent, experienced and confident Aboriginal researchers and support workers to assist and support the delivery of the program. The team leaders included senior Aboriginal researchers from WA (MK) and NSW (JC) who provided oversight and monitoring of the research. The senior Aboriginal researcher from WA (MK) also provided mentoring to the primary researcher (MJRG) who was a senior Noongar Wadjuk woman. A senior WA researcher on the team (AMH), who was not Aboriginal, worked closely with both WA Aboriginal researchers to take a stance of critical reflexivity that included letting go of certainties and working outside of one's own comfort zone (28, 29). It involves shared learning and building a respectful relationship between Aboriginal researchers and non-Aboriginal team members. This stance recognized privileging Aboriginal ways of working within an Aboriginal and Torres Strait Islander ethics framework, and the importance of Aboriginal and Torres Strait Islander values and principles being central to the research. Both MK and AMH visited both groups at regular intervals to work with Elders and staff.

Aboriginal Elders living on Noongar Boodjar (Country) have their own cultural practices and dialect although they engage in similar ways it is easy to make the mistake that they will work the same way, but this "one size fits all" approach does not work. One Group accepted male participants, the other did not. One group included a welcome to Country, the other did not. The PA program ran according to the needs and expectations of the Elders who would at times correct the Aboriginal and non-Aboriginal staff on how they needed to meet and work together, while the lead Researcher (MJRG) maintained a neutral position, that allowed for the voices and direction from the Elders collaborating with the Aboriginal health workers to develop their own terms (rules) for working successfully together. We were always mindful of not overstepping our boundaries as visiting researchers. This method of working with the Aboriginal Elders on Noongar Boodjar was in accordance with their "ways of working," where could reinforce how they wanted the PA groups to operate. These relationships form part of Indigenous methodology that is essential to successfully deliver programs when working with Aboriginal and Torres Strait Islander peoples (30). The research was undertaken between February 2019 and July 2021. Ways of working commenced with building relationships, leadership from Aboriginal researchers and community members and continued through to operating the program each week in a way that is comfortable and safe for each person that attended the groups (31).

Program Interruption

After 12 months of operation there was a gap in program delivery of 6 months in 2020 due to the COVID-19 pandemic restrictions. The program resumed at 18 months and continued for another 6 months.

Ethics

Ethics approvals for the study were obtained from WA Aboriginal Health Ethics Committee (HE 842) and Curtin University (HE number 2018-0425). All participants provided written, informed consent prior to participating in the study.

Participants and Setting

Aboriginal Elders who resided on Noongar Boodjar in the South West of WA were invited to participate. Inclusion criteria were being aged 45 years or older, able to attend the group and participate in exercises. Participants were Noongar Elders and Elders who lived on Noongar Country but came from other Boodjars (Countries) in WA and other regions in Australia. Groups operated at local community centers. Participants were asked to obtain a medical clearance to attend the program. Two groups of Elders were recruited, one from a regional area and one from a metropolitan area. The metropolitan group collaborated with a government department and the regional group was conducted by the local Aboriginal Controlled Community Health Service (ACCHS). The government department had an Aboriginal program director and provided an Aboriginal project officer to support the metropolitan group. Both groups were supported by Aboriginal health workers and non-Aboriginal health workers (physiotherapist and exercise physiologist, program assistants, research assistants) as an operational team. Non-Aboriginal health workers who had undertaken previous work with the Aboriginal Elders were recruited to the team. These workers were guided by their own cultural competency training and worked closely with the Aboriginal team members, so they were mindful of awareness of ways of working with Aboriginal Elders.

The program was operated in local community centers which were culturally safe spaces. These centers were used by other local Aboriginal people for their cultural activities and multi-cultural activities that the local Aboriginal Community participated in, so they felt comfortable in using these venues. Both venues were open and welcoming of the program, and offered use of suitable rooms. There was a regular traffic of Aboriginal faces coming in and out of both community centers. The project officer at the metropolitan group and the ACCHO in the regional setting, both in consultation with the Elders, discussed the venue and Elders provided confirmation that the venue was suitable after attending for several weeks.

Intervention

Ironbark means standing tall and strong like the Ironbark tree (32). The Ironbark program in NSW was named this as part of developing the program. After discussion, this name was retained for the project in WA, because WA has the same Ironbark tree with different colored flowers. The Ironbark was a weekly program that included PA and

yarning, along with morning tea. The research team adapted the original material from NSW Ironbark program to suit the preferences of Aboriginal Elders residing on Noongar Country and referenced a holistic, decolonizing approach to implement it. This decolonizing approach was about understanding the challenges and complexities of working with Aboriginal Elders on Noongar Country and recognizing it is a positive strategy toward providing better supportive and stronger research practices that will benefit both the community and the researcher. Too often in the past research was done without the informing, the approval and consent of Aboriginal people and evaluations resulted in recommendations and decisions made about Aboriginal people by non-Aboriginal people which almost always failed (4). Decolonization is also about understanding the relational aspects of communities that are important, respectfully understanding the diversity that exists within communities and groups, and always collaborating with them, enabling their voices to be heard, particularly in our research, the decision-making aspects of the weekly PA program (29, 33). Aboriginal health workers at both sites endeavored to make the PA program as comfortable as possible for the Elders by providing group and individual support for all aspects of attendance and participation. They worked with each Elder to ensure that they were comfortable doing the exercises and this continued until they were confident to do them. The program focused on exercises that have been shown to be effective in reducing falls, namely exercises that have a strong balance and functional component (34). This 1-h exercise component was delivered alongside yarning circles (35). Yarning is a respectful and culturally acceptable way to engage with Elders, for it helps to improve and build lasting relationships simply by honoring the Elders through actively listening (36). The exercises were led by the health professionals who provided the exercise training supported by Aboriginal health workers, in a space that was culturally safe and secure. Each session commenced with a warm-up, then included a variety of lifting light weights, ball activities, balance and strength exercises, as well as walking and occasional dancing (in modern, casual style) to music. Individual advice regarding exercise was provided as appropriate for participants by the attending health professional. A home exercise program (HEP) was prescribed based on the exercises done in the group. Participants were given handouts of the exercises and encouraged to complete their HEP twice weekly. Health educational topics relevant to fall prevention were discussed in the yarning circle using topics in the Ironbark manual (37). In the WA translation of the Ironbark program, participating Elders assisted to plan the schedule for yarning sessions and chose additional topics they felt were relevant to their needs, including those that focused on managing their health. Asthma, diabetes, heart disease and cancer were examples of popular topics for discussions. Yarning circles were facilitated each week by the Aboriginal project officer or Aboriginal health workers.

Outcomes

Health outcomes evaluated were:

(i) Physical function - measured using the Short Physical Performance Battery (SPPB) (38). This is a hierarchical test of standing balance, participants' usual gait speed, and lower limb strength (standing five times from a seated position in a chair). Each test is scored on a 0–4 scale and summed for an overall score range of 0–12, with zero indicating the lowest physical performance, and 12 indicating the highest performance. Gait speed and lower limb strength were also evaluated as individual measures since both are measures of independent physical function in older adults (39).

(ii) Functional mobility - measured using the timed up and go (TUG) test that measures the time it takes in seconds for a person to stand from a chair and walk three meters, turn around, return to the chair, and sit down (40).

(iii) Cardiovascular health–measured by waist circumference (cm) which is an easy anthropometric measure that predicts cardiovascular disease (41). Weight (kgs) was also measured since exercise is known to be an effective means of reducing weight (42), which can in turn improve cardiovascular risk profiles (43).

(iv) Falls self-efficacy–measured participants' concern about falling using the Short Falls Efficacy Scale International (Short FES-1) (44), where a minimum score of 7 indicates no concern about falling, and a maximum score of 28 indicates severe concern. Since the Ironbark was designed as a fall prevention program it was felt that participants' concern about falling might be impacted by the program.

(v) Health related quality of life (HRQoL)–measured using the Assessment of Quality of Life (AQoL-4) instrument (score range 12–48, lower score indicates better HRQoL) (45). This instrument has been validated and found to be reliable in Australian populations and has been tested in an Aboriginal and Torres Strait Islander population (46).

Participants' feedback about the program was undertaken using a questionnaire and "yarning" to capture the cultural appropriateness of the PA program and how it could be improved. These types of feedback had previously been used by researchers to evaluate the pilot trial that was conducted in NSW (10). The questionnaire contained closed-ended and open-ended items. It aimed to seek participants' feedback about whether they found the program relevant, useful, and culturally appropriate and gather suggestions for any changes to the program. The feedback provided by participants through yarning about the PA program has been reported separately (26).

Demographic data gathered at baseline included age gender, language, education, number of health conditions, history of falls (defined as "an event which results in a person coming to rest inadvertently on the ground or floor or other lower level") (47), exercise in the past 12 months, and number of prescribed medications taken. The number of medications was considered a feasible measure to collect as a surrogate marker of chronic disease (48).

Procedure

Aspects of the procedure have been described previously (26). Briefly, the development of the research procedure was underpinned by the guidelines for ethical conduct for conducting research in Aboriginal and Torres Strait Islander Peoples and Communities (49). Consultation with WA Aboriginal communities occurred prior to program commencement.

Initially researchers from NSW met in WA with Aboriginal led organizations and interested researchers, including senior Aboriginal researchers (MK and JC) from both NSW and WA. This was undertaken through local Aboriginal organizations in Perth and a number of Aboriginal Controlled Community Health Organizations (ACCHO) in regional areas. These organizations include local Elders and, more broadly, community representation. The success of the Ironbark program in NSW and interest in having a similar program for Elders in WA was discussed and both groups sought more feedback from their communities. Meetings were flexible in time and frequency depending on questions that arose and communication occurred throughout these preparation phases. This included the senior WA researchers (one Aboriginal–MK, one non-Aboriginal–AMH) meeting with community Elders by meetings arranged through the two interested organizations. After ∼2 years of formal and informal consultations it was agreed to form two groups that would evaluate the program. The final team, including one ACCHO, one WA government department that led Aboriginal public health strategy, the original NSW Ironbark researchers and WA researchers was formed and AMH and MK led applications for funding for the research. When the program was operationalized each Elder's group developed their own terms of reference. This described their values and expectations about how the program would be conducted to meet the needs of the community (21). Understanding that one's own cultural beliefs, values, attitudes and practices may vary considerably and being able to accept and be respectful of these differences was fundamental (18, 50). Having knowledge of the history of older Aboriginal and Torres Strait Islander peoples which includes trauma, loss and illness, means that steps can be taken toward mutual understanding and building partnerships for more respectful and meaningful communication, leading to successful outcomes (3, 4).

Health outcomes were measured at baseline, six, and 12 months and a final assessment was completed at 24 months at the conclusion of the program. Outcome measurement days were led by the Aboriginal student researcher, who was experienced at leading data collection in communities, with the physical outcome assessments being supervised by the lead physiotherapist researcher. Participants were administered the feedback questionnaire at the 12 months timepoint, or if they were not available at the 12-month timepoint they were asked to answer the questionnaire at the 24-month timepoint. Data collection was supported by the Aboriginal health workers, the Aboriginal project officer and Aboriginal research assistants. Training for health workers and research team assistants to assist with the data collection was provided prior to program commencement and at intervals throughout the program. The Ironbark research team from NSW and WA completed training together prior to the PA program commencement in the South West of WA. This combined team was made up of an Aboriginal researcher (JC) who was the former advisor of the original Ironbark training, the WA Aboriginal lead researcher (MJRG) and the WA Aboriginal project officer and Aboriginal project officers and health workers who would be present at both Elders' groups during the 2-year PA program.

Statistical Analysis

Analyses were completed using STATA version 17.1 (StataCorp. 2019, Stata Statistical Software: Release 17. College Station, TX: StataCorp LLC). All data from both regional and metropolitan groups were combined for analysis. All health outcomes data were summarized using descriptive statistics and presented using frequency distributions for categorical data and means and standard deviations or medians and interquartile ranges (IQR) for continuous data. Linear mixed models and mixed effects negative binomial models, with random subject effects, were used to examine longitudinal continuous and count outcomes over four timepoints (baseline, six, 12 and 24 months). Model results were summarized using marginal mean estimates and 95% confidence intervals. As mixed effects models use maximum likelihood estimation to estimate parameters based on assumed probability distributions, all available data points, regardless of missing timepoints, were included in analysis. Data obtained from the feedback questionnaire were summarized using descriptive statistics. Data from open-ended questions were coded and summarized using frequency and percentages.

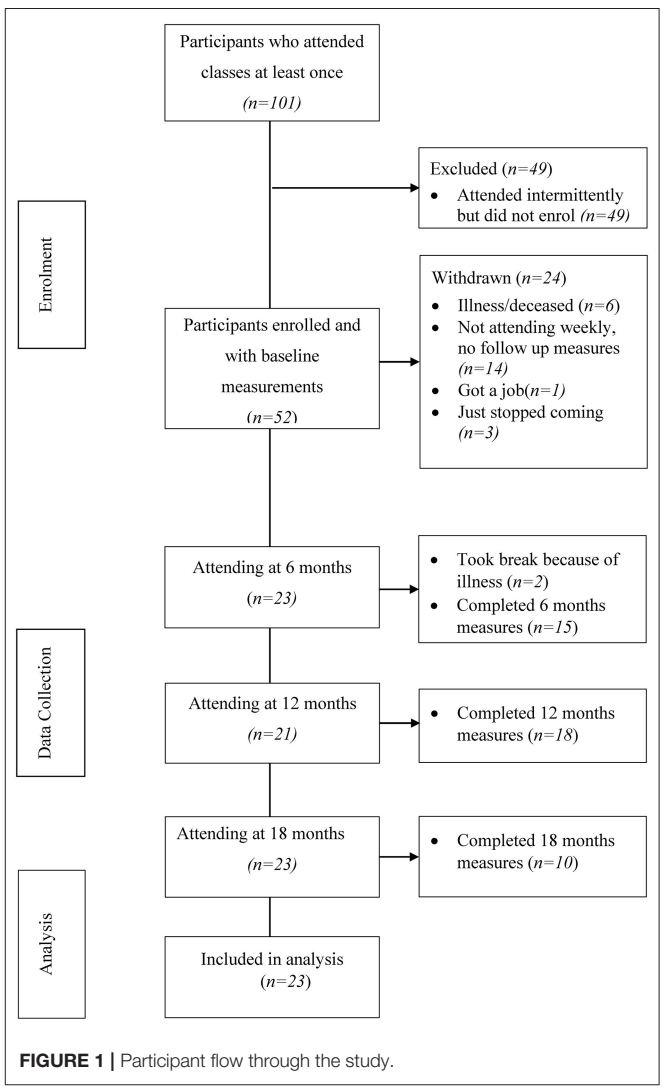

FIGURE 1 | Participant flow through the study.

TABLE 1 | Participants' characteristics ($n = 23$).

Characteristic	*N* (%)
Site *n* (%)	
Regional	13 (56.52)
Metropolitan	10 (43.48)
Age, mean (SD), years	62.5 (10.85)
Gender, female, *n* (%)	21 (91.3%)
Language, *n* (%)	
English spoken as first language	22 (95.65)
Education, *n* (%)	
Primary school	4 (17.39)
Completed year 10	8 (34.78)
Completed year 12	4 (17.39)
Completed higher education	7 (30.43)
Falls history, *n* (%)	
Falls in the last 12 months	7 (30.43)
Injury from fall, *n* %	4 (57.14)
Attended an exercise class in last 12 months[a], *n* %	5 (21.73)
Medications	
Number of medications, median (IQR)	4 (3–5)
More than four medications, *n* (%)	10 (43.47)
Primary medical conditions[b], *n* (%)	
Respiratory condition	3 (13)
Diabetes	6 (26)
Musculoskeletal (low back pain, gout arthritis)	3 (13.04)
Cardiovascular disease (including hypertension)	12 (52.17)
Other medical conditions[c]	13 (56.52)

[a] *At least once per week in the last 3 months.*
[b] *Participants could have more than one health condition.*
[c] *Including cancer, renal disease, depression.*

Sample Size

For a within group repeated measures ANOVA over four timepoints a sample of $n = 12$ has 90% power to detect an effect size $f = 0.41$. Feedback from the community partners suggested that it would be reasonable to expect each group to consist of between 7 and 10 regular participants.

RESULTS

Program Delivery

There were 46 sessions delivered in year one of the program and 25 sessions in year two at the metropolitan site (36/31 in the regional site). Sessions were timed to fit into school terms with some gaps in school holidays and around public holidays. The reduction in sessions in year two was due to the COVID pandemic lockdown.

Participant Flow Through the Study

The flow of participants through the study is presented in **Figure 1**. There were 52 older Aboriginal people who enrolled and undertook baseline measurements, of these 14 (26.9%) did not attend the groups regularly, 6 participants withdrew due to medical illness or died, while 3 stopped attending with no reason stated. There were 23 participants who regularly attended the two groups. Fourteen (60%) participants attended at least 50% of all weekly sessions over the 2 years and 9 (40%) attended between 30 and 40% of sessions. All available participant data were included in analyses. Participants' characteristics are presented in **Table 1**. Participants had a mean age of 62 (±10.8) years and 21 (91.3%) participants were female. Participants took a median (interquartile range) of four (3–5) medications.

Health Outcomes Measurements

Predicted marginal means for physical function (SPPB, gait speed, lower limb strength), functional mobility (TUG test), cardiovascular health (waist circumference, weight), falls self-efficacy (Short FES-1) and HRQoL (AQOL-4D) at time points of six, 12 and 24 months compared to baseline are presented in **Table 2**.

Physical Function

Physical function measures are summarized in **Figure 2**, with comparisons between baseline and follow-up periods presented in **Table 2**. Physical function (as measured by the SPPB) significantly improved at 12 months compared to baseline. Scores were also improved at 24 months compared to baseline, but the improvement was not significant. Gait speed showed significant improvement at 12 and 24 months compared to baseline. Lower limb strength (chair stand test) was significantly improved at 6 and 12 months compared to baseline. Functional mobility showed significant improvement at 12months compared to baseline.

Cardiovascular Risk Factors

Cardiovascular risk factors are summarized in **Figure 3**, with comparisons between baseline and follow-up periods presented in **Table 2**. There were improvements in cardiovascular risk factors (waist circumference and weight) at 6, 12 and 24 months compared to baseline, but these changes were not significant.

Falls Self-Efficacy and Health-Related Quality of Life

Falls self-efficacy and HRQoL are summarized in **Figure 4** with comparisons between baseline and follow-up periods presented in **Table 2**. Falls self-efficacy significantly declined at 12 months compared to baseline. Further analysis of this outcome was conducted by using linear mixed models with random subject effects to examine FES scores at 24 months compared to 12 months as compared to baseline. Results demonstrated that falls self- efficacy scores at 24 months significantly improved compared to 12 months [mean score at 24 months: 7.90 (95% CI 4.65, 11.14) compared to 12 months: 11.89 (95% CI 9.84, 13.93): $p = 0.03$], with participants' scores returning to less than baseline levels. HRQoL was significantly declined at 12 months compared to baseline, but not at 24 months.

Participants' Feedback Regarding the PA Program

Participant feedback regarding the program is presented in **Table 3**. Eighteen participants provided feedback at the 12-month timepoint and five at 24 months. All participants enjoyed

TABLE 2 | Predicted marginal mean health outcomes over four time points.

	Margins	95% CI Lower	95% CI Upper	*P*-value*
Short physical performance battery (SPPB score range 0–12)[#]				
Baseline	8.85	8.10	9.61	
6 m	9.55	8.69	10.41	0.110
12 m	10.28	9.44	11.13	<0.001
24 m	9.60	8.59	10.60	0.140
Gait speed (meters/second)[&]				
Baseline	0.81	0.69	0.93	
6 m	0.75	0.61	0.88	0.340
12 m	1.14	1.01	1.27	<0.001
24 m	1.11	0.95	1.26	<0.001
Chair stand test (seconds)[$]				
Baseline	17.13	14.93	19.33	
6 m	13.11	10.84	15.38	0.006
12 m	13.53	11.40	15.67	0.008
24 m	14.42	11.66	17.18	0.100
Timed up and go test, (seconds)[$]				
Baseline	11.62	9.40	13.84	
6 m	10.46	8.11	12.81	0.330
12 m	8.79	6.77	10.82	0.010
24 m	10.63	7.89	13.38	0.490
Waist circumference (cm)				
Baseline	111.36	102.93	119.79	
6 m	107.19	98.42	115.95	0.060
12 m	109.02	100.30	117.73	0.270
24 m	107.97	98.86	117.08	0.180
Weight (kg)				
Baseline	82.94	73.12	92.75	
6 m	81.17	71.11	91.23	0.320
12 m	82.24	72.33	92.15	0.640
24 m	80.65	70.49	90.81	0.230
Falls self-efficacy (FES-1, score range 7–28)[±]				
Baseline (ref)	8.77	6.87	10.67	
6 m	10.81	8.42	13.21	0.170
12 m	11.89	9.84	13.93	0.020
24 m	7.90	4.65	11.14	0.640
Health-related quality of life, (AQOL-4D score range 12–48)[€]				
Baseline	16.48	14.57	18.38	
6 m	16.94	14.83	19.05	0.580
12 m	17.95	15.98	19.93	0.030
24 m	17.24	14.68	19.79	0.480

**Mean comparison from baseline; [#]SPPB score range 0–12, higher score indicates better mobility; [&]faster speed indicates better mobility; [$]faster time indicates better mobility; [±]FES-1 score range 7–28, low score indicates no concern, maximum score of 28 indicates severe concern about falling; [€]AQOL-4D score range 12–48, lower score indicates better HRQoL.*

the program and agreed that it was culturally appropriate. Some participants [$n = 14$, (82.6%)] were willing to pay a fee to continue engaging in the program, while four participants were not. Most participants suggested they would be willing to pay a fee of $5, with four participants suggesting one dollar and one participant suggesting $10. Almost all participants suggested at least one improvement that could be enacted in the program. Improvements that were suggested were more outdoor activity [$n = 12$, (52.2%)], more exercises ($n = 6$), a different venue ($n = 5$) and a larger group ($n = 4$). Participants who reported improvements in their health ($n = 19$, (82.6%)] reported improved balance, confidence and a renewed desire to walk more, particularly in public places. Some participants ($n = 7$) responded that they found it difficult to complete their home program. Reasons for not completing home program were: not liking to walk alone, not liking walking at all, lack of motivation or doing other exercises outside of home and family commitments.

DISCUSSION

Aboriginal Elders on Noongar Boodjar (Country) who participated in a 2-year PA program made significant improvements in physical function. Participants showed significant improvement in gait speed, lower limb strength and functional mobility at 12 months. These changes were reflected in the improvement in the SPPB (a composite measure of physical ability) with scores increasing from 8.8 at baseline to 10.28 at 12 months. Since a score lower than 10 is predictive of all-cause mortality, these changes demonstrate how the program was of positive benefit to participants' health (51). Mean gait speed significantly improved up to 24 months (1.11 m/s) compared to baseline (0.81 m/s) showing the program led to some sustained physical improvements. Baseline gait speed was below normative values for age-matched older adults' community walking speed but speed at both 12 and 24 months aligned with normative community values (52). Gait speed is predictive of functional ability and general wellbeing (53). In the delivery of the NSW Ironbark program gait speed improved to 0.94 m/s (10), however the NSW program ran for 6 months whereas our program continued for 24 months. Our findings suggest that with resources to run the program for longer, older Aboriginal and Torres Strait Islander adults may make even greater improvement. There was some decrease in physical function overall at 24 months compared to 12 months including the SPPB, TUG test and chair stand test. This corresponded with the closure of the program during the COVID 19 pandemic. However, after participants returned to the program improvement was still observable at 24 months compared to baseline in most measures. Our results concur with other studies that have evaluated PA programs for older Indigenous peoples (10, 11, 14, 54).

Cardiovascular risk factors (both waist circumference and weight) improved throughout the trial, even after the gap in program delivery in the second year, although not significantly. In the NSW Ironbark program participants showed a significant improvement in BMI. The WA program ran over 2 years

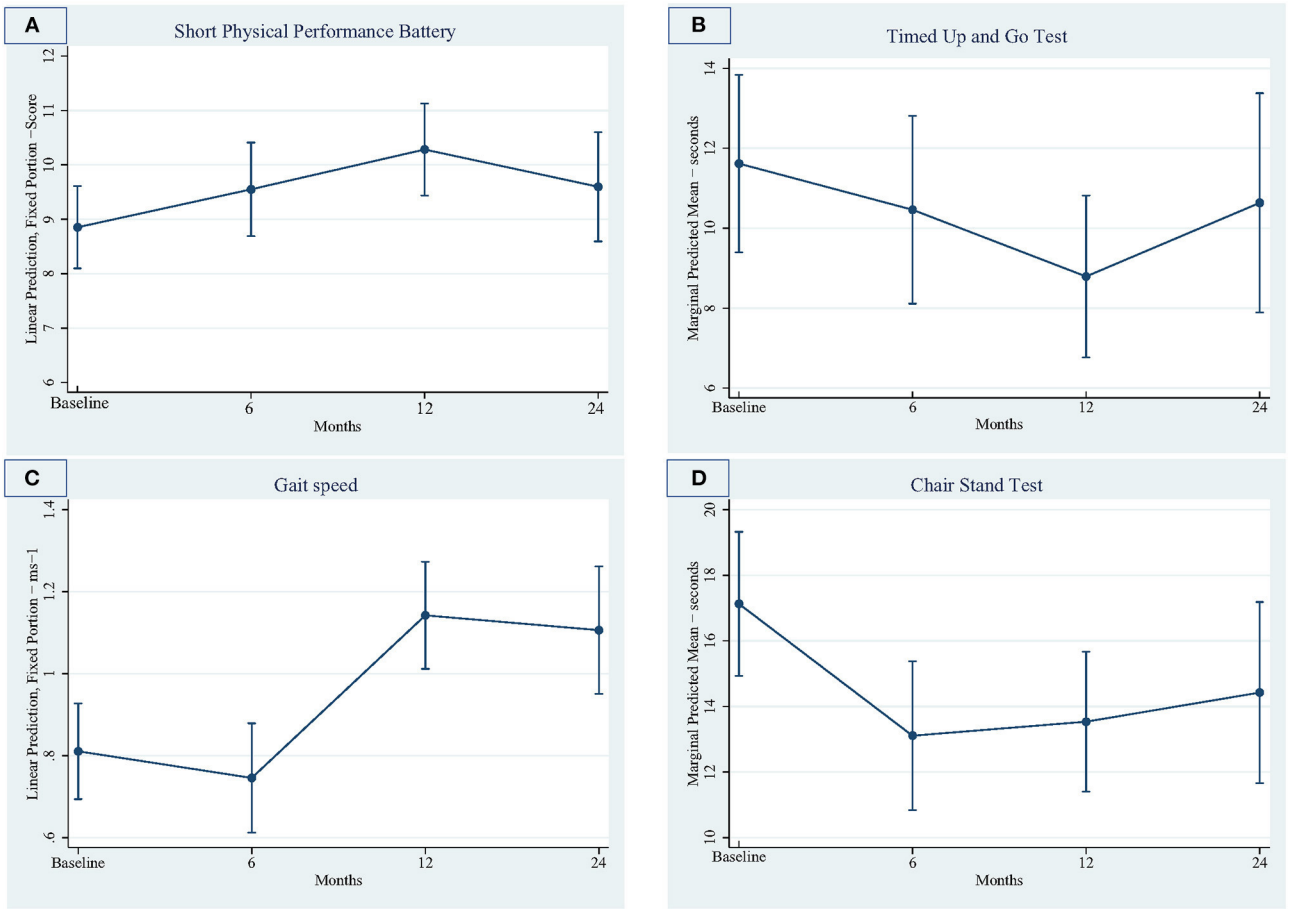

FIGURE 2 | Physical function outcomes over four timepoints. **(A)** Short physical performance battery, **(B)** Timed up and go test, **(C)** Gait speed, **(D)** Chair stand test.

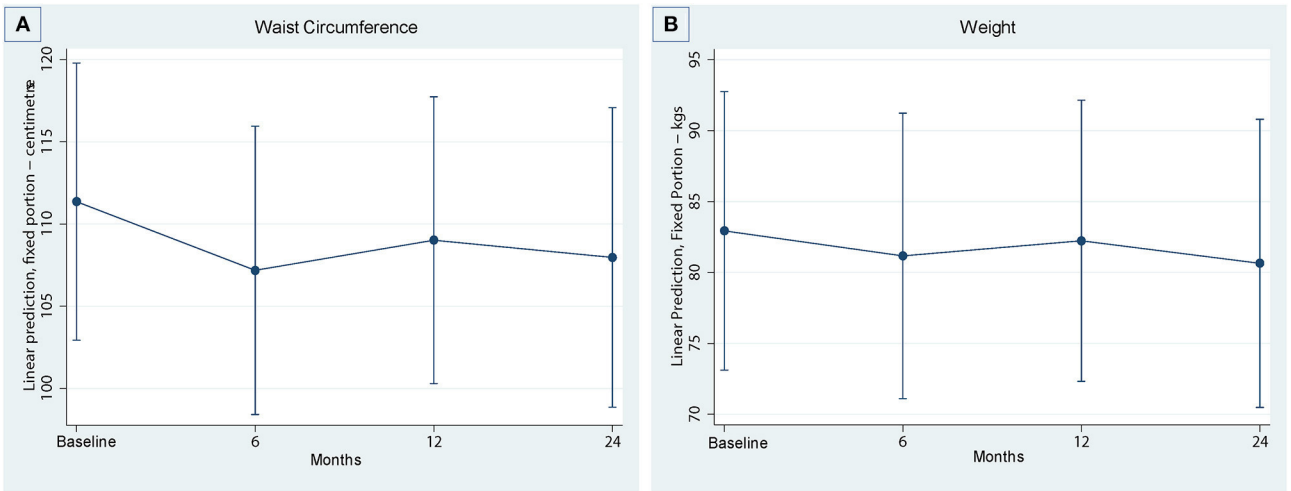

FIGURE 3 | Cardiovascular outcomes over four timepoints. **(A)** Waistcircumference, **(B)** Weight.

and there were some sessions on nutrition, similar to the NSW program (10). Our program may have benefited from additional nutrition-focused interventions to increase impact on cardiovascular risk factors, since diet is known to impact on

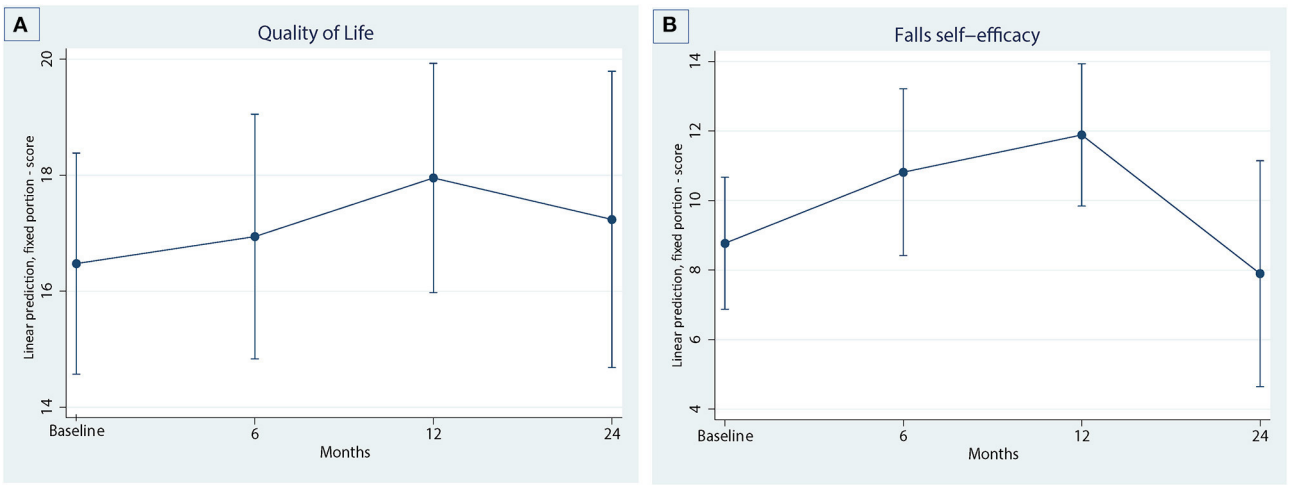

FIGURE 4 | Quality of life outcomes over four timepoints. **(A)** Quality of life, **(B)** Falls self-efficacy.

cardiovascular health (42). We also found that HRQoL showed small but significant decline at 12 months compared to baseline, and while improved at was still declined at 24 months compared to below baseline measures. This could have been due to the COVID pandemic as the social restrictions and class closure occurred at around the 12- month to 18-month time period of the program. COVID pandemic impacts on communities are known to have caused adverse effects on mental health for populations internationally (55).

Elders' Feedback and Program Translation

Elders' feedback regarding the program was highly positive. Participants stated the program was excellent and culturally appropriate and they reported feelings of confidence that developed from the program. This was important as Aboriginal and Torres Strait Islander people are not likely to attend health services that are not provided in a culturally appropriate manner (18, 56). Previous research has found that Indigenous peoples know what their health burdens are and there needs to be a partnership approach to addressing existing barriers that prevent Indigenous participation in PA programs (18, 25, 56). Researchers should seek to actively listen to the voices of Indigenous people when building meaningful, culturally appropriate service provision and delivery for Indigenous populations (18, 25). PA programs should be designed using an Indigenous perspective, that ensures a decolonizing approach is taken. This will include elements of appropriate engagement, building leadership qualities, giving and receiving respect and providing a safe place for "yarning" as part of its conception. These qualities help improve communication and address the social determinants of health for disadvantaged people and communities, making the program more likely to succeed (18, 21, 56). Planning programs that take account of cultural identities is fundamental to ongoing program success (57, 58). Our findings are supported by other research that has found that PA programs designed with a decolonizing approach have successful outcomes among Indigenous peoples (11, 12, 18, 19). We noted the Elders commented on cost, and future translation needs to continue to address subsidizing the cost of PA programs. Effects of colonization have caused ongoing negative effects on social determinants of health, including education, employment and access to health services (3). A recent Australian national report summarizes that social determinants of health strongly impact on Aboriginal and Torres Strait Islander peoples' health. Aboriginal and Torres Strait Islanders who are more advantaged across social and economic measure have better health (59).

The success of the translation of the Ironbark program was that it was developed with the fundamentals of Aboriginal research methodology (24, 30). This research is the first to our knowledge to translate a culturally appropriate PA program for Aboriginal peoples in the South West of WA. Our PA program (the Ironbark program) was able to be successfully tailored for older Aboriginal people in WA because it took a working together approach, which included recognizing cultural identities. In order to provide better solutions for Indigenous communities, there needs to be an incorporation of "ways of working" from an Indigenous perspective that acknowledges language and customs and provides strong development of a culturally safe space (2, 4).

Strengths and Limitations of the Research

Strengths of the program were the culturally appropriate design which led to Elders attending regularly, with feedback showing that 22 of the 23 Elders thought it was culturally appropriate and wanted to keep attending the program. The physical outcomes were measured at regular timepoints by trained Aboriginal health workers assisted by health professionals, using validated and reliable measures of physical function (38). Hence evidence for physical improvement was robust. A major strength of the study is to the authors' knowledge it is the first study to evaluate

TABLE 3 | Participants' feedback about the program ($n = 23$).

No	Question	Response	*n* (%)
1	Is the program relevant to your needs?	Very relevant	18 (78.26)
		Somewhat relevant	5 (21.74)
2	Was the group discussion useful?	Very useful	17 (73.92)
		Somewhat useful	6 (26.08)
3	How much did you know about falls prevention before the program?	Had some idea	11 (47.83)
		Already knew a lot	5 (21.74)
		Not much or nothing at all	7 (30.43)
4	How much do you know about falls prevention now the program has finished?	A lot	22 (95.65)
		Nothing at all	1 (4.35)
5	Was the venue suitable?	Very suitable	21 (91.30)
		Somewhat / not at all	2 (8.70)
6	Was the program culturally appropriate?	Yes	22 (95.65)
		Somewhat	1 (4.35)
7	Did you have time to come to every session?	Yes	20 (86.95)
		No	3 (13.05)
8	Would you like to continue being involved in the program?[#]	Yes	22 (95.65)
9*	Would you be willing to pay a small fee to keep the program running?[&]	Yes	19 (82.60)
		Not sure	2 (8.69)
10	Was transport to the program a problem for you at any stage? [&]	No	20 (86.95)
		Yes	1 (4.34)
11	Has this program improved your confidence with walking?[#]	Yes	20 (86.95)
		Unsure	2 (8.69)
12*	Do you feel your health has improved since attending the program?[#]	Yes	19 (82.60)
		No	1 (4.34)
		Not sure	2 (8.69)
13*	Were you able to complete your home exercises? [&]	Yes	16 (69.56)
		No	5 (21.73)
14	Would you recommend this program to others?[#]	Yes	22 (95.65)

[*] *Participants could also provide an open-ended response to this item;* [#] *Missing data n = 1;* [&] *Missing data n = 2.*

the effect of a culturally appropriate PA intervention on the physical function of Aboriginal Elders living on Noongar Boodjar (Country).

A major strength of the Ironbark PA program in the South West of WA was that the majority of the program team were Aboriginal people who partnered with non-Aboriginal team members to implement and facilitate the exercise and yarning circles. The program was a unique opportunity that enabled older Aboriginal people to take part in PA, because it was culturally acceptable. We delivered the program using an Indigenous "ways of working" approach, that was relevant to the two communities. Maintaining strong relationships throughout the research was fundamental to its success. The research was only undertaken after an extensive 2-year community consultation that enabled Aboriginal and non-Aboriginal researchers to work closely together in a manner that privileged Aboriginal people's worldviews (27). Extensive consultation with Aboriginal community groups is an important requisite to being able to honor ways of being, knowing and doing (56).

There was a major disruption to program delivery due to the COVID 19 pandemic in 2020. The main social restrictions period of over 4 months prevented program delivery, with subsequent delay in recommencement due to new program requirements that needed to be operationalized. The research team provided support by telephone and text messages, with the aim of providing mental health support and encouraging Elders to continue their home exercises and managing their health. Elders provided Facebook support to each other through these difficult times, which was felt to contribute to participants resuming regular attendance when the program recommenced. A limitation of the research was that we did not collect data that measured the amount of home exercise that participants completed. Another limitation was that we did not re-assess participants when they returned to the program at 18 months after a 6 month pause in the program. Requirements related to COVID restrictions were perceived as causing significant increased procedural burden to both staff and participants and it was felt important to recommence the program with as few barriers as possible.

To avoid participants and staff burden in future programs, it could be useful to undertake a single, simple weekly assessment that rates improvement, rather than multiple assessments. Elders who enrolled were always not able to attend weekly due to medical appointments, family commitments or community relationships. More flexibility in the program delivery might assist with these barriers. Our study was limited to providing one class per week. Additionally, not all Elders attended the program and it could be because they were not favorably disposed to the program. Also, not all Elders chose to enroll in the study or provide feedback about the Ironbark program even though they intermittently attended and participated. It would be valuable for future translation of the program, to gain these Elders' perspectives about how the program could be improved or tailored to increase regular attendance.

The research did not use an experimental design. Since the benefits of exercise for older adults are well-established (5). The Ironbark project in WA, of which this study formed a component, took an implementation science approach which asks how can established evidence be translated into clinical practice (60). No control group is a limitation as Elders may have made improvements without attending the program, although very few of the Elders reported engaging in other PA programs prior to or during our program. Elders provided valuable perspectives on the Ironbark program. It is also important to consider the views of the communities and key stakeholders about what they saw and felt was relevant to the success of the program (26, 56, 61). A future study to explore these perspectives is planned.

CONCLUSION

Few PA programs are designed specifically for older Aboriginal and Torres Strait Islander peoples. Westernized health care delivery has not addressed and acknowledged the impacts of colonization which has created exclusion, and exposure to inequalities of health service delivery (2–4). Translating the Ironbark PA Program into the South West of WA with two older Aboriginal communities was successful because there was Aboriginal leadership and strong relationship building. The program provided a unique opportunity not previously available for older Aboriginal people. Participants demonstrated positive changes in their health and wellbeing, including significant improvements in physical function. The groups' success highlighted that having a culturally appropriate PA program that is flexible and designed with a decolonizing approach can attract and retain older Aboriginal people who are seeking to improve their health and wellbeing. The learnings from translating this PA program could be of assistance to other communities and researchers who are seeking to promote PA with older Aboriginal and Torres Strait Islander peoples. The Ironbark PA program was a positive step toward breaking down barriers and building strategies toward closing the gap in health disparities for Indigenous peoples worldwide. Encouraging leadership by the Elders throughout the program was part of the decolonizing approach of the program that led to its success. Further research that partners with Aboriginal and Torres Strait Islanders Elders and communities to expand culturally appropriate PA programs is required.

TERMINOLOGY

Acknowledgment of Boodjar (Country): Authors acknowledge that this research was conducted on Noongar Country. We respectfully acknowledge the Noongar peoples as the Traditional Owners of Country in the South West of Western Australia (WA), where this research has been conducted. We recognize Indigenous peoples of all Nations' continuing connection to lands, waters, and communities. We pay our respects to all Indigenous Elders past and present. Authors respectfully acknowledge all the Aboriginal and Torres Strait Islander communities and Nations who contributed knowledge to this research.

Terms used by the authors: When describing the setting and interviews authors have chosen the words Noongar, acknowledging that there are many different Boodjars of Noongar people in the South West of WA. The term Aboriginal Elders is used when discussing all participants, as the groups included Aboriginal Elders from more than one Boodjars in WA, as well as Nations in other States of Australia. Elders is used as a term for all participants, respecting their knowledge and age in the community. When discussing studies from other countries the authors have respectfully used the authors' descriptions of the participants and their Nations. When discussing Australian studies in general from around Australia, the term Aboriginal and Torres Strait Islanders is used. When discussing research methodology in general and Indigenous peoples worldwide, the term Indigenous is used.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

Ethics approvals for the study were obtained from WA Aboriginal Health Ethics Committee (HE 842) and Curtin University (HE number 2018-0425). All participants provided written, informed consent prior to participating in the study.

AUTHOR CONTRIBUTIONS

MJRG led the original drafting of the manuscript. A-MH led the study conception and design with MK, RI, JC, KH,

MJRG, NB, VP, and AJ. MJRG led study procedures including ethics procedures, program delivery and data collection and management, with assistance from A-MH, TW, MK, VP, and NB. MJRG and A-MH completed statistical analyses with oversight and assistance from AJ. Revisions to the manuscript were addressed by A-MH and MJRG and approved by all authors for the final revised version of the manuscript.

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Association of vision and hearing status with depressive symptoms among middle-aged and older Chinese adults

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Objective: Long-term untreated vision and hearing impairments can negatively impact physical and mental wellbeing. We investigated the association of vision and hearing status with depressive symptoms among middle-aged and older Chinese adults.

Methods: This was a prospective cohort study of 9,492 participants from the China Health and Retirement Longitudinal Study (CHARLS) carried out in 2011, 2013, 2015, and 2018. This study used self-reported vision and hearing status to determine the degree of impairment. Depressive symptoms were examined using the 10-item Center for Epidemiologic Studies Depression Scale (CESD-10), with a total score of $\geq$ 12 indicating depressive symptoms. A Cox proportional hazards model adjusted for age, sex, residence, marital status, educational level, smoking history, alcohol consumption, hypertension, diabetes, heart disease, digestive disease, arthritis, wearing glasses, and hearing aids was used to estimate the association of vision and hearing status with depressive symptoms among middle-aged and older Chinese adults.

Results: Of the 9,492 participants [mean (SD) age at CHARLS baseline, 58.12 (9.00) years], 3,238 (34.11%) participants reported incident depressive symptoms during the 7-year follow-up period. Participants who self-reported only vision impairment [hazard ratios (HR): 1.14, 95% confidence intervals (CI): 1.05–1.24], only hearing impairment (HR: 1.24, 95% CI: 1.06–1.46), and both vision and hearing impairments (HR: 1.25, 95% CI: 1.08–1.45) were independently associated with a greater increase in the hazard risk of incident depressive symptoms compared to those without vision and hearing impairments. An increase in participants' vision and hearing scores was associated with a significant increase in the hazard risk of incident depressive symptoms (HR: 1.04, 95% CI: 1.03–1.06).

Conclusion: Vision and hearing status was associated with increased depressive symptoms among middle-aged and older Chinese adults during the 7-year follow-up period. Participants' use of glasses and hearing aids did not improve their depressive symptoms.

Our findings may facilitate the development of effective treatments to prevent and treat vision and hearing impairments, thereby enhancing the physical and mental wellbeing of middle-aged and older adults.

KEYWORDS

vision impairment, hearing impairment, depressive symptoms, older adults, China

Introduction

Vision and hearing impairments are common among middle-aged and older adults but are typically neglected or dismissed as a natural part of aging (1). The prevalence of vision and hearing impairments among middle-aged and older adults is high and is expected to further increase with the growth of the aging population (2, 3). The Global Burden of Disease (GBD) project results suggest that the prevalence of child and adult hearing impairment is substantially higher in middle- and low-income countries than in high-income countries, demonstrating the global need for attention to hearing impairment (4). According to a 2015 cross-sectional study, individuals' self-reported prevalence of vision and hearing impairments was higher in China than in European countries and the United States (5, 6). Despite the higher prevalence of vision and hearing impairments among middle-aged and older Chinese adults, most cases remain untreated. Accordingly, there is an urgent need to address the negative effects of vision and hearing impairments on physical and mental health.

Mental health among middle-aged and older adults often includes depressive symptoms, the risk of which increases with age (7). Indeed, previous studies estimated that ∼20% of elderly individuals experience depressive symptoms (8). The prevalence of depressive symptoms among older adults with vision and/or hearing impairments is estimated to be 10–30%. Crucially, depressive symptoms may negatively impact the quality of life among elderly individuals (9). Most previous studies found that age, gender, location, chronic conditional diseases, physical activity, social isolation, IADL impairment, life satisfaction, and physical health are linked to depressive symptoms (10–12). Previous studies have indicated that vision and hearing impairments are of relevance in this regard, as vision and hearing-impaired older adults are more likely to develop depressive symptoms compared to those without vision and hearing impairments. Collectively, the literature suggests that vision and hearing impairments among older adults are associated with a higher risk of depressive symptoms compared to that among non-impaired older adults (5, 11, 12). Furthermore, the number of middle-aged and older adults with vision and/or hearing impairments in China is high. Notably, older adults with vision and/or hearing impairments receive insufficient medical care largely due to poor recognition, which highlights the need for adequate attention to be paid to this vulnerable population in conjunction with effective interventions.

Most previous studies that focused on the effects of vision and hearing impairments on depressive symptoms were conducted in developed countries and yielded mixed results. A systematic review reported the inability to perform a meta-analysis or establish a clear association between vision impairments and depressive symptoms in elderly individuals (13). Several cross-sectional studies have investigated the association of vision and hearing impairments with depressive symptoms among older Chinese adults (5). Nevertheless, no prospective cohort studies to date have examined the association of vision and hearing impairments with depressive symptoms in the elderly Chinese population. Accordingly, this study explored the hazard risk between vision and hearing status and depressive symptoms based on the China Health and Retirement Longitudinal Study (CHARLS) from 2011 (Wave 1) to 2018 (Wave 4). In this study, we hypothesized that: (1) compared to participants without vision and hearing impairment, participants with only vision impairment, only hearing impairment, and both vision and hearing impairment would have a significantly higher risk of depressive symptoms; (2) the hazard risk between vision and/or hearing impairments and depressive symptoms would persist even after adjusting for all risk factors (sociodemographic, lifestyle, and five types of chronic conditional diseases); (3) an increase in participants' vision and hearing scores would be associated with a greater increase in the risk of incident depressive symptoms among middle-aged and older adults; and (4) the effect size of wearing glasses and hearing aids would be implicated in the occurrence of depressive symptoms.

Methods

Data and participants

The CHARLS data utilized in this study were obtained in 2011 (Wave 1), 2013 (Wave 2), 2015 (Wave 3), and 2018 (Wave 4) (14). The CHARLS waves constituted a nationally representative longitudinal study that collected information regarding the demographic background, health status and functioning, and depressive symptoms of Chinese individuals

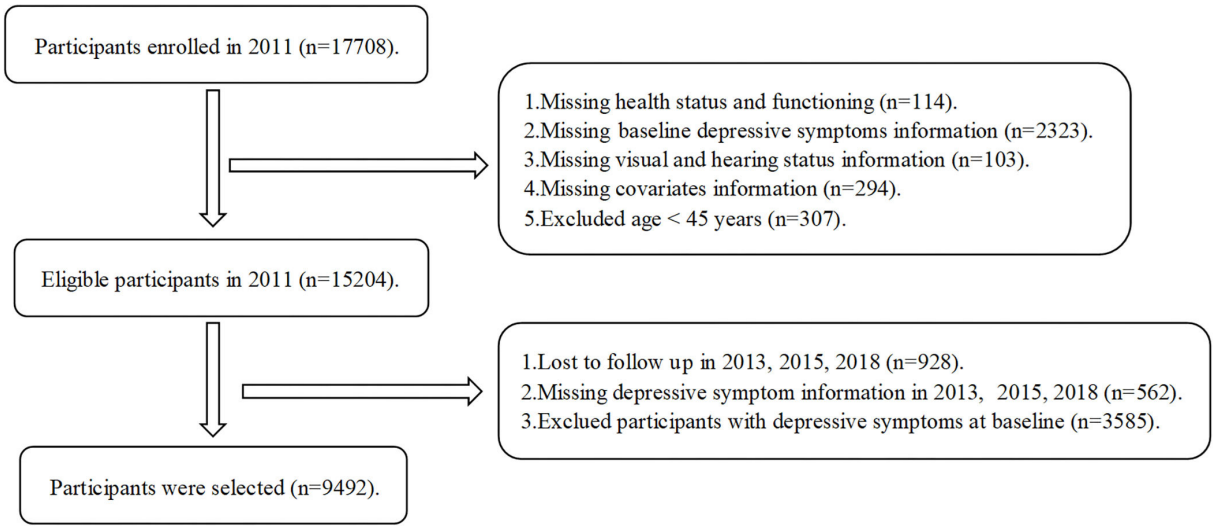

FIGURE 1
Flowchart of the selected participants from the CHARLS.

aged 45 years and older. To ensure the representativeness of the participants, each wave employed a multistage probability sampling method to enroll individuals from 450 villages and 150 counties in 28 Chinese provinces. After the CHARLS 2011 baseline assessment, the CHARLS proceeded to follow-up with participants in three waves in 2013, 2015, and 2018. In response to deficiencies of incomplete baseline information in CHARLS, this study applied the following inclusion criteria: (1) participants aged 45 years or older and (2) participants not lost to follow-up. Furthermore, this study applied exclusion criteria as follows: (1) missing information on depressive symptoms at CHARLS 2011 baseline; (2) missing information on vision and hearing impairments at CHARLS 2011 baseline; (3) missing covariate information at CHARLS 2011 baseline; and (4) missing information on depressive symptoms during the 7-year follow-up. In this study, we used all data from 2011 (Wave 1), 2013 (Wave 2), 2015 (Wave 3), and 2018 (Wave 4). The final three waves were defined as three follow-up surveys during the 7-year follow-up period. This study was conducted in accordance with the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) reporting guidelines (15). This study included middle-aged and older adults aged 45 years and older. A list-wise deletion approach was used to treat for missing data, and this study excluded 8,416 participants. The final cohort included 9,492 participants at the CHARLS 2011 baseline. The detailed sampling selection process of the 9,492 participants with depressive symptoms included in the analysis in this prospective cohort study is presented in Figure 1. Furthermore, this study performed additional analyses to evaluate the robustness of our findings by adopting an inverse probability weighting (IPW) method to adjust for bias from non-random selection and missingness to obtain valid estimates in this study.

The CHARLS project was approved by the Peking University Biomedical Ethics Review Committee (IRB00001052-11015) (14). All participants provided written informed consent before participating in the study.

Assessment of vision and hearing status

Assessment of vision and hearing impairments included three major questions based on participants' self-reported vision and hearing status from the CHARLS 2011 baseline. To evaluate participants' vision and hearing (6, 16), participants were asked the following questions: (1) "How good is your eyesight for seeing things at a distance, such as recognizing a friend from across the street?"; (2) "How good is your eyesight for seeing things up close, such as reading ordinary newspaper prints?"; and (3) "How good is your hearing?". These three questions were evaluated on a five-point scale ranging from 1 to 5 (1 = excellent, 2 = very good, 3 = good, 4 = fair, and 5 = poor). Participants with vision impairments were defined as having poor eyesight for seeing things at a distance or up close, while participants with hearing impairments were defined as having poor hearing. Participants without vision and hearing impairments were defined as the absence of vision and hearing impairments. Conversely, participants with vision and hearing impairments were defined as having both vision and hearing impairments (5, 17, 18). To represent vision and hearing status, three types of independent variables were defined as follows:

(1) the three questions included eyesight for seeing things at a distance (1 = excellent, 2 = very good, 3 = good, 4 = fair, and 5 = poor), eyesight for seeing things up close (1 = excellent, 2 = very good, 3 = good, 4 = fair, and 5 = poor), and hearing (1 = excellent, 2 = very good, 3 = good, 4 = fair, and 5 = poor); (2) vision and hearing impairments were divided into four groups (1 = no vision and hearing impairments, 2 = only vision impairments, 3 = only hearing impairments, and 4 = both vision and hearing impairments); and (3) three questions were combined to obtain vision and hearing scores (as a continuous variable) ranging from 3 to 15, with the highest score representing both vision and hearing impairments.

Ascertainment of depressive symptoms

Depressive symptoms were treated as primary outcome events during follow-up. Participants were assessed using a 10-item short form of the Center for Epidemiologic Studies Depression Scale (CESD-10) in each CHARLS wave survey (19). Using the 10 items, participants were asked about their depressive feelings and behaviors in the previous week, such as whether they felt depressed, lonely, or fearful. Each question of the CESD-10 was evaluated on a four-point scale ranging from 0 to 3 [0 = <1 day (never or rarely), 1 = 1–2 days (some days), 2 = 3–4 days (occasionally), and 3 = 5–7 days (always)]. Before calculating the total 10-item scores, items 1, 2, 3, 4, 6, 7, 9, and 10 were scored, and reverse scoring was applied to items 5 and 8. Scale scores varied from 0 to 30, with a higher total score indicating a higher level of depressive symptoms. Depressive symptoms were defined as a binary dependent variable (1 = yes and 2 = no), with a total score of 12 indicating depressive symptoms (20, 21). The CESD-10 scale has been reported to have adequate reliability and validity among Chinese community-dwelling elderly individuals (17, 21).

Covariate information assessment

Participants' covariate information at CHARLS 2011 baseline include (1) age (in years; 1 = 45–54, 2 = 55–64, 3 = 65–74, and 4 ≥ 75), sex (1 = male and 2 = female), residence (1 = rural and 0 = urban), education level (1 = illiterate, 2 = elementary school and below, 3 = middle school, and 4 = high school and above), marital status (1 = married/cohabiting and 2 = separated/divorced/widowed/never married), chronic diseases (1 = yes and 2 = no), smoking history (1 = yes and 2 = no), and alcohol consumption history (0 = none, 1 = drinks more than once a month, and 2 = drinks but less than once a month); (2) presence of chronic diseases, namely, hypertension (1 = yes and 0 = no), diabetes (1 = yes and 0 = no), heart disease (1 = yes and 0 = no), digestive disease (1 = yes and 0 = no), arthritis (1 = yes and 0 = no); and (3) self-assessed daily use of wearing glasses and/or a hearing aid (1 = yes and 0 = no). These risk factors were included as covariates in different models in this analysis.

Statistical analyses

For dichotomous covariate information at the CHARLS 2011 baseline, we compared the differences among participants with and without depressive symptoms using a *t*-test or a chi-square test. A Cox proportional hazards model was used to calculate the hazard risk between vision and/or hearing status and depressive symptoms. Stratified analysis according to different characteristics was conducted to calculate the hazard risks between vision and hearing scores and depressive symptoms among participants, and the significance of all risk factor group interactions between vision and hearing scores and depressive symptoms was also calculated. The following four models were estimated in this study: Model 0 was unadjusted; Model 1 was adjusted for age, sex, residence, marital status, and educational level; Model 2 was adjusted for factors in Model 1 plus smoking history, alcohol consumption history, hypertension, diabetes, heart disease, digestive disease, and arthritis; and Model 3 was adjusted for factors in Model 2 plus wearing glasses and hearing aids. Covariate information was assumed to be missing at random in this study, and we performed a complete case analysis. The level of statistical significance was set at 95% (P-value < 0.05). Associations are presented as hazard ratios (HRs) with 95% confidence intervals (CIs). All data analyses were conducted using R statistical software version 4.1.2.

We performed two additional analyses to evaluate the robustness of our findings: (1) the Fine and Gray competing risk model to calculate the hazard risk of depressive symptoms and (2) the IPW method to adjust for bias from non-random selection and missingness to obtain valid estimates.

Results

Of the 17,708 participants at CHARLS 2011 baseline, we excluded 114 participants with incomplete information on health status and functioning, 2,323 participants with incomplete information on depressive symptoms, 103 participants with missing vision and/or hearing status information, 294 participants with incomplete information on covariates, 307 participants younger than 45 years, 928 participants who were lost to follow-up, 562 participants without answers to the questions on depressive symptoms during the 7-year follow-up period, and 3,585 participants with depressive symptoms at CHARLS 2011 baseline. A final total of 9,492 participants were included in the analysis (Figure 1).

The average age of the 9,492 participants was 58.12 years (SD: 9.00 years). Of participants, 4,930 (51.94%) were men and

TABLE 1 The characteristics of the selected participants at CHARLS 2011 baseline.

Characteristics	Participants, No. (%)			*P*-value[a]
	Total ($N = 9,492$)	Depressive symptoms[b]		
		No ($n = 6,254$)	Yes ($n = 3,238$)	
Age, years, mean (SD)	58.12 (9.00)	57.98 (9.03)	58.39 (8.94)	0.033
Gender				
Male	4,930 (51.94)	3,573 (57.13)	1,357 (41.91)	<0.001
Female	4,562 (48.06)	2,681 (42.87)	1,881 (58.09)	
Residence				
Urban	5,441 (57.32)	3,299 (52.75)	2,142 (66.15)	<0.001
Rural	4,051 (42.68)	2,955 (47.25)	1,096 (33.85)	
Education level				
Illiterate	2,107 (22.20)	1,142 (18.26)	965 (29.80)	<0.001
Elementary school and below	3,681 (38.78)	2,321 (37.11)	1,360 (42.00)	
Middle school	2,258 (23.79)	1,623 (25.95)	635 (19.61)	
High school and above	1,446 (15.23)	1,168 (18.68)	278 (8.59)	
Marital status				
Married/cohabiting	8,614 (90.75)	5,712 (91.33)	2,902 (89.62)	0.006
Separated/divorced /widowed/never married	878 (9.25)	542 (8.67)	336 (10.38)	
Smoking history				
Yes	3,915 (41.25)	2,766 (44.23)	1,149 (35.48)	<0.001
No	5,577 (58.75)	3,488 (55.77)	2,089 (64.52)	
Alcohol consumption				
Drink more than once a month	2,648 (27.48)	1,919 (30.68)	689 (21.18)	<0.001
Drink but less than once a month	787 (8.29)	546 (8.73)	241 (7.44)	
None of these	6,097 (64.23)	3,789 (60.59)	2,308 (71.28)	
Hypertension				
Yes	2,166 (22.82)	1,403 (22.43)	763 (23.56)	0.214
No	7,326 (77.18)	4,851 (77.57)	2,475 (76.44)	
Diabetes				
Yes	483 (5.09)	305 (4.88)	178 (5.50)	0.192
No	9,009 (94.91)	5,949 (95.12)	3,060 (94.50)	
Heart disease				
Yes	948 (9.99)	597 (9.55)	351 (10.84)	0.046
No	8,544 (90.01)	5,657 (90.45)	2,887 (89.16)	
Digestive disease				
Yes	1,779 (18.74)	1,059 (16.93)	720 (22.24)	<0.001
No	7,713 (81.26)	5,195 (83.07)	2,518 (77.76)	
Arthritis				
Yes	2,651 (27.93)	1,542 (24.66)	1,109 (34.25)	<0.001
No	6,841 (72.07)	4,712 (75.34)	2,129 (65.75)	
Wearing glasses				
Yes	1,098 (11.57)	753 (12.04)	345 (10.65)	0.045
No	8,394 (88.43)	5,501 (87.96)	2,893 (89.35)	
Wearing hearing aids				
Yes	46 (0.48)	30 (0.48)	16 (0.49)	0.924
No	9,446 (99.52)	6,224 (99.52)	3,222 (99.51)	

[a] *T*-test or Pearson's χ^2-test for the significance of the difference between participants with and without depressive symptoms.
[b] Defined as a score of 12 or greater on the 10-item Center for Epidemiologic Studies Depression scale.

4,562 (48.06%) were women. The significance of the differences between participants with and without depressive symptoms stratified by different characteristics is presented in Table 1. Univariate analysis revealed that compared with those without incident depressive symptoms, participants with depressive symptoms were more likely to be older (57.98 ± 9.03 vs. 58.39 ± 8.93, *P*-value = 0.033), and significant differences were observed in gender (*P*-value < 0.001), residence (*P*-value < 0.001), education level (*P*-value < 0.001), marital status (*P*-value = 0.006), smoking history (*P*-value < 0.001), alcohol consumption (*P*-value < 0.001), heart disease (*P*-value = 0.046), digestive disease (*P*-value < 0.001), arthritis (*P*-value < 0.001), and wearing glasses (*P*-value = 0.045) among participants with incident depressive symptoms. Table 2 presents a comparison of the differences in CHARLS 2011 baseline characteristics between the included participants and those who were excluded from the analysis.

At CHARLS 2011 baseline, 6,463 (68.09%) participants had no vision and hearing impairments, 2,154 (22.69%) had only vision impairments, 407 (4.29%) had only hearing impairments, and 468 (4.93%) had both vision and hearing impairments. After a 7-year follow-up period, 3,238 (34.11%) participants reported incident depressive symptoms. Table 3 presents the association of vision and hearing status with depressive symptoms and the effect size of wearing glasses and hearing aids on depressive symptoms. After adjusting for potential covariates (in Model 3), a comparison of poor with excellent revealed adjusted HRs of 1.59 (95% CI: 1.16–2.17) for eyesight for seeing things at a distance, 1.28 (95% CI: 0.91–1.83) for eyesight for seeing things up close, and 1.42 (95% CI: 1.02–1.98) for hearing. Compared with no vision and hearing impairments, only vision impairments (HR: 1.13, 95% CI: 1.04–1.22), only hearing impairments (HR: 1.20, 95% CI: 1.02–1.41), and both vision and hearing impairments (HR: 1.21, 95% CI: 1.05–1.41) were significantly associated with depressive symptoms. The hazard risk of depressive symptoms increased with an improvement in vision and hearing scores (HR: 1.04, 95% CI: 1.02–1.06). Furthermore, compared with participants that did not wear glasses and hearing aids, participants that wore glasses (HR: 1.02, 95% CI: 0.91–1.15) and hearing aids (HR: 1.25, 95% CI: 0.76–2.05) did not dismiss the association.

Restricted cubic spline regression revealed a positive linear association between vision and hearing scores and the hazard risk of depressive symptoms (for non-linearity: χ^2-value = 7.30, *P*-value = 0.026) (Figure 2) and a positive linear association between age and the hazard risk of depressive symptoms (for non-linearity: χ^2-value = 1.22, *P*-value = 0.545) (Figure 3).

There was no evidence that our results lacked robustness in the two additional analyses. Table 4 presents similar findings between the Fine and Gray competing risk model and Cox proportional hazards model in Table 3. Table 5 presents the association of vision and hearing scores with depressive symptoms before using the Cox proportional hazards model

TABLE 2 The characteristics between participants included and not included at baseline.

Characteristics	Not included	Included	*P*-value
Participants, No. (%)	8,216 (46.40)	9,492 (53.60)	
Age, years, mean (SD)	60.13 (11.25)	58.12 (9.00)	<0.001
Gender, No (%)			
Male	3,541 (43.80)	4,930 (58.20)	<0.001
Female	4,659 (50.53)	4,562 (49.47)	
Residence, No (%)			
Rural	3,117 (43.48)	4,051 (56.52)	<0.001
Urban	5,096 (48.36)	5,441 (51.64)	
Education level, No (%)			
Illiterate	2,696 (56.13)	2,107 (43.87)	<0.001
Elementary school and below	3,271 (47.05)	3,681 (52.95)	
Middle school	1,394 (38.17)	2,258 (61.83)	
High school and above	800 (35.62)	1,446 (64.38)	
Marital status, No (%)			
Married/cohabiting	6,803 (44.13)	8,614 (55.87)	<0.001
Separated/divorced /widowed/never married	1,380 (61.12)	878 (38.88)	
Smoking history, No (%)			
Yes	3,016 (43.51)	3,915 (56.49)	<0.001
No	5,051 (47.53)	5,577 (52.47)	
Alcohol consumption, No (%)			
Drink more than once a month	1,775 (40.50)	2,608 (59.50)	<0.001
Drink but less than once a month	597 (43.14)	787 (56.86)	
None of these	5,688 (58.26)	6,097 (51.74)	
Hypertension, No (%)			
Yes	2,118 (49.44)	2,166 (50.56)	<0.001
No	5,860 (44.44)	7,326 (55.56)	
Diabetes, No (%)			
Yes	510 (51.36)	483 (48.64)	<0.001
No	7406 (45.12)	9009 (54.88)	
Heart disease, No (%)			
Yes	1,145 (54.71)	948 (45.29)	<0.001
No	6,830 (44.43)	8,544 (55.67)	
Digestive disease, No (%)			
Yes	2,123 (54.41)	1,779 (45.59)	<0.001
No	5,902 (43.35)	7,713 (56.65)	
Arthritis, No (%)			
Yes	3,122 (54.08)	2,651 (45.92)	<0.001
No	4,910 (41.78)	6,841 (58.22)	
Wearing glasses, No (%)			
Yes	870 (44.21)	1,098 (55.79)	0.184
No	7,091 (45.79)	8,394 (54.21)	
Wearing hearing aid, No (%)			
Yes	52 (53.06)	46 (46.94)	0.158
No	8,024 (45.93)	9,446 (54.07)	

TABLE 3 Association of vision and hearing status with depressive symptoms among middle-aged and older Chinese adults.

Vision and hearing status (No.)	Outcome case, No (%)	Depressive symptom[e] HR (95% CI)			
		Model 0[a]	Model 1[b]	Model 2[c]	Model 3[d]
Eyesight for seeing things at a distance					
Excellent (189)	43 (22.75)	1.00 (Reference)	1.00 (Reference)	1.00 (Reference)	1.00 (Reference)
Very good (1,413)	376 (26.61)	1.12 (0.87–1.64)	1.15 (0.84–1.57)	1.15 (0.84–1.58)	1.15 (0.84–1.58)
Good (2,693)	894 (33.20)	1.56 (1.14–2.11)**	1.39 (1.02–1.89)*	1.36 (1.01–1.86)*	1.37 (1.01–1.86)*
Fair (3,732)	1,303 (34.91)	1.66 (1.22–2.24)**	1.43 (1.05–1.94)*	1.37 (1.02–1.87)*	1.38 (1.02–1.87)*
Poor (1,465)	622 (42.46)	2.15 (1.57–2.93)***	1.71 (1.25–2.33)***	1.59 (1.17–2.17)**	1.59 (1.16–2.17)**
Eyesight for seeing things up close					
Excellent (132)	33 (25.00)	1.00 (Reference)	1.00 (Reference)	1.00 (Reference)	1.00 (Reference)
Very good (978)	293 (29.96)	1.24 (0.87–1.78)	1.19 (0.83–1.71)	1.20 (0.84–1.73)	1.20 (0.84–1.72)
Good (2,470)	827 (33.48)	1.42 (1.00–2.01)	1.30 (0.91–1.84)	1.27 (0.89–1.80)	1.27 (0.89–1.79)
Fair (4,085)	1,371 (33.56)	1.43 (1.01–2.02)*	1.25 (0.89–1.77)	1.21 (0.86–1.71)	1.21 (0.86–1.71)
Poor (1,827)	714 (39.08)	1.59 (1.73–2.46)**	1.47 (1.04–2.09)*	1.39 (0.98–1.98)	1.39 (0.91–1.97)
Hearing					
Excellent (158)	40 (25.31)	1.00 (Reference)	1.00 (Reference)	1.00 (Reference)	1.00 (Reference)
Very good (1,534)	438 (28.55)	1.15 (0.83–1.59)	1.10 (0.80–1.53)	1.10 (0.80–1.53)	1.10 (0.80–1.52)
Good (3,221)	1,042 (32.35)	1.33 (0.97–1.82)	1.22 (0.89–1.67)	1.20 (0.88–1.65)	1.20 (0.88–1.65)
Fair (3,704)	1,355 (36.58)	1.56 (1.14–2.13)**	1.40 (1.02–1.91)*	1.33 (0.97–1.83)	1.33 (0.97–1.83)
Poor (875)	363 (41.49)	1.82 (1.31–2.53)***	1.58 (1.14–2.20)**	1.50 (1.08–2.08)*	1.49 (1.07–2.07)*
Vision and hearing impairment group					
No vision and hearing impairment (6,463)	2,043 (31.61)	1.00 (Reference)	1.00 (Reference)	1.00 (Reference)	1.00 (Reference)
Only vision impairment (2,154)	832 (38.62)	1.30 (1.19–1.40)***	1.18 (1.09–1.28)***	1.14 (1.05–1.24)**	1.14 (1.05–1.24)**
Only hearing impairment (407)	161 (40.15)	1.31 (1.12–1.54)***	1.27 (1.08–1.49)**	1.25 (1.06–1.47)**	1.24 (1.06–1.46)**
Both vision and hearing impairment (468)	202 (43.16)	1.49 (1.29–1.73)***	1.33 (1.15–1.54)***	1.25 (1.08–1.45)**	1.25 (1.08–1.45)**
Risk factors[f]					
Age			1.00 (0.99–1.00)	1.00 (0.99–1.00)	1.00 (0.99–1.00)
Gender					
Male			1.00 (Reference)	1.00 (Reference)	1.00 (Reference)
Female			1.52 (1.41–1.64)***	1.42 (1.28–1.58)***	1.42 (1.28–1.58)***
Residence					
Urban			1.00 (Reference)	1.00 (Reference)	1.00 (Reference)
Rural			0.71 (0.66–0.76)***	0.71 (0.66–0.76)***	0.71 (0.65–0.76)***
Education level					
Illiterate			1.00 (Reference)	1.00 (Reference)	1.00 (Reference)
Elementary school and below			0.92 (0.84–1.00)	0.91 (0.83–0.99)*	0.90 (0.83–0.99)*
Middle school			0.71 (0.63–0.79)***	0.71 (0.64–0.80)***	0.71 (0.63–0.79)***
High school and above			0.50 (0.43–0.57)***	0.50 (0.43–0.57)***	0.49 (0.43–0.57)***
Marital status					
Married/cohabiting			1.00 (Reference)	1.00 (Reference)	1.00 (Reference)
Separated/divorced/widowed/never married			1.04 (0.92–1.17)	1.04 (0.93–1.18)	1.04 (0.93–1.18)
Smoking history					
Yes				1.05 (0.95–1.16)	1.05 (0.95–1.16)
No				1.00 (Reference)	1.00 (Reference)

(Continued)

TABLE 3 Continued

Vision and hearing status (No.)	Outcome case, No (%)	Depressive symptom[e] HR (95% CI)			
		Model 0[a]	Model 1[b]	Model 2[c]	Model 3[d]
Alcohol consumption					
Drink more than once a month				1.15 (1.00–1.34)	1.15 (0.99–1.33)
Drink but less than once a month				1.22 (1.10–1.34)***	1.22 (1.10–1.34)***
None of these				1.00 (Reference)	1.00 (Reference)
Hypertension					
Yes				1.03 (0.95–1.13)	1.03 (0.95–1.13)
No				1.00 (Reference)	1.00 (Reference)
Diabetes					
Yes				1.21 (1.03–1.41)*	1.21 (1.03–1.41)*
No				1.00 (Reference)	1.00 (Reference)
Heart disease					
Yes				1.07 (0.96–1.21)	1.07 (0.96–1.21)
No				1.00 (Reference)	1.00 (Reference)
Digestive disease					
Yes				1.21 (1.11–1.32)***	1.21 (1.11–1.31)***
No				1.00 (Reference)	1.00 (Reference)
Arthritis					
Yes				1.29 (1.20–1.39)***	1.29 (1.20–1.39)***
No				1.00 (Reference)	1.00 (Reference)
Wearing glasses					
Yes					1.02 (0.91–1.15)
No					1.00 (Reference)
Wearing hearing aids					
Yes					1.25 (0.76–2.05)
No					1.00 (Reference)

HR, hazard ratio; CI, confidence interval. *0.01 < *P*-value <0.05, **0.001 < *P*-value <0.01, ***P-value < 0.001.
[a]Model 0 was unadjusted.
[b]Model 1 was adjusted for age, sex, residence, marital status, and educational level.
[c]Model 2 was adjusted for age, sex, residence, marital status, educational level, smoking history, alcohol consumption, hypertension, diabetes, heart disease, digestive disease, and arthritis.
[d]Model 3 was adjusted for age, sex, residence, marital status, educational level, smoking history, alcohol consumption, hypertension, diabetes, heart disease, digestive disease, arthritis, wearing glasses, and wearing hearing aids.
[e]Defined as a score of 12 or greater on the 10-item Center for Epidemiologic Studies Depression scale.
[f]Hazard ratio on the risk factors of vision and hearing impairment group.

(HR: 1.05, 95% CI: 1.03–1.06) and after using the IPW method (HR: 1.93, 95% CI: 1.75–2.12).

Table 6 presents the association of vision and hearing impairments with depressive symptoms, stratified by different risk factors. No significant interactions were noted among risk factors (all *P*-values for interaction > 0.05). The association of vision and hearing scores with depressive symptoms differed among participants stratified according to different risk factors at baseline. The analysis stratified according to different risk factors revealed that participants with depressive symptoms were more likely to be younger, had a higher level of education, did not consume alcohol, and did not wear glasses or hearing aids.

Discussion

This study established the association between vision and hearing status and depressive symptoms in middle-aged and older Chinese adults. Our findings provide evidence based on a nationally representative cohort study sample of 9,492 Chinese community-dwelling elderly individuals and longitudinal follow-up to support our hypotheses. This study had four major findings based on the cohort study data. First, participants with only vision impairments, only hearing impairments, and both vision and hearing impairments exhibited incident depressive symptoms during the 7-year follow-up period. Second, the fact that all risk factors (e.g.,

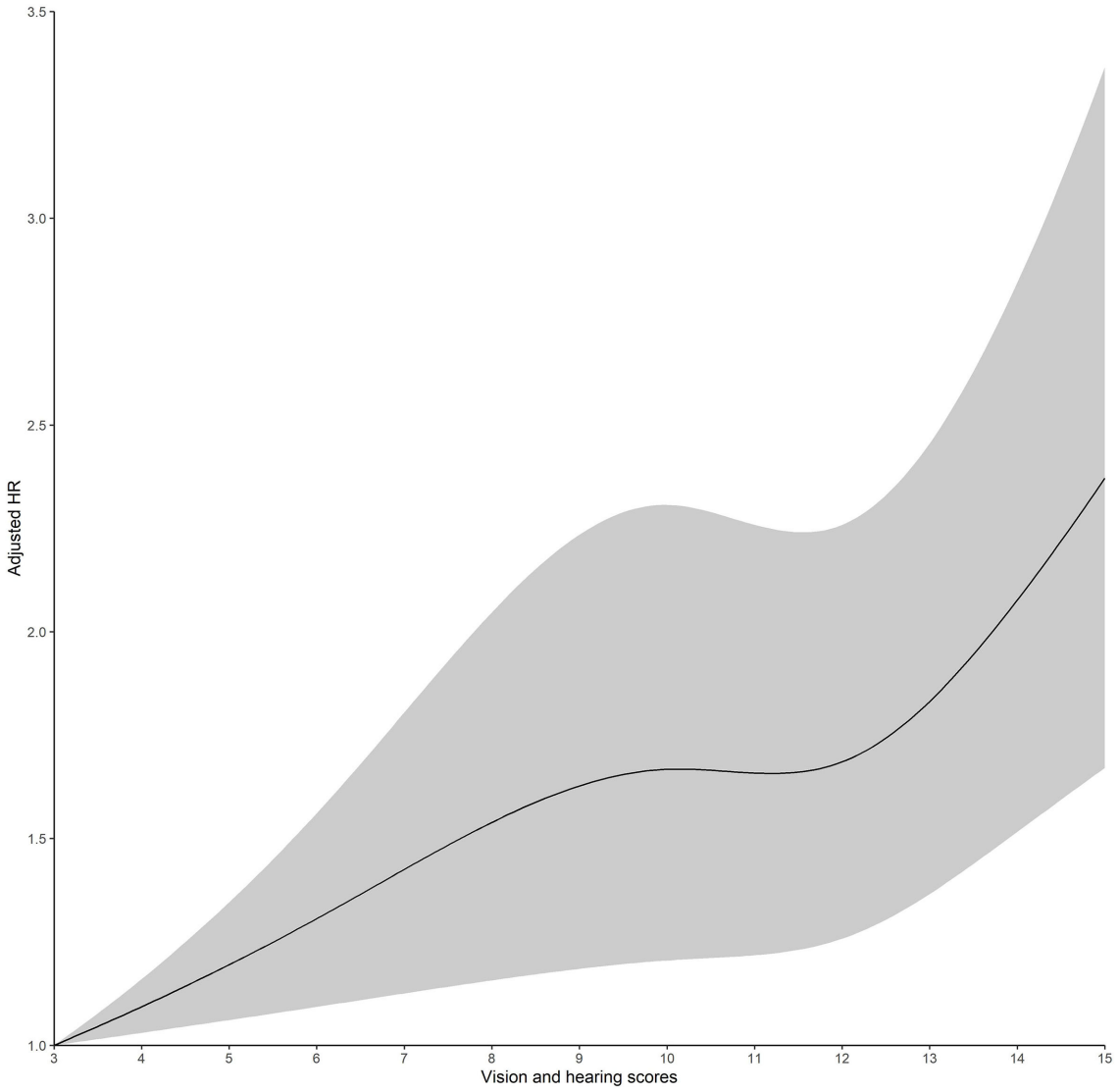

FIGURE 2
Adjusted hazard ratios (HRs) of depressive symptoms, according to vision and hearing scores. Graphs show HRs for depressive symptoms adjusted for age, sex, residence, marital status, educational level, smoking history, alcohol consumption, hypertension, diabetes, heart disease, digestive disease, arthritis, wearing glasses, and wearing a hearing aid. Data were fitted by a restricted cubic spline Cox proportional hazards regression model. The vision and hearing scores range from 3 to 15, with the highest score representing impairment of vision and hearing. Solid lines indicate HRs, and dashed lines indicate 95% CIs.

age, sex, chronic diseases, and lifestyle) were obtained using CHARLS self-reported questionnaires does not diminish the interpretation of the association between vision and/or hearing status and depressive symptoms. Third, participants with higher vision and hearing scores had a greater risk of depressive symptoms. Finally, the use of glasses and hearing aids did not improve depressive symptoms. In addition, this study excluded 8,416 participants from the CHARLS baseline, which may have contributed to the non-representativeness of the 9,492 participants included in this study and the acquisition of erroneous estimates. Therefore, this study used the IPW method to adjust for bias from non-random selection and missingness to obtain valid estimates of the association.

Our findings identified a total of 2,154 (22.69%) participants with only vision impairments, 407 (4.29%) with only hearing impairments, and 468 (4.93%) with both vision and hearing impairments at the CHARLS 2011 baseline. After the 7-year follow-up period, 3,238 (34.11%) participants reported incident depressive symptoms. Our findings revealed that higher vision and hearing scores were indicative of more depressive symptoms. As reported by Armenia (11), the prevalence of vision impairments (moderate and severe poor vision) was

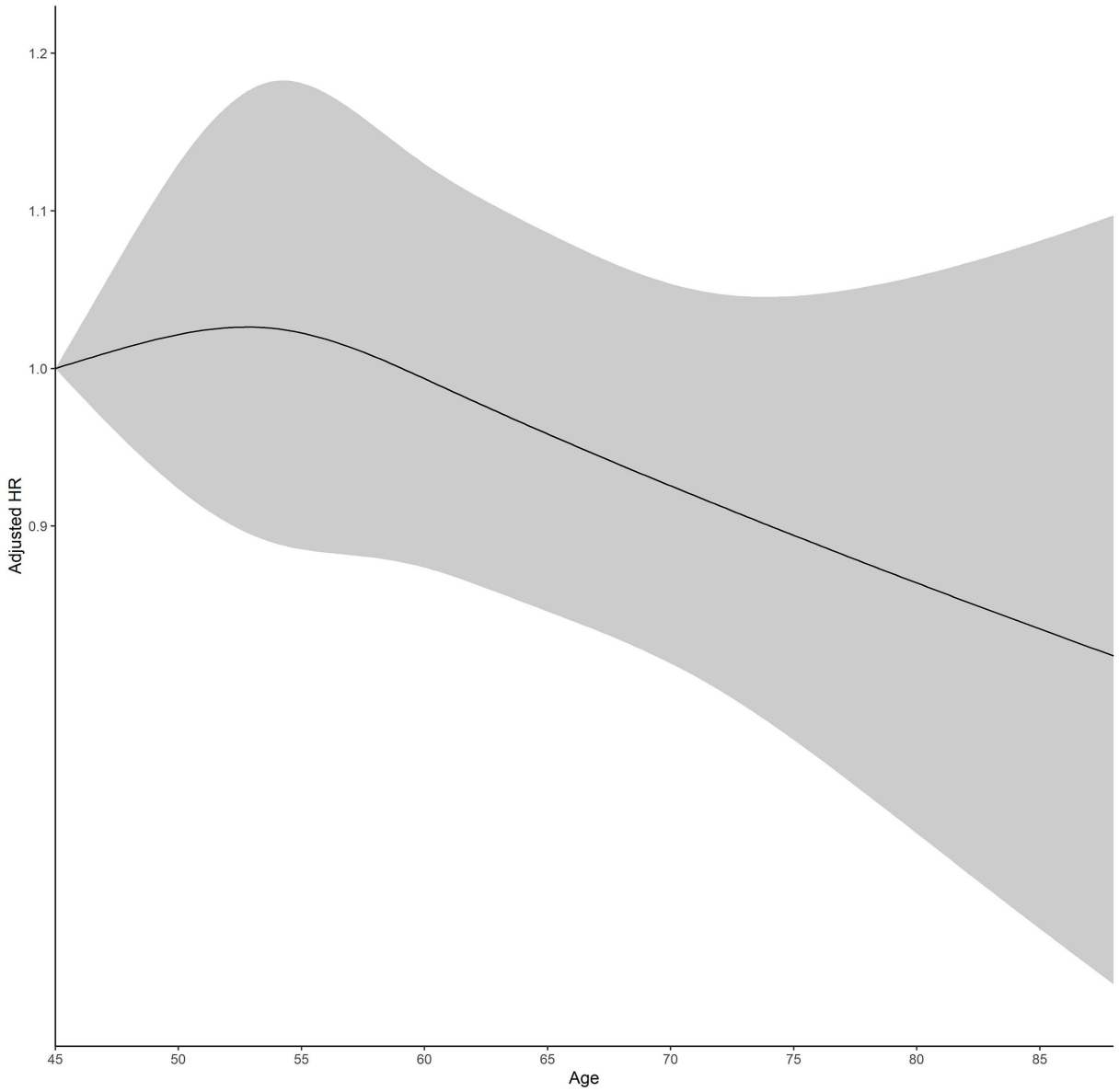

FIGURE 3
Adjusted hazard ratios (HRs) of depressive symptoms, according to age. Graphs show HRs for depressive symptoms adjusted for vision and hearing scores, sex, residence, marital status, educational level, smoking history, alcohol consumption, hypertension, diabetes, heart disease, digestive disease, arthritis, wearing glasses, and wearing a hearing aid. Data were fitted by a restricted cubic spline Cox proportional hazards regression model. The vision and hearing scores range from 45 to 85. Solid lines indicate HRs, and dashed lines indicate 95% CIs.

13.3%, and almost 3.8% of patients were blind. A study on Italian elderly individuals revealed that the incidence of vision impairments was 1.4% and the prevalence of hearing impairments was as low as 0.2% but increased with age (22). A survey conducted in four typical Chinese provinces reported that over two-thirds of Chinese adults aged 60 years and older had hearing impairments (23). Moreover, a study in Singapore reported that patients with glaucoma often presented with coexisting psychiatric disorders such as anxiety and depression. And there was a relatively high prevalence of depression (30%) and anxiety disorder (64%) among glaucoma patients in Singapore; notably, female patients with glaucoma were more likely to present with depressive symptoms (24). Our findings revealed that the prevalence of vision and hearing impairments in China was distinct from that reported in other studies, which could be due to the different assessment methods and characteristics of the populations involved in the studies performed in different countries.

TABLE 4 Association of vision and hearing status with depressive symptoms by the Fine and Gray competing risk analysis.

Vision and hearing status	Depressive symptom status[b] HR (95% CI) Model[a]
Eyesight for seeing things at a distance	
Excellent	1.00 (Reference)
Very good	1.14 (0.84–1.54)
Good	1.34 (1.00–1.18)
Fair	1.35 (1.01–1.80)*
Poor	1.54 (1.15–2.07)**
Eyesight for seeing things up close	
Excellent	1.00 (Reference)
Very good	1.19 (0.85–1.67)
Good	1.25 (0.91–1.73)
Fair	1.20 (0.87–1.66)
Poor	1.36 (0.99–1.89)
Hearing	
Excellent	1.00 (Reference)
Very good	1.09 (0.81–1.49)
Good	1.19 (0.88–1.60)
Fair	1.31 (0.97–1.76)
Poor	1.44 (1.06–1.97)*
Vision and hearing impairment group	
No vision and hearing impairment	1.00 (Reference)
Only vision impairment	1.13 (1.05–1.22)***
Only hearing impairment	1.22 (1.05–1.41)***
Both vision and hearing impairment	1.23 (1.07–1.40)***

HR, hazard ratio; CI, confidence interval. *0.01 < *P*-value < 0.05, **0.001 < *P*-value < 0.01, ****P*-value < 0.001.

[a]Model was adjusted for age, sex, residence, marital status, educational level, smoking history, alcohol consumption, hypertension, diabetes, heart disease, digestive disease, arthritis, wearing glasses, and wearing hearing aids.

[b]Defined as a score of 12 or greater on the 10-item Center for Epidemiologic Studies Depression scale.

Our results revealed that participants with only vision impairments, only hearing impairments, and both vision and hearing impairments presented with depressive symptoms but with a different degree of risk. Several population-based longitudinal studies in Canada (25), the Salisbury Eye Evaluation Study (26), and the National Health and Aging Trends Study (27) confirmed a link between depressive symptoms and vision impairments. A prevailing concern among hearing-impaired individuals in China is the impact of hearing impairments on physical and mental health (23, 28). Indeed, the Korean health insurance cohort study (29) reported that severe hearing impairments significantly increased the risk of depressive symptoms in all age groups of the study population after matching for age, sex, income, and region. A population-based longitudinal study reported that vision and hearing impairments were significantly associated with depressive symptoms and suggested that treating or rehabilitating either vision or hearing impairments may incident depressive symptoms (25, 30, 31). According to several prospective studies, the presence of depressive symptoms is associated with reduced sensory function, and the risk of depressive symptoms increases over subsequent years (28, 32). A multi-site cohort study of community-dwelling persons aged 65 years and over from the electoral rolls of three French cities suggested that this relationship is complex depending on whether the loss is related to near visual impairment or visual function loss and visual decline across time (33). Consistent with previous studies, our findings also demonstrated that an increase in vision and hearing scores was associated with a higher risk of depressive symptoms after adjusting for potential confounders, and further studies are warranted to clarify this dose–effect relationship. However, it should be noted that CESD-10 is different from clinical measures of depressive symptoms, and these results should be interpreted with caution among middle-aged and older adults.

Consistent with previous studies, our findings indicated that participants with depressive symptoms stratified by potential risk factors were more likely to be younger, have a high level of education, not consume alcohol, and not wear glasses and hearing aids. Our data revealed that age was not a significant risk factor for this association. Depression is a serious public health concern among elderly individuals; it causes disability, medical illnesses, mental health problems, and increased mortality (11). Previous research has reported that individuals with vision and/or hearing impairments have a higher risk of depressive symptoms (2, 34). In addition to vision and hearing impairments, previous studies found that older age, female sex, lower education, illness, mobility, IADL, sleep time, smoking, residential setting, emotional support, negative interactions with family members, social participation, and physical activities are more likely to be associated with depressive symptoms (6, 30, 35). As participants' chronic diseases were self-reported, the results obtained in this stratified analysis should not be used to infer causal associations between chronic diseases and depressive symptoms. Nevertheless, we observed an increased likelihood of depression with age. Of note, a higher education level did not reduce the occurrence of depressive symptoms, which may be because individuals with higher levels of education have more risk factors influencing their mental health.

In this study, vision and hearing status was self-reported in CHARLS. In this regard, objective clinical vision and hearing screening are more appropriate than subjective self-reported vision and hearing status, although a previous study reported the opposite result (36). Consistent with existing literature, our findings suggest longitudinal trends in self-reported vision impairments and depressive symptoms. Clinical vision and hearing screening may be more appropriate than self-reported vision and hearing impairment status to more accurately assess

TABLE 5 Associations between vision and hearing scores and depressive symptoms by Cox and IPW methods.

Methods	Depressive symptom status[b] HR (95% CI) Model[a]
Vision and/or hearing score (Cox)	1.05 (1.03–1.06)***
Vision and/or hearing score (IPW)	1.93 (1.75–2.12)***

HR, Hazard Ratio; CI, Confidence Interval; Cox, Cox proportional hazards model; IPW, Inverse probability weighting. *** P-value < 0.001.
[a]Model was adjusted for age, sex, residence, marital status, educational level, smoking history, alcohol consumption, hypertension, diabetes, heart disease, digestive disease, arthritis, wearing glasses, and wearing hearing aids.
[b]Defined as a score of 12 or greater on the 10-item Center for Epidemiologic Studies Depression scale.

vision and hearing status in older adults. A prospective study employed objective hearing tests to assess the relationship between hearing impairments and depressive symptoms (29). Results of the Georgia Centenarian Study suggest that objective vision status does not always reflect subjective status, and various factors affect the relationship between objective vision function and self-reported vision problems (37). Previous studies have predominantly focused on self-reported vision and hearing status as a key indicator of actual vision and hearing impairments in elderly individuals. Some studies have compared the two vision measures regarding mental health and reported that self-reported vision function loss was a better predictor of depression compared to the indicators of objective vision acuity (38, 39). Previous research comparing vision measurements in relation to mental health has indicated that self-reported vision functional impairments were a stronger predictor of depressive symptoms compared to objective measures of vision acuity (38). In addition, a systematic review suggested the inability to conduct a meta-analysis or establish an association between vision impairments and depressive symptoms in elderly individuals for various reasons, namely, a lack of standardized vision impairment measures, different depressive symptom scales, comparability of the studies, and the potential bias caused by different variables (13). Consistent with previous studies, our findings demonstrated that subjective self-reported vision and hearing impairments were associated with depressive symptoms among middle-aged and older adults. Future research should examine objective measures and subjective self-reported disparities in vision and hearing impairments in China.

In this study, only a small number of participants wore glasses and hearing aids. Moreover, the use of glasses and hearing aids did not attenuate the association of vision and hearing impairments with depressive symptoms. The use of glasses and hearing aids is lower in older Chinese adults, which may be modulated by outdated beliefs (e.g., wearing glasses or hearing aids can lead to further impairments in vision or hearing) (6). Furthermore, older adults with vision and hearing impairments

TABLE 6 Association of vision and hearing scores with depressive symptoms stratified by different risk factors using Cox.

Characteristics	Depressive symptom[b] HR (95% CI)	P-value	P-value for interaction
Overall	1.05 (1.03–1.06)	<0.001	
Age (years)			0.735
45–54	1.06 (1.03–1.08)	0.001	
55–64	1.03 (1.00–1.06)	0.037	
65–74	1.07 (1.03–1.11)	<0.001	
≥75	1.06 (0.98–1.14)	0.128	
Gender			0.484
Male	1.05 (1.02–1.08)	<0.001	
Female	1.04 (1.02–1.07)	<0.001	
Residence			0.853
Urban	1.04 (1.02–1.06)	<0.001	
Rural	1.05 (1.02–1.08)	<0.001	
Education level			0.272
Illiterate	1.03 (1.00–1.06)	0.082	
Elementary school and below	1.05 (1.02–1.07)	0.001	
Middle school	1.06 (1.02–1.10)	0.004	
High school and above	1.09 (1.03–1.16)	0.002	
Marital status			0.751
Married/cohabiting	1.04 (1.03–1.06)	<0.001	
Separated/divorced/ widowed/ never married	1.06 (1.01–1.11)	0.026	
Smoking history			0.825
Yes	1.05 (1.02–1.08)	<0.001	
No	1.05 (1.02–1.07)	<0.001	
Alcohol consumption			0.294
Drink more than once a month	1.03 (0.99–1.06)	0.137	
Drink but less than once a month	1.09 (1.03–1.16)	0.005	
None of these	1.05 (1.03–1.07)	<0.001	
Hypertension			0.866
Yes	1.06 (1.02–1.09)	0.003	
No	1.04 (1.02–1.06)	<0.001	
Diabetes			0.107
Yes	1.10 (1.01–1.19)	0.022	
No	1.04 (1.03–1.06)	<0.001	
Heart disease			0.111
Yes	1.02 (0.96–1.07)	0.540	
No	1.05 (1.03–1.07)	<0.001	
Digestive disease			0.892
Yes	1.04 (1.01–1.08)	0.020	
No	1.05 (1.01–1.07)	<0.001	

(Continued)

TABLE 6 Continued

Characteristics	Depressive symptom[b] HR (95% CI)	*P*-value	*P*-value for interaction
Arthritis			0.134
Yes	1.03 (1.00–1.07)	0.029	
No	1.05 (1.03–1.07)	<0.001	
Wearing glasses			0.909
Yes	1.05 (0.99–1.10)	0.101	
No	1.05 (1.03–1.06)	<0.001	
Wearing hearing aids			0.284
Yes	0.79 (0.52–1.19)	0.253	
No	1.05 (1.03–1.07)	<0.001	

HR, hazard ratio; CI, confidence interval.
[a]Model was adjusted for age, sex, residence, marital status, educational level, smoking history, alcohol consumption, hypertension, diabetes, heart disease, digestive disease, arthritis, wearing glasses, and wearing hearing aids.
[b]Defined as a score of 12 or greater on the 10-item Center for Epidemiologic Studies Depression scale.

who are treated with glasses, hearing aids, and other therapeutic approaches exhibit improvements in depressive symptoms, wellbeing, and quality of life (6, 22, 40). A population-based longitudinal study reported that vision impairments were significantly associated with depressive symptoms and suggested that the treatment or rehabilitation of vision impairments could help to prevent depressive symptoms (30). Similarly, other studies have suggested that vision impairments in elderly individuals can increase their risk of developing depressive symptoms. Accordingly, early interventions to prevent the occurrence and onset of vision impairments are warranted to improve the quality of life of these individuals (41, 42). The severity of hearing impairments is closely related to multiple physical and mental health outcomes among middle-aged and older Chinese adults, and actions should be taken to prevent and treat hearing impairments to improve health and wellbeing (28, 32). In this regard, the use of glasses and hearing aids to improve depressive symptoms is noteworthy, and medical and health education initiatives for older adults with vision and hearing impairments are warranted.

The strengths of our research design based on a large population in China and distinct vision and hearing analyses revealed a significant connection between vision and hearing status and depressive symptoms, which was based on the CHARLS design of a prospective cohort study with a 7-year follow-up period. However, this study has several limitations. First, additional confounding factors linked with depressive symptoms, such as income, life satisfaction, and social support, were not included as covariates for model adjustment. Second, vision and hearing status was self-reported and was not based on medical records in CHARLS. Third, only a small number of participants wore glasses and hearing aids; hence, any improvements could not be conclusively determined. Participants were only asked about their vision and hearing impairments and use of glasses and hearing aids at baseline but not during the 7-year follow-up period, during which we focused only on depressive symptoms. Finally, the self-reported variables may have introduced recall bias when the study included older adults in CHARLS.

In conclusion, this study demonstrated that vision and hearing impairments were associated with depressive symptoms among middle-aged and older Chinese adults. Furthermore, our findings revealed that participants with only vision impairments, only hearing impairments, and both vision and hearing impairments were at a higher risk of incident depressive symptoms. Based on our findings, individuals with both vision and hearing impairments had the highest risk of developing depressive symptoms, followed by those with only hearing or vision impairments. The presence of other risk factors did not affect the interpretation of the association of vision and hearing impairments with depressive symptoms. Moreover, an increase in participants' vision and hearing scores was associated with an increase in the hazard risk of incident depressive symptoms among middle-aged and older Chinese adults. In addition, participants' use of glasses and hearing aids did not improve depressive symptoms. Despite the growing burden of vision and hearing impairments in China's aging society, these conditions have been overlooked. Accordingly, effective treatments to prevent and treat vision and hearing impairments are warranted to improve the mental health and quality of life of middle-aged and older individuals with vision and hearing impairments.

Data availability statement

Publicly available datasets were analyzed in this study. This data can be found here: http://charls.pku.edu.cn/.

Ethics statement

The studies involving human participants were reviewed and approved by Peking University Biomedical Ethics Review Committee (IRB00001052-11015). The patients/participants provided their written informed consent to participate in this study.

Author contributions

Y-GL performed data analysis, interpreted the data, and drafted the manuscript. C-CW interpreted the data and reviewed the manuscript. QH and LZ performed data collection

and data cleaning. YL designed the study, reviewed, and critically revised the manuscript. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Identification of radiographic characteristics associated with pain in hallux valgus patients: A preliminary machine learning study

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Objective: To investigate the association between the structural deformity and foot pain in hallux valgus (HV) patients using a multi-variate pattern analysis (MVPA) approach.

Methods: Plain radiographic metrics were calculated from 36 painful and 36 pain-free HV feet. In analysis 1, univariate analyses were performed to investigate the clinical and radiographic differences between painful and pain-free HV. In analysis 2, we investigated the pattern differences for radiographic metrics between these two groups using a MVPA approach utilizing a support vector machine. In analysis 3, sequential backward selection and exhaustive search were performed as a feature-selection procedure to identify an optimal feature subtype. In analysis 4, hierarchical clustering analysis was used to identify the optimal radiographic HV subtype associated with pain in HV.

Results: We found that: (1) relative to feet with pain-free HV, the painful ones exhibited a higher hallux valgus angle, i.e., the magnitude of distal metatarsal and phalangeal deviation; (2) painful HV could be accurately differentiated from pain-free HV *via* MVPA. Using sequential backward selection and exhaustive search, a 5-feature subset was identified with optimal performance for classifying HV as either painful or pain-free; and (3) by applying hierarchical clustering analysis, a radiographic subtype with an 80% pain incidence was identified.

Conclusion: The pain in HV is multifactorial and associated with a radiographic pattern measured by various angles on plain radiographs. The combination of hallux valgus angle, inter-phalangeal angle, distal metatarsal articular angle, metatarsal cuneiform angle and metatarsal protrusion distance showed the optimal classification performance between painful and pain-free HV.

KEYWORDS

hallux valgus, multi-variate pattern analysis, pain, support vector machine, hierarchical clustering

Introduction

Hallux valgus (HV) is characterized as a combined deformity with mal-positioning of the first metatarsophalangeal joint caused by a lateral deviation of the great toe and a medial deviation of the first metatarsal bone. This can progress to significant metatarsophalangeal (MTP) joint subluxation, which is frequently encountered in foot and ankle clinic with a prevalence exceeding 20% in adults over 50 years of age (1). HV is often associated with the pain (2), impaired physical function (3) with consequent poorer general health (4) and diminished quality of life (5). Pain is the primary complaint related to HV (6), and typically the severity of the deformity directly correlates with the degree of pain. A prior publication noted a positive correlation between self-reported severity of HV (Short Form 36 or Foot Pain and Disability Index) and increasing levels of pain (5). However, there have also been conflicting reports of only a modest correlation between pain and structural HV deformity (i.e., HV angle measured from a radiographic image). Moreover, there have been contradictory reports concerning the link between foot pain and HV (5, 7–9). Discrepancies have been noted such as patients with a large HV angle yet without any pain, and others with only a mild HV angle that experience severe foot pain. The precise mechanism behind such phenomena has yet to be identified. In recent years, some authors have postulated alternative explanations that HV has affected the entire foot rather than just the MTP joint (10–12). When pain could not be explained by the degree of the HV angle alone, which has been traditionally used to evaluate the deformity of MTP joint, other radiographic angles, such as the intermetatarsal angle, and the metatarsal cuneiform angle have been implicated as potentially associated with pain in HV patients.

In recent decades, with the development of artificial intelligence and machine learning algorithms, multi-variate pattern analysis (MVPA) has been widely applied in the medical imaging field (13–15). MVPA methods provide a rich characterization of imaging data, often in a data-driven manner. This technique has enabled researchers to identify the key, significantly important parameters of a complex disease in a multi-variate manner rather than exploring univariate differences between the disease and healthy controls (15). Prior studies exploring the correlates of foot pain in HV patients have relied only on univariate analyses to determine the association between pain and HV deformity (e.g., two sample *T*-test or univariate correlation analyses between radiographic findings and degree of pain). Although the results of univariate analysis were straight-forward and easy to interpret, only linear-relations between the radiographic findings and clinical assessments were considered. Pattern information consisting of different radiographic metrics to evaluate the deformity of the entire foot was largely overlooked. More importantly, HV affected the structure of the entire foot rather than just the MTP joint (10–12). It has been shown that hallux valgus could affect the transverse arch structure and its force loading patterns (12). Furthermore, HV not only alters the geometry structure of forefoot but also causes biomechanics function changes of the foot (16, 17). A more comprehensive understanding of the deformity pattern associated with pain in HV would likely provide the basis for foot surgeons to develop novel surgical techniques to correct the HV deformity and resolve the pain.

Therefore, in this study, we first (1) conducted a MVPA to test whether the various radiographic angles could be used to classify painful HV patients from pain-free HV patients in a supervised manner; (2) performed a sequential backward selection and exhaustive search as a feature selection procedure to identify the optimal feature subset of radiographic features; and (3) carried out hierarchical clustering in an unsupervised manner to identify the radiographic HV subtype which was associated with pain in HV patients.

Materials and methods

Subjects

Written informed consent was obtained from each participant prior to each procedure. Ethical approval was granted by the Local Institutional Ethics Committee. The study comprised a total of 103 feet with HV, from 81 patients, recruited from January 2021 to January 2022 at both inpatient and outpatient departments of foot and ankle surgery. To control the degree of overall HV deformity, we used a HV angle above 20° as a cut-off value for patient recruitment rather than a traditional criterion for HV angle of >15° determined by standard radiographic images.

The exclusion criteria were as following: (1) history of foot or ankle surgery or trauma; (2) history of neurological diseases; (3) ankle joint or foot sprain within 3 months; (4) presence of concomitant hallux limitus (i.e., a minimum of 50 degrees of passive dorsiflexion at the first MTP joint was required) (2).

Clinical assessment

The demographic data of the participants including sex, age, education years, ethnicity was obtained by questionnaire. The total years of education was determined from the patient's self-report of completed years of education. The Visual Analog Scale (VAS) was implemented to assess the degree of foot pain in each HV foot. Feet with a VAS score of 0 were

identified as pain-free. Feet with VAS scores >3 extending more than 3 months were classified as painful (18, 19). Painless feet were selected from the dataset and excluded those that meet the exclusion criteria. Therefore, 36 painless HV feet were obtained. To further performed machine learning analyses and to avoid class-imbalance problem, 36 painful HV feet from the dataset to match the painless HV feet with age, gender, education years and ethnicity. Finally, 72 HV feet from 63 patients, 36 painful and 36 pain-free, were included in our study.

Radiographic assessment

Bilateral weight bearing radiographs were obtained for all participants using a standardized procedure (tube to film distance 100 cm, angled 15° from vertical). All radiographic assessments were carried out in ImageJ toolbox. The assessment procedure of radiographic metrics we used were as follows. (1) Hallux Valgus angle (HVA): the hallux valgus angle is formed by the longitudinal axis of the first proximal phalanx and the longitudinal axis of the first metatarsus (20, 21). (2) Inter-Metatarsal Angle (IMA): the IMA, or metatarsus primus adducts angle, is the angle between the longitudinal axes of the first and second metatarsals (22). (3) Inter-Phalangeal Angle (IPA): the IPA is the angle between longitudinal axes of the proximal and distal phalanges (22). (4) Distal Metatarsal Articular Angle (DMAA): the DMAA is the angle between the perpendicular to the effective articular surface of the first metatarsal head and the longitudinal axis of the first metatarsal bone (22). (5) Distal Articular Set Angle (DASA): the DASA is the angle between the perpendicular to the effective articular surface of the 1st proximal phalanx and the longitudinal axis of the 1st proximal phalanx (22, 23). (6) Metatarsal Cuneiform Angle (MCA): the MCA is the measured angle between the longitudinal axis of the first metatarsal bone and the longitudinal axis of the medial cuneiform bone. (7) Metatarsal Adducent Angle (MAA): we used the method devised by Engel et al. (24) to measure the MAA. We measured the angle between the axis of the second metatarsal and the axis perpendicular to the transverse axis of the tarsus using the most lateral and most distal points of the joints of the cuboid, with the fifth metatarsal as a reference. (8) Metatarsal Protrusion Distance (MPD): located at the most distal extent of the second metatarsal bone, perpendicular to the longitudinal axis, this line reflects the distal-most protrusion of the second metatarsal. A line parallel to this is now constructed coursing through the distal-most point of the first metatarsal. The difference between these 2 parallel lines is the MPD (25). (9) Sesamoid Position (SP): The position of the tibial sesamoid was graded I, II, III, IV, V, VI, or VII according to its position relative to the functional longitudinal axis of the first metatarsal (26).

Analysis 1: Univariate analyses for exploring radiographic differences between painful and pain-free HV feet

Two sample *t*-tests were performed for continuous variables and chi-square test was used for categorical variables to compare the baseline demographic data between two groups. Subsequently, Shapro-Wilk tests were performed to check the normal distribution of the radiographic measurements and QQ plots were also generated for illustrating normality of our data. All statistical analyses and figures were generated using GraphPad prism 9. Two sample *t*-tests were performed for continuous variables and chi-square test was used for categorical variables to compare the radiographic metrics between groups. Moreover, parametric test was performed for between group comparison for radiographic metrics which passed the Shapiro-Wilk test, otherwise nonparametric test was performed (i.e., Mann-Whitney test). The significant level was set to $P < 0.05$. Moreover, to elucidate the associations among clinical measures. Pearson correlation analyses were performed to demonstrate the association among radiographic metrics.

Analysis 2: Multi-variate pattern analyses (MVPA) using a support vector machine (SVM) for classifying painful HV feet from pain-free ones

The SVM was use to distinguish painful HV feet from pain-free ones using radiographic features according to the homemade MATLAB script based on LibSVM's (http://www.csie.ntu.edu.tw/~cjlin/libsvm/) implementation of linear SVM using the default parameters: We used linear kernel, the penalty coefficient (c) was set to 1, other parameters were not adjustable therefore we made no further adjustment. To overcome the loss of generalization due to the relative sample size, the Leave-one-out-cross-validation (LOOCV) technique was used in this study. One of the available data-points in LOOCV was held-out, and the model was trained using the remainder of the data in the dataset and tested against the held-out data. This procedure was repeated until all data-points had been held-out once as the testing data. Because nearly the entire dataset was used for training, and the trained model was close to the real one, we expected the LOOCV error bias to be small. The corresponding *P*-value for the classification for painful HV vs. pain-free HV was calculated from the null distribution obtained from 10,000 random permutation tests by randomly shuffling the labels of samples in the dataset. The *p*-values were calculated as a proportion of the number of permutations generated that were greater than or equal to actual classification

accuracy, and the total number of permutations. If none of 10,000 permutations reached the actual accuracy, the *P*-value was $P < 0.0001$.

Analysis 3: Sequential backward selection and exhaustive search for identifying an optimal feature subset *via* MVPA

The sequential backward selection procedure was initiated from the full set of features; at each iteration we compared the performances of different models built by sequentially removing each of the features from the current set of candidate features. We then excluded the feature whose subtraction resulted in the most increase in classification accuracy from the next iteration the feature. This procedure was repeated until the classification accuracy showed no increase by excluding features.

However, using sequential backward selection could end up with a global optimum rather than a local optimal feature subset. The exhaustive search was also performed to enumerate all possible models for classifying painful HV vs. pain-free HV. The *P*-value for the classification was also generated using permutation test as described in *analysis 2*.

Analysis 4: Hierarchical clustering analysis for identifying radiographic HV subtype associated with pain in HV

Hierarchical clustering of the 72 HV samples was performed based on homemade MATLAB script using Euclidean distance as distance measure. All other parameters were set to default values. The dendrogram along with silhouette index, Calinski-Harabasz index and Davies-Bouldin index were conducted to determine the optimal number of clusters. Subsequently, the mean of radiographic metrics of each subtype were illustrated in a radar map along with the X-ray of the most representative sample of each subtype (e.g., with the closest distance to the cluster-average). Last, the prevalence of foot pain in each subtype was compared using chi-square test between subtypes.

Results

Demographic data

The demographic data and the clinical assessments of all participants are summarized in Table 1. There were no significant inter-group differences with regards to age, sex, or education years ($P > 0.05$).

TABLE 1 Demographic data of painful and pain-free hallux valgus (HV).

	Painful HV	Pain-free HV	*P*-value
Age (Years)	58.61 ± 14.67	58.82 ± 14.75	0.86
Sex (female/male)	18/18	18/18	1
Education (Years)	10.64 ± 3.67	11.03 ± 3.54	0.74
VAS score	4.75 ± 2.35	0	0
Duration (Years)	25.67 ± 16.42	25.71 ± 17.68	0.81

VAS, visual analog scale.

Analysis 1: Univariate analyses for exploring radiographic differences between painful and pain-free HV feet

Relative to the pain-free group, the painful group exhibited a significantly higher HVA ($P = 0.001$, Mann-Whitney $U = 364$), DMAA ($P = 0.001$, Mann-Whitney $U = 369.5$) and a higher level of sesamoid subluxation ($P = 0.04$, Mann-Whitney $U = 477$). No significant differences between groups were observed in the following metrics: IMA, IPA, DASA, MCA, MAA, MPD (Figure 1). Significant positive correlations were observed between the following metrics: HVA and DMAA ($R = 0.84$, $P < 0.001$), HVA and IMA ($R = 0.53$, $P < 0.001$), IMA and DMAA ($R = 0.46$, $P < 0.005$), HVA and SP ($R = 0.53$, $P < 0.001$), IMA and SP ($R = 0.55$, $P < 0.001$), and DMAA and SP ($R = 0.61$, $P < 0.001$). Significant negative correlation was observed between IMA and MCA ($R = -0.32$, $P < 0.05$) (Figure 2), however, this negative correlation did not survive the Bonferroni correction.

Analysis 2: Multi-variate pattern analyses (MVPA) using a support vector machine (SVM) for classifying painful HV feet from pain-free ones

The MVPA was performed to determine whether the pattern of radiographic features could be used to distinguish painful HV feet from pain-free ones. The painful group could be accurately distinguished from the pain-free group using the entire feature set (i.e., all 9 radiographic features) with a 76.4% classification accuracy. The corresponding *P*-value was 0.0054 (Figure 3). This result indicated that a pattern of radiographic features of the foot might accurately predict pain.

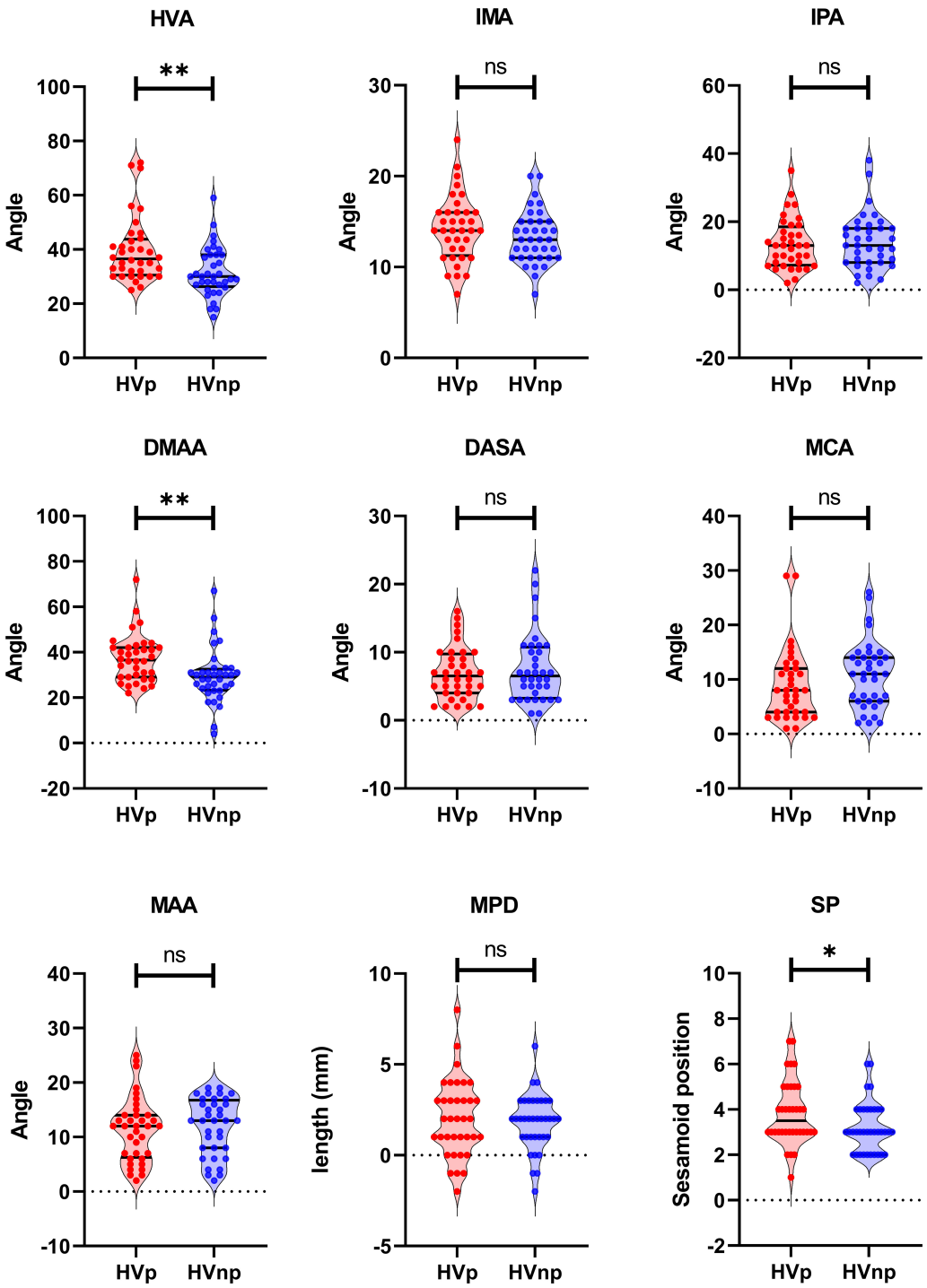

FIGURE 1
Univariate differences for radiographic metrics between painful and pain-free HV. HVp, Hallux Valgus with Pain; HVnp, Hallux Valgus without Pain; HVA, Hallux Valgus Angle; IMA, Inter-Metatarsal Angle; IPA, Inter-Phalangeal Angle; DMAA, Distal Metatarsal Articular Angle; DASA, Distal Articular Set Angle; MCA, Metatarsal Cuneiform Angle; MAA, Metatarsal Adducent Angle; MPD, Metatarsal Protrusion Distance; SP, Sesamoid Position. $^{**}P < 0.005$; $^{*}P < 0.05$. ns means non-significant.

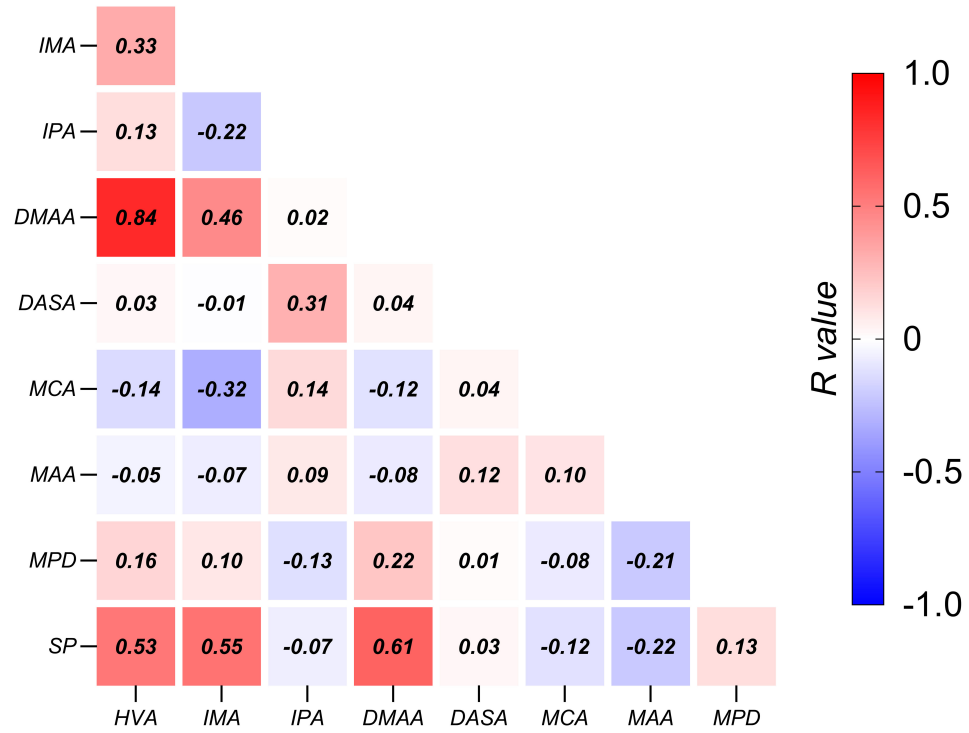

FIGURE 2
Associations among radiographic metrics in HV. The correlation coefficients are shown in the center of each box. HVA, Hallux Valgus Angle; IMA, Inter-Metatarsal Angle; IPA, Inter-Phalangeal Angle; DMAA, Distal Metatarsal Articular Angle; DASA, Distal Articular Set Angle; MCA, Metatarsal Cuneiform Angle; MAA, Metatarsal Adducent Angle; MPD, Metatarsal Protrusion Distance; SP, Sesamoid Position.

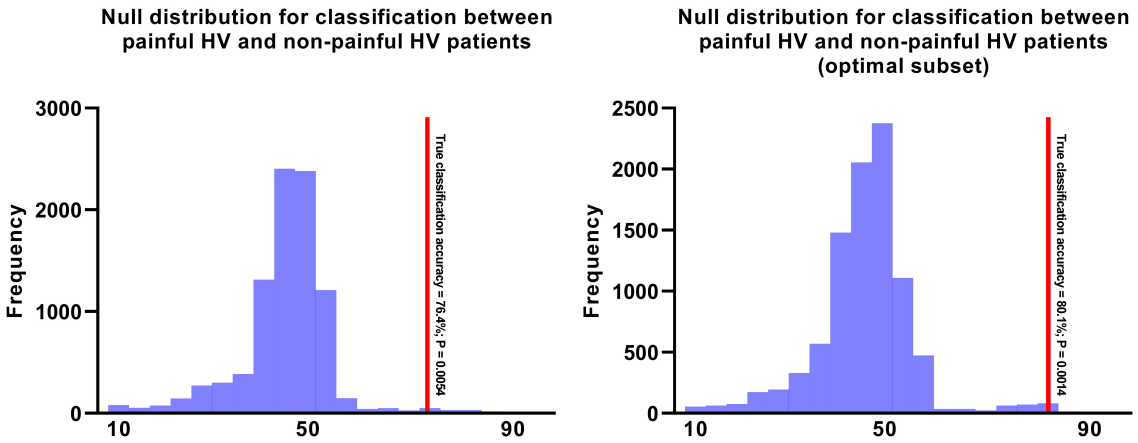

FIGURE 3
The null distributions for Painful HV vs. Pain-free HV. The left panel illustrates the null distribution of 10,000 permutations for Painful HV vs. Pain-free HV using the entire feature set. The right panel illustrates the null distribution of 10,000 permutations for Painful HV vs. Pain-free HV using the optimal feature set including hallux valgus angle, inter-phalangeal angle, distal metatarsal articular angle, metatarsal adducent angle, metatarsal protrusion distance.

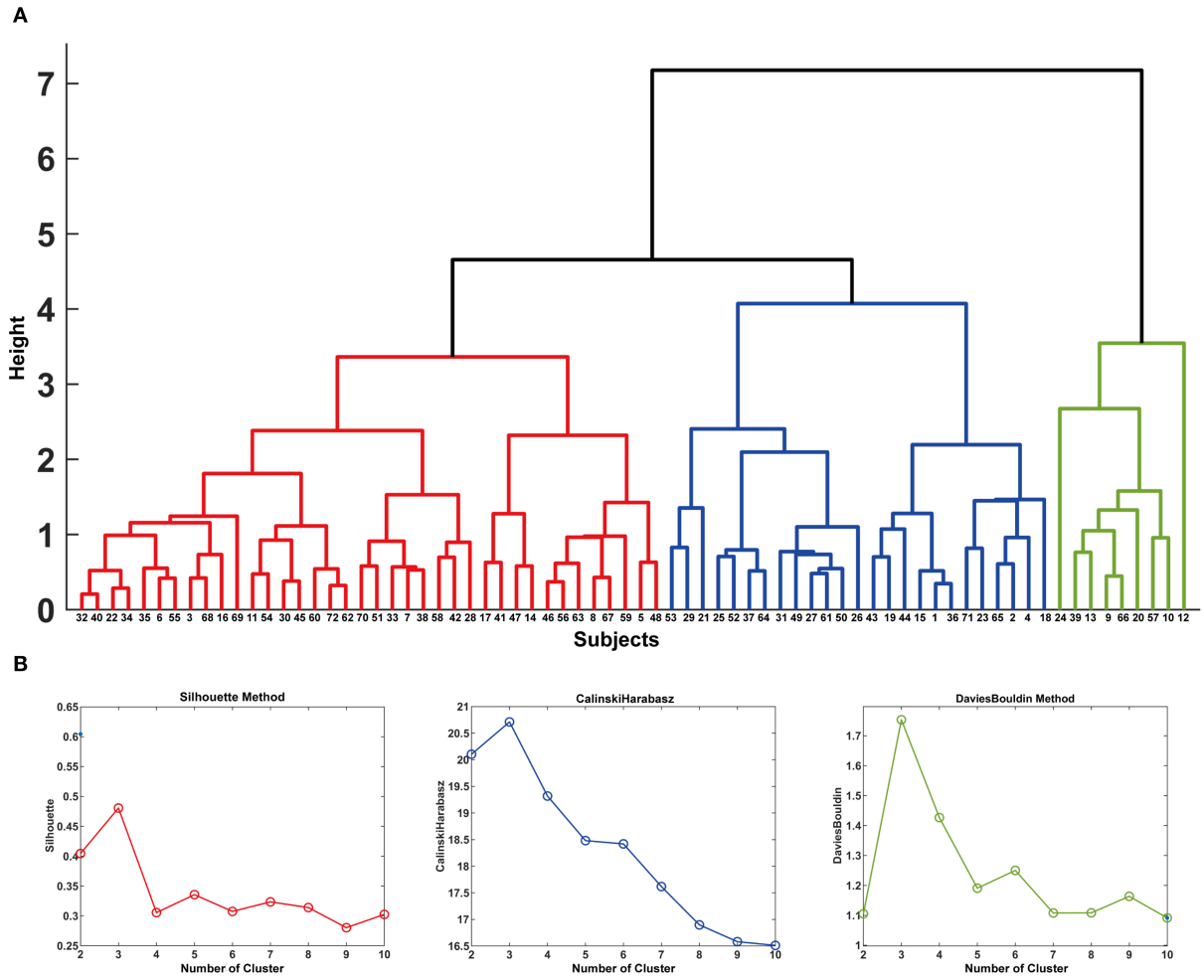

FIGURE 4
In **(A)**, the dendrogram of the hierarchical clustering is illustrated. The *y*-axis shows the study-specific distances between the clusters as height h. When $h = 0$, each volume forms its own cluster, and $h = 2$ corresponds to splitting the volumes into 13 clusters. The *x*-axis shows the number for each subject. The results of Silhouette index, Calinski-Harabasz index and Davies-Bouldin index analyses are shown in **(B)**.

Analysis 3: Sequential backward selection and exhaustive search for identifying an optimal feature subset *via* MVPA

Because *Analysis 2* indicated that the painful HV could be accurately distinguished from pain-free HV using the entire feature set of radiographic measures, the next step was to define an optimal subset of radiographic features that would correlate with HV-related pain. Sequential backward selection procedure was performed, and we found a 5-feature subset with an optimum performance of 80.1% classification accuracy ($P = 0.0014$; Figure 3). Moreover, the exhaustive search also identified the same subset. The 5-feature subset consisted of the following 5 metrics: HVA, IPA, DMAA, MAA and MPD.

Analysis 4: Hierarchical clustering analysis for identifying radiographic HV subtype associated with pain in HV

The dendrogram showed that the optimal number of clusters was 3 (Figure 4A). The results of Silhouette index, Calinski-Harabasz index and Davies-Bouldin index analyses also showed the optimal number of clusters was 3 (Figure 4B). After hierarchical clustering, 3 subtypes were identified: subtype 1 had the largest sample size (e.g., 38 HV), subtype 3 had the smallest sample size (e.g., 9 HV), and the sample size of subtype 2 was 25. The characteristics of each subtype were illustrated in the radar map and the most representative images of each subtype were also illustrated (e.g., with the closest distance to

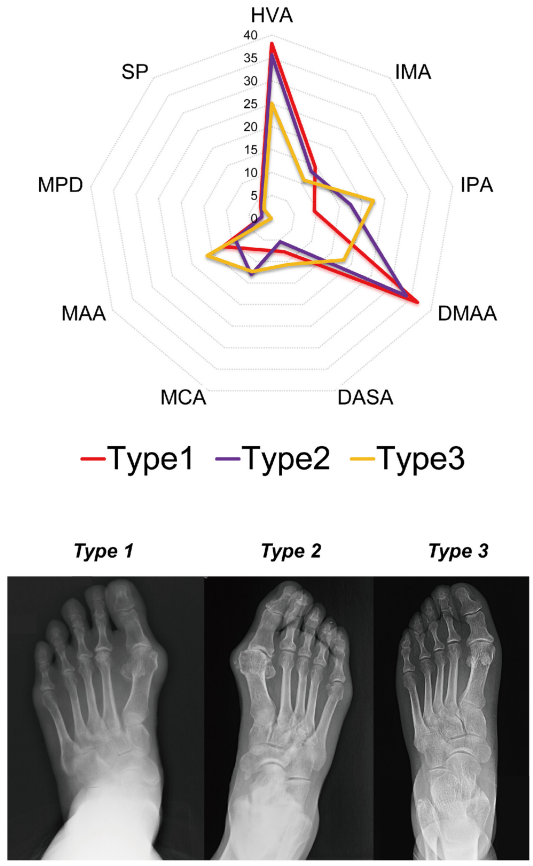

FIGURE 5
The characteristics of each subtype are illustrated in the radar map and the most representative images of each subtype are illustrated (e.g., with the closest distance to the cluster-average). HVA, Hallux Valgus Angle; IMA, Inter-Metatarsal Angle; IPA, Inter-Phalangeal Angle; DMAA, Distal Metatarsal Articular Angle; DASA, Distal Articular Set Angle; MCA, Metatarsal Cuneiform Angle; MAA, Metatarsal Adducent Angle; MPD, Metatarsal Protrusion Distance; SP, Sesamoid Position.

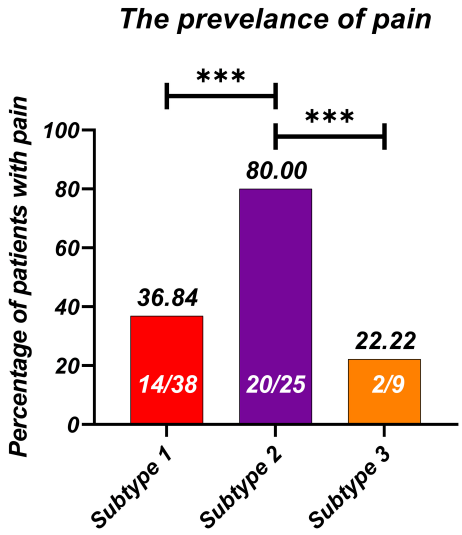

FIGURE 6
The incidence of foot pain in each radiographic subtype. ***$P < 0.001$.

the cluster-average; Figure 5). Furthermore, the incidence of foot pain was highest in subtype 2 (e.g., 80%; Figure 6).

Discussion

The three main findings of the present study were: (1) relative to the pain-free group, the painful group exhibited higher HVA, DMAA, and these two metrics were positively correlated; (2) the painful group could be accurately distinguished from the pain-free group using a MVPA. Using sequential backward selection and exhaustive search, an optimal subset was developed that contained 5 radiographic metrics: HVA, IPA, DMAA, MAA and MPD that had optimal performance for classifying painful and pain-free HV; and (3) by applying hierarchical clustering analysis, a radiographic subtype associated with foot pain was also identified.

Radiographic correlates of pain in HV patients illustrated by univariate analysis

Previous studies had correlated higher HVA with foot pain in HV patients, to which the present study provided further evidence that increased degrees of HV deformity were associated with worse pain in HV. This finding corroborated prior research that had shown pain intensity to be directly correlated with higher degrees of HV deformity. However, whether HV deformity is the major cause of foot pain remains controversial (2, 6, 7, 9, 10). Foot pain in patients with HV has also been associated with patient characteristics such as general health status and occupational physical activity levels rather than severity of hallux deviation (2). Our results partly support with the previous reports that pain intensity is correlated with HV deformity in HV patients. The reasons for contradiction reports were two folds: (1) the inclusion criteria vary from different studies. In our current study, we included HV patients with moderate to severe deformity (i.e., hallux valgus angle above 20°). Several past studies have a relatively wide inclusion criteria that using a HVA above 15° as an inclusion criterion (2, 6, 7). The biomechanical compensatory changes of the foot could partly neutralize the pain and might affect the association between pain intensity and degree of deformity; (2) past studies only explore the univariate association between HV deformity and pain intensity,

ignored subtypes which determined by the combination of various angles measured from the HV foot. In our current study, we identified a radiographic painful subtype and two painless subtypes. Interestingly, one of the painless subtypes has a HV angle close to painful subtype, indicating that pain in HV patients is multifactorial.

The pain of HV is multifactorial, determined by multiple radiographic measurements

In past studies, a large proportion of HV patients with variability of pain intensity remained unexplained. These controversial results were mainly based on univariate analyses, with no attention to associations of other radiographic variables. In the current study, the results of clustering analyses showed that subtypes 1 and 2 exhibited no differences in HVA yet there was significant difference in pain incidence. This finding further supported the idea that pattern information of radiographic variables was crucial in correlation with HV-related pain. The direct comparison of HVA between pain and non-pain participants and liner regression are straight-forward procedures that reveal the association between pain and HVA. However, it only characterizes the quantitative liner association between HVA and pain intensity, which neglects the relationships of HVA and other radiographic measures. Using the MVPA approach and pattern information, the structural morphology of the entire foot was characterized. Recently, studies have shown that HV affected not only the first metatarsophalangeal joint but also the structure of the entire foot including the transverse arch structure (12) and sesamoid platform that led to the biomechanical changes in the foot (11). These findings indicated that the hallux valgus deformity was a multiplanar deformity that affected a wide range of foot structures and could not be adequately evaluated by HVA alone. Our current conclusion that the pattern of radiographic measures could be used to classify painful and pain-free HV also supported this concept. By applying feature selection procedures such as sequential backward selection and exhaustive search, an optimal feature subset which included HVA, IPA, DMAA, MAA and MPD was identified with the best classification performance. Therefore, the pattern of these metrics appeared to have strong correlation to foot pain in patients with HV.

Clinical significance

In our current study, we found that pain of HV was multifactorial and determined by multiple radiographic measurements. By applying sequential backward selection and exhaustive search, 5 measurements were identified as the optimal feature subset which showed optimal performance classifying painful and pain-free HV feet. It is worth mentioning that the importance of these metrics could not be ranked by our current procedure, and ranking the importance of these metrics would be partial considering our current data failed to include other pain-related factors such as soft tissue of the forefoot, which is also crucial to the pathology of HV. In clinical practice, surgical approaches were designed to correct HVA, DMAA and IMA. By applying distal soft tissue (e.g., McBride procedure) surgery and osteotomies (e.g., Chevron osteotomy, Scarf osteotomy, etc.), these deformities could be significantly corrected (i.e., HVA, IMA) and were effective to alleviate symptoms in HV patients (21). Therefore, from clinical aspect, these metrics would be more of importance than other measurements (3). The deformities measured by IPA, MAA and MPD were corrected only in patients with specific symptoms (e.g., kiss corn, metatarsus adductus and metastatic metatarsalgia) or with residual interphalangeus following metatarsal osteotomy (23). In general, our current results were consistent with clinical experience that the corrective surgery for HV should be holistic rather than only correct the HVA, DMAA and IMA. Our current results provided theoretic basis for this clinical consensus. More importantly, our results suggested that there is a pain-free HV subtype which exhibited similar HVA, DMAA and IMA to painful HV subtype. The differences between these two subtypes were IPA, MCA, indicating that when metatarsal osteotomy was unsatisfactory, other procedures for correcting IPA and MCA [e.g., Akin procedure (23) and Lapidus procedure] would be of potential efficacy for reducing clinical symptoms in HV patients. To our knowledge, the present study is the first conducted using MVPA to identify radiographic correlates of pain in HV patients. Future studies are still needed to validate our results.

Limitations

Regarding limitations in our current study: (1) we had no external validation set to verify our current results, so multi-center studies with larger sample sizes are needed; (2) we only included the axial images of plane radiographs, future studies are needed to encompass sagittal or even 3-dimensional imaging; (3) our current study is retrospective, lacking assessments of psychological factors which are also considered influential in HV patients with foot pain; (4) our current sample size is relatively small according to the Vapnik-Chervonenkis Dimension of the linear classifier. SVM is well-suited for modeling small samples with powerful

predictability, and we also conducted leave-one-out-cross-validation (LOOCV) to include as much data as possible in the training set for model training to minimize the possible effect of small sample size. Still, future study is needed to enlarge the sample size.

Conclusion

The pain in HV is multifactorial and associated with a radiographic pattern measured by the various angles on plain radiographs. The combination of HVA, IPA, DMAA, MAA and MPD showed the optimal classification performance between painful and pain-free HV.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary materials, further inquiries can be directed to the corresponding author/s.

Ethics statement

The studies involving human participants were reviewed and approved by Tianjin Medical Univerisity General Hospital. The patients/participants provided their written informed consent to participate in this study.

Author contributions

CW designed the study. RZhan, CL, and RZhao analyzed the data and wrote the manuscript. ZL, YZ, SL, and HZ collected the data. XC help analyzed the data. RZhao and CW revised the manuscript. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

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Optimizing bowel preparation for colonoscopy: A cross-sectional study of the Chinese population

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Background: The quality of bowel preparation is an important factor in the success of colonoscopy. However, the quality of bowel preparation is often affected by multiple factors. The main objective of this study was to explore the specific factors that affect the quality of bowel preparation.

Methods: Patients were consecutively recruited from the gastroenterology department in Union Hospital, Tongji Medical College, Huazhong University of Science and Technology in Wuhan from May 2018 to December 2018. All patients were undergoing colonoscopy. Bowel preparation was evaluated by the Ottawa Bowel preparation Scale (OBPS) and all patients were categorized into 2 groups according to the OBPS. Multivariate analysis was conducted to identify the factors associated with bowel preparation quality.

Results: A total of 910 patients were included in the analysis with an average age of 48.62 ± 13.57 years. Patient source ($P < 0.001$) and the preparation method ($P = 0.029$) were correlated with OBPS adequacy. In addition, after stratified by age, preparation method ($P = 0.022$) was a significant factor among patients under 50 years old; whereas waiting time ($P = 0.005$) was a significant factor among patients over 50 years old.

Conclusion: Bowel preparation should be tailored based on the age of the patients to determine the most appropriate plan, including the most appropriate waiting time and the most appropriate purgative combination. Doctors should also focus more on the quality of bowel preparation in inpatients, who are more likely than outpatients to have an inadequate bowel preparation.

KEYWORDS

bowel preparation, colonoscopy, Ottawa Bowel preparation Scale, age, quality of bowel preparation

Introduction

Colonoscopy is the preferred procedure for investigating large-bowel and terminal ileal disease in patients with digestive system disorders (1, 2). Given the high diagnostic sensitivity and specificity, colonoscopy had become the gold standard for colorectal adenoma and carcinoma among the populations at high risk (3). To observe bowel mucosa clearly for endoscopists, optimal bowel preparation is essential to achieve a high-quality colonoscopy (4, 5). However, the quality of bowel preparation is often affected by many factors, such as waiting time (the time between the last laxative administration and the beginning of colonoscopy), type and method of administration of laxative, patient compliance, etc. An inadequate bowel preparation regimen is an important factor that affects the adequacy of bowel preparation. It is reported that the rate of inadequate bowel preparation ranges from 20 to 30% (6). Therefore, it is crucial to improve the preparation adequacy rate.

A variety of different bowel preparation methods such as simethicone, mannitol, polyethylene glycol electrolyte (PEG) solution, and colonoscopy bowel capsule are available to be used to clean the bowel (7–9). However, as multiple factors may influence the preparation quality, none of the above bowel preparation methods has achieved satisfactory quality for both the clinician and the patient. It had been reported that patients' factors such as age, sex, education level, personal preference, and income status may be associated with the quality of bowel preparation (1, 10). In addition, as severe electrolyte disturbances may occur, the latest international guideline also recommends that the preparation protocol, especially the effectiveness of split dose preparation and adding bisacodyl or Senna to the standard preparation are also pivotal to good bowel preparation (11, 12). Yadav et al. reported that split-dose polyethylene glycol (PEG) was superior to single-dose PEG for patient compliance and side effects (13).

Nowadays, a lot of studies had reported the importance of preparation protocol in bowel preparation; however, the conclusions lack conformity (14, 15). Apart from the existing evidence, this study aimed to assess the variability of bowel preparation regimes employed within the inpatient and outpatient, and to find the correlation between different methods and the adequacy of bowel preparation before colonoscopy.

Methods

Patients enrolled

This was a single-center cross-sectional study. Patients were consecutively recruited from the gastroenterology department in Union Hospital, Tongji Medical College, Huazhong University of Science and Technology in Wuhan from May 2018 to December 2018. All patients were undergoing colonoscopy. Patients with allergies to the bowel preparations used, suspected or diagnosed with bowel obstruction, infectious disease, previous bowel preparation in the past 14 days, decompensated heart failure, severe acute renal failure, severe liver disease, or severe electrolyte imbalance were excluded from this study. The study was approved by the Ethics Committee of Union Hospital and conducted in accordance with the Declaration of Helsinki. Written informed consent forms were obtained from all participants.

All patients enrolled accepted one of the bowel preparation methods as follows according to the Chinese guideline for bowel preparation for colonoscopy (16). Briefly, bowel preparation methods were as follows: 1. Mannitol (Preparation method 1); 2. Three packs of Fu Jing Qing (Polyethylene Glycol Electrolytes), one pack at eight o 'clock the night before, one pack at four o 'clock in the morning, and one pack at five o 'clock (Preparation method 2); 3. Three packs of Fu Jing Qing (same time as above) and 1 bottle of Simeticone (Preparation method 3). The quality of bowel preparation was evaluated by the Ottawa Bowel preparation Scale, and those with OBPS $\leq$ 7 points were considered as qualified intestinal preparation (OBPS, 0–14 points, the higher the score, the worse the quality of bowel preparation) (7). All patient demographics including age, sex, source, preparation method, wait time, and patient self-assessment were extracted manually from electronic medical records.

Statistics

The baseline characteristics of participants with adequate or inadequate OBPS were compared using the chi-square test for categorical variables and the two-sample *t*-test for continuous variables. A *P*-value of < 0.05 was considered statistically significant. Odds ratios (OR) and 95% confidence intervals (CI) for the association between OBPS adequacy and potential risk factors were estimated using the multivariable logistic regression model. An OR>1 is associated with a higher Ottawa score, and consequently, poorer bowel preparation. The association was further analyzed in different age groups using the multivariable logistic regression model. All statistical analyses were performed using R software, version 4.1.1.

Results

Basic characteristic

A total of 922 patients were recruited, and finally, 910 patients were included in the analysis after removing missing values, as shown in Figure 1. The average age of the patients was 48.62 $\pm$ 13.57 years. Among them, 831 had adequate bowel

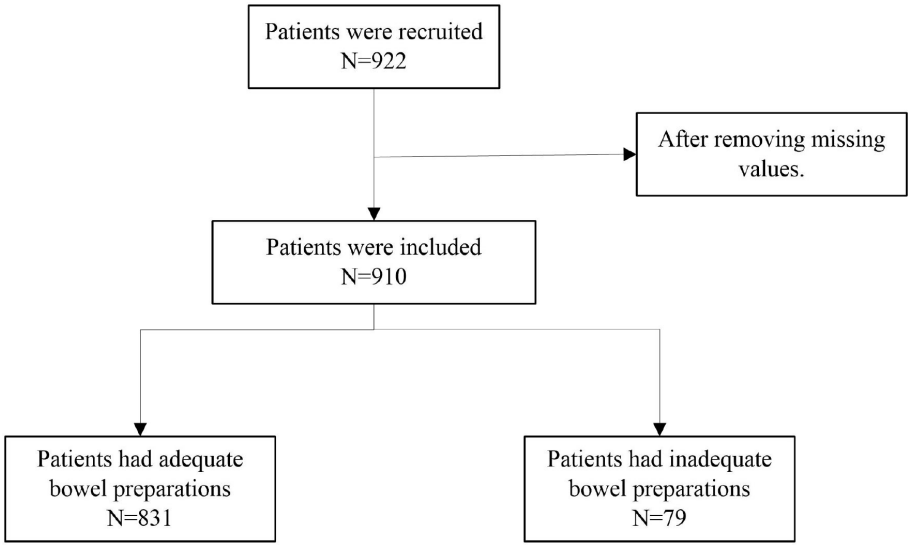

FIGURE 1
Flow chart of patients included in the experiment.

preparations, with an average age of 48.47 ± 13.54 years. A total of 79 patients had inadequate bowel preparations, with an average age of 50.24 ± 13.87 years. Of all patients, 363 were from the inpatient unit and 547 were from the outpatient unit. A total of 315 (37.91%) patients from the inpatient care and a total of 516 (62.09%) patients from the outpatient care had got adequate preparations. In addition, 672 (80.87%) patients who got adequate preparations and 61 (77.22%) patients who got inadequate preparations received the third preparation method. The baseline characteristics of patients stratified by preparation adequacy were summarized in Table 1.

The relationship between the OBPS and the risk factors

Briefly, a total of 831 patients were qualified according to the OBPS. After conducting a univariate analysis of patients' age, gender, source (inpatient/outpatient), preparation method, waiting time, and self-assessment with the OBPS adequacy rate, we found that the effect of patient source on the OBPS adequacy rate was statistically significant ($P < 0.001$).

The results of the multivariate analysis of the OBPS adequacy rate were shown in Table 2. After further integrating all the above factors into the logistic regression model, we found that the source ($P < 0.001$) had statistically significant effects on whether the OBPS was adequate. The results showed that inpatients were more likely to have inadequate OBPS than outpatients (OR = 3.18). We also found that the preparation method ($p = 0.029$) had significant effects on whether the OBPS was adequate. The results showed that patients who used the first preparation method were more likely to have inadequate OBPS than patients who used the third preparation method (OR = 2.27).

Multivariate analysis: The relationship between OBPS adequacy and risk factors in patients less than or over 50 years old

The results of the multivariate analysis of the OBPS adequacy rate stratified by age were shown in Table 3. Age, sex, source, preparation plan, waiting time, and patient self-assessment results were incorporated into the logistic regression model (<50 years or ≥ 50 years). It was found that source ($P = 0.001$) and preparation method ($P = 0.022$) had significant effects on whether the OBPS was adequate for patients who were < 50 years old. The results showed that inpatients were more likely than outpatients to have an inadequate OBPS (OR = 3.79); and patients who used preparation method 1 were more likely to have an inadequate OBPS than patients who used preparation method 3 (OR = 3.05). For those patients who were older than or equal to 50 years old, patient source ($P = 0.005$), waiting time 6–8 h ($P = 0.005$), and patient self-assessment ($P = 0.039$) had significant effects on OBPS adequacy. The results showed that inpatients were more likely to have an inadequate OBPS than outpatients (OR = 3.15); patients who waited between 6 and 8 h were more likely to have an inadequate OBPS than patients who waited between 4 and 6 h (OR = 3.65); and patients who had a higher self-assessment score were more likely to have an adequate OBPS (OR = 0.41).

TABLE 1 Baseline characteristics of the OBPS.

Variable	All ($n = 910$)	Adequate ($n = 831$)	Inadequate ($n = 79$)	*P* Value
Age (yrs)	48.62 ± 13.57	48.47 ± 13.54	50.24 ± 13.87	0.279
Gender (male)	555 (60.99)	505 (60.77)	50 (63.29)	0.661
Source				
Inpatient	363 (39.89)	315 (37.91)	48 (60.76)	<0.001
Outpatient	547 (60.11)	516 (62.09)	31 (39.24)	
Preparation method				
One	69 (7.58)	63 (7.58)	6 (7.59)	0.630
Two	108 (11.87)	96 (11.55)	12 (15.19)	
Three	733 (80.55)	672 (80.87)	61 (77.22)	
Waiting time (h)				
< 4	102 (11.21)	96 (11.55)	6 (7.59)	0.186
(4–6)	311 (34.18)	290 (34.90)	21 (26.58)	
(6–8)	360 (39.56)	324 (38.99)	36 (45.57)	
≥ 8	137 (15.05)	121 (14.56)	16 (20.25)	
Patient self-evaluation score	3.78 ± 0.44	3.78 ± 0.43	3.73 ± 0.50	0.400

Discussion

The effectiveness of a colonoscopy depends on adequate bowel preparation (17); however, adequate bowel preparation is a complex process that is influenced by several factors. In this study, we proposed a single-center cross-sectional study to evaluate the risk factors that may influence bowel preparation. The results showed that patient source ($P < 0.001$) and the preparation method ($P = 0.029$) were important risk factors that might influence the quality of bowel preparation. This was in accordance with what cao et al. had reported in a meta-analysis (9). Furthermore, after stratified by age, preparation method ($P = 0.022$) was a significant factor among patients under 50 years old; whereas waiting time ($P = 0.005$) was a significant factor among patients over 50 years old.

Due to its high diagnostic sensitivity and specificity, colonoscopy has become the gold standard for colorectal cancer screening (18). The quality of a colonoscopy depends on adequate visualization, which relies on the quality of bowel cleaning. It has been shown that up to 26% of adenomas are missed by standard colonoscopy. This missing rate could be decreased by adequate bowel preparation and auxiliary techniques (19). Thus, it is important to choose a suitable method according to the patient's self-physical condition before the colonoscopy (20). Seo et al. found that the time interval between the last dose of the agent and the start of colonoscopy is one of the important factors to determine satisfactory bowel preparation quality (21). Ray-Offor et al. have reported that the educational status of patients is a strong risk factor associated with inadequate bowel preparation for colonoscopy in the Nigerian population (22). Therefore, it is necessary to further explore the factors that may influence bowel preparation quality.

TABLE 2 Multivariate analysis of factors associated with the OBPS.

Variable	Odds ratio	95% CI	*P* Value
Age (yrs)	1.00	0.98–1.02	0.750
Gender (male)	1.24	0.76–2.05	0.397
Source (inpatient)	3.18	1.83–5.66	<0.001
Preparation method			
Three	1 (Reference)		
One	2.27	1.05–4.65	0.029
Two	0.77	0.28–1.75	0.559
Waiting time (h)			
(4–6)	1 (Reference)		
< 4	0.91	0.32 – 2.23	0.844
(6–8)	1.55	0.88 – 2.78	0.133
≥8	1.44	0.70 – 2.88	0.313
Patient self-evaluation score	0.73	0.44 – 1.25	0.232

In our study, we found that inpatients were more likely than outpatients to have inadequate bowel preparation (OR = 3.18). The reason for the result might be that inpatients have a more serious disease than outpatients. We also found that patients who used the first preparation method were more likely to have inadequate OBPS than patients who used the third preparation method (OR = 2.27). In addition, after stratified by age, the preparation method was a significant predictor for the OBPS adequacy among patients under 50 years old; while waiting time was a significant predictor among patients over 50 years old. For patients under 50 years old, those who used preparation method 1 were more likely to have an inadequate bowel preparation than

TABLE 3 Multivariate analysis of factors associated with the OBPS segmented by age.

Subgroup	Variable	Odds ratio	95% CI	*P* Value
Age group (< 50 years)	Age (years)	1.00	0.95–1.04	0.914
	Gender (male)	0.86	0.42–1.84	0.686
	Source (inpatient)	3.79	1.71–8.70	0.001
	Preparation method			
	Three	1 (Reference)		
	One	3.05	1.13–7.88	0.022
	Two	0.32	0.02–1.68	0.281
	Waiting time (h)			
	(4–6)	1 (Reference)		
	<4	0.41	0.06–1.66	0.271
	(6–8)	0.66	0.28–1.52	0.330
	≥8	1.27	0.48–3.21	0.615
	Patient self-evaluation score	0.96	0.50–1.99	0.911
Age group (≥ 50 years)				
	Age (years)	1.01	0.97–1.06	0.555
	Gender (male)	1.72	0.88–3.45	0.117
	Source (inpatient)	3.15	1.45–7.31	0.005
	Preparation method			
	Three	1 (Reference)		
	One	1.79	0.47–5.66	0.346
	Two	1.12	0.35–3.01	0.829
	Waiting time (h)			
	(4–6)	1 (Reference)		
	<4	2.07	0.51–7.40	0.273
	(6–8)	3.65	1.57–9.62	0.005
	≥8	1.66	0.53–5.15	0.374
	Patient self-evaluation score	0.41	0.18–1.00	0.039

those who used the preparation method 3 (OR = 3.05); and for patients over 50 years old, those who waited between 6 and 8 h before colonoscopy were more likely to have an inadequate bowel preparation than those who waited between 4 and 6 h before colonoscopy (OR = 3.65). Our study was in accordance with what had been reported by other researchers (23–25).

This study has several limitations. First, it was conducted at a single center and was a single-arm, retrospective study, which may cause bias of the results. Second, it has demonstrated that patient-related factors like drugs intake, previous abdominal surgery, and chronic constipation may be associated with an increased risk of inadequate preparation; nevertheless, we did not enroll these factors, which may influence the accuracy of the results (26–29). Third, past research showed that poor patient compliance may also cause inadequate bowel preparation (30). Educating and motivating patients to improve compliance could obtain better bowel cleansing; however, our study did not evaluate such aspect. Last but not least, tolerability is a major factor in good bowel preparations. Most patients that use laxatives to promote bowel preparation may experience nausea, vomiting, and other adverse reactions, which may also influence the quality of bowel preparation.

Conclusion

In conclusion, we believe that bowel preparation should be tailored based on the age of the patients to determine the most appropriate plan, including the most appropriate waiting time and the most appropriate purgative combination. In addition, the results of our study showed that doctors should focus more on the quality of bowel preparation in inpatients, who are more likely than outpatients to have inadequate bowel preparation.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Ethics statement

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. Written informed consent for participation was not required for this study in accordance with the national legislation and the institutional requirements. Ethical review and approval was not required for the animal study because this project is a retrospective study.

Author contributions

LL wrote the manuscript. LL, EW, YLiu, and LZ collected the data. YLi, KL, YLai, HG, and DJ assisted with data statistics and interpretation. All authors have read and approved the final version of the manuscript.

Conflict of interest

Authors YLi, KL, YLai, HG, and DJ were employed by DHC Mediway Technology Co., Ltd.

The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Global burden and trends of pelvic organ prolapse associated with aging women: An observational trend study from 1990 to 2019

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Purpose: Worldwide, about 40% of women will experience pelvic organ prolapse (POP), and this proportion is expected to increase with the aging of the population. We investigated the global, regional and national influenza burden in the past 30 years through the age and sociodemographic index (SDI).

Patients and methods: Data were extracted from the Global Burden of Disease (GBD) 2019 database for 195 countries and territories between 1990 and 2019. Estimated annual percentage changes (EAPCs) were used to explore the age-standardized incidence rate (ASIR) and age-standardized disability adjusted life years (AS-DALYs) trends, and the corresponding 95% uncertainty intervals (UI). In addition, the time cut-off points of 1990 and 2019 were used to separately analyze the incidence rate and DALYs.

Results: In 2019, the global ASIR and AS-DALYs for POP were 316.19 (95%UI: 259.84–381.84) and 10.37 (95%UI: 5.79–17.99) per 100,000 population, respectively. Moreover, from 1990 to 2019, the ASR of both showed a downward trend, and EAPCs were −0.46 (95%CI: −0.52 to −0.4) and −0.53 (95%CI: −0.58 to −0.47), respectively. In addition, DALYs of POP also showed a downward trend in most regions and countries with high SDI. From 1990 to 2019, the global incidence rate and DALYs rate were highest in the 65–75 and ≥60 age groups, respectively.

Conclusion: Over the past three decades, the incidence and DALY of POP have been decreasing from 1990 to 2019. However, POP remains a major health problem, especially among females in less developed countries. Primary and secondary prevention measures of POP should be integrated into the practice of healthcare professionals dealing with aging women.

KEYWORDS

aging, pelvic organ prolapse, epidemiology, incidence, disability adjusted life years

Introduction

The aging process has always been the main risk factor for the development of age-related diseases (1, 2). The World Health Organization (who) has issued disease standards to apply to the aging assessment of human organisms, which directly defines aging phenomena and can be classified as diseases (3–5).Worldwide, pelvic organ prolapse (POP) is defined as descent of pelvic organs from the normal anatomic position usually to or beyond the hymenal remnants, owing to loss of support from the connective tissue, muscles, or both. It can lead to symptoms of pelvic pressure, vaginal bulge, urinary and bowel dysfunction, and sexual dysfunction in elderly patients (6–8). However, aging was the most frequently reported risk factor for POP, followed by parity and obesity (9). It is reported that the proportion of women aged 70–79 seeking medical consultation due to symptomatic POP is the highest, as high as 18.6/1,000 (10, 11). And most remarkably, POP remains a problem even in high-income countries, as shown in the United States, the annual incidence rate of POP is 1.5–1.8/1,000, and the highest incidence rate is among women aged 60–69 (11, 12). Given the aging population in the United States, the number of women suffering from POP is expected to increase by about 50% by 2050 (6). A study from the Gambia found that 46% of women had some degree of prolapse on examination, but only 12.5% of the women reported symptoms related to POP (13). Another study predicted that the total number of women who will undergo surgery for POP disorders will increase 48.1% by 2050 due to the aging population (14). Undoubtedly, the development of POP disrupts the quality of life (QoL) and damages social and personal activities. In general, the QoL among women with prolapse was worse than that of the age-standardized population. Although most patients perceived their condition to be improved after non-surgical and surgical treatment (15), POP is still highly prevalent among rural women and remains untreated (16). In general, POP, as the most important factor affecting the health quality of elderly women, its incidence rate has attracted more and more attention, and taking necessary prevention and control strategies is the fundamental to truly improve the health quality of these women.

To date, the treatment of POP depends on the symptoms, type, and grade of prolapse and any related medical complications, including observation, non-surgical and surgical techniques (9). Management should be individualized and guided by what the patient wishes to achieve. Notably, surgical treatments are often performed in the women with more severe prolapse and associated symptoms. For example, transvaginal bilateral sacrospinous fixation appears to be safe and effective to improve both the QoL and sexual functions in patients with second recurrence of vaginal vault prolapse (17, 18). Da-Vinci robotic system was also feasible for the treatment of pelvic organ prolapse with 95% surgical success rate (19). In addition, biocompatible porcine dermis graft to treat severe cystocele considerably improves the QoL and sexual function, and does not influence clitoral blood flow (20). However, the management of POP worldwide is a common and challenging task, especially since the exact prevalence is difficult to establish. In addition, the severity and degree of symptoms can vary widely, so it is difficult to determine and define "treatment success." To some extent, the diagnosis and treatment of pop still need to be continuously optimized and improved. Up to now, there is still a long way to go.

According to existing studies, the reported prevalence of POP varies widely, ranging from 3 to 50% (21–23). Therefore, up-to-date and comprehensive evidence in this regard is essential for the development of intervention strategies, especially epidemiological investigations are urgently needed on a variety of issues, including women's views on prolapse symptoms and the exact incidence trend. Fortunately, the global burden of disease (GBD) studies have derived detailed and comparable epidemiological and burden of disease estimates for POP (24).

As with most non-communicable diseases, a better understanding of the epidemiology of pelvic floor dysfunction may help to improve the effectiveness of prevention and treatment. Given this, the study introduces the global burden and trends of GBD 2019 research, describes the incidence rate, life lost year (YLS), disability year (YLDs), and disability-adjusted life year (DALYs) in 195 countries (including the time nodes in 1990 and 2019, and the trend of EAPC over 30 years), and provides information for POP control through policy, resource allocation and health system planning.

Materials and methods

A framework of the 2019 GBD study

In this study, we obtained the data from GBD 2019 using the online Global Health Data Exchange (GHDx) query tool (http://ghdx.healthdata.org/gbd-results-tool), including incidence cases, DALY across 195 countries (e.g., taking 1990 and 2019 as time nodes, the 2 years were analyzed separately), as shown in Figure 1. To further investigate the global burden of POP, the social-demographic index (SDI) was used to classify these countries and regions into five categories, namely high SDI, high-middle SDI, middle SDI, and low-middle SDI, and low SDI (25, 26). Additionally, we also drew the world map to observe the incidence rate and DALY of POP in 195 countries, and the corresponding trend in different countries and regions over the three decades. This study complies with the provisions of the Helsinki Declaration (revised in 2013) and was approved by the Institutional Review Committee of Tongji Hospital, Tongji Medical College, Huazhong University of Science and Technology (TJ-IRB20210631).

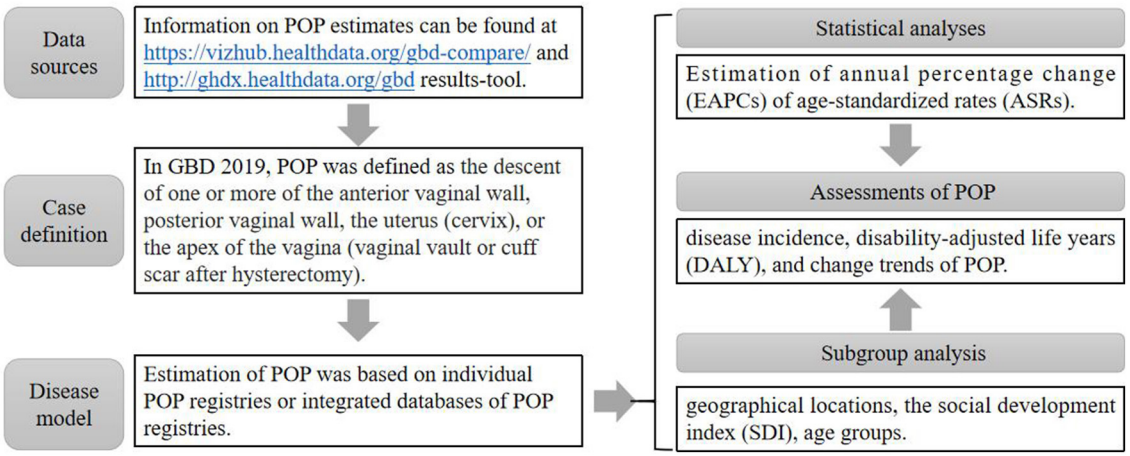

FIGURE 1
Flow chart of GBD data acquisition. Notes. ASR is assumed to be linear along with time; that is, $Y = \alpha + \beta X + \varepsilon$, where Y refers to ln (ASR), X the calendar year, and ε the error term. Based on this formula, β represents the positive or negative ASR trends. The EAPC was calculated as EAPC = 100 × (exp(β)-1). Its 95% confidence intervals (CI) could be obtained from the linear model. Disability-adjusted life-years for any corresponding subpopulation of a specific cause was the sum of the corresponding YLDs and YLLs. YLLs: years of life lost; YLDs: years lived with disability. Social development index (SDI). The SDI, which is based on national-level income per capita, average years of education among persons older than 15, and total fertility rate, was used to categorize the countries into five SDI quintiles (high, high-medium, medium, low-medium, and low levels).

Statistical analysis

To evaluate trends of incidence and burden for POP, we calculated relevant evaluation indicators, namely the annual age-standardized incidence rate (ASIR) and age-standardized DALY rate (AS-DALY), and the corresponding estimated annual percentage changes (EAPCs). Among them, DALY is the sum of years lived with disability (YLD) and years of life lost (YLLs) (27). EAPC is a widely used index that describes the trend of ASR (28), which can be calculated using a linear regression model as follows:

$$ln\,(ASR) = \alpha + \beta\, x + \varepsilon,$$
$$EAPC = 100 \times \left(exp\,(\beta) - 1\right).$$

In where x refers to the calendar year, and the ASR was obtained as follows:

$$ASR = \frac{\sum_{i=1}^{A} aiwi}{\sum_{i=1}^{A} wi} * 100,000.$$

(In the ith age subgroup, $a_i$is represented as age class. w_i denotes the number of persons (or weight), where i is equal to the selected reference standard population) (29). Meanwhile, the judgments of trends were the follows: (1) an increasing trend of ASR was found when both the EAPC value and its 95% CI >0; (2) a decreasing trend of ASR was found when both the EAPC value and 95% CI <0; and (3) any other trends meant the ASR was stable over time (30, 31). In general, EAPC can be used to evaluate the ASIR and AS-DALY of POP over the past 30 years. At the same time, a cross-sectional comparison of the incidence rate and DALY before and after 30 years was made at the time points of 1990 and 2019.

In addition, the human development index SDI is a sociodemographic variable to help differentiate countries to classify the world population in homogeneous groups through more comprehensive indicators (25), which can be used as the evaluation index of health care level in each country. We also used a scatter diagram for visualization to depict the correlation between EAPC, ASR, and SDI, in which the Pearson's correlation coefficient (R) represents the strength of the correlation. All analysis was performed using the Python programming language (version 3.9.2, Python Software Foundation, https://www.python.org/) and R Project for Statistical Computing (version 4.0.4, http://www.r-project.org/).

Results

Age-standardized incidence rate trends of POP

At the global level, there were 13 million (95% UI: 11–16) incident cases of POP in 2019, with an age-standardized incidence rate of 316.19 per 100,000 population (95% UI: 259.84–381.84), which is 0.85% lower than in 1990 (95% UI: 304.93–455.87).

As for age distribution, the ratio of female incidence among different ages showed a bimodal distribution, with peaks in the

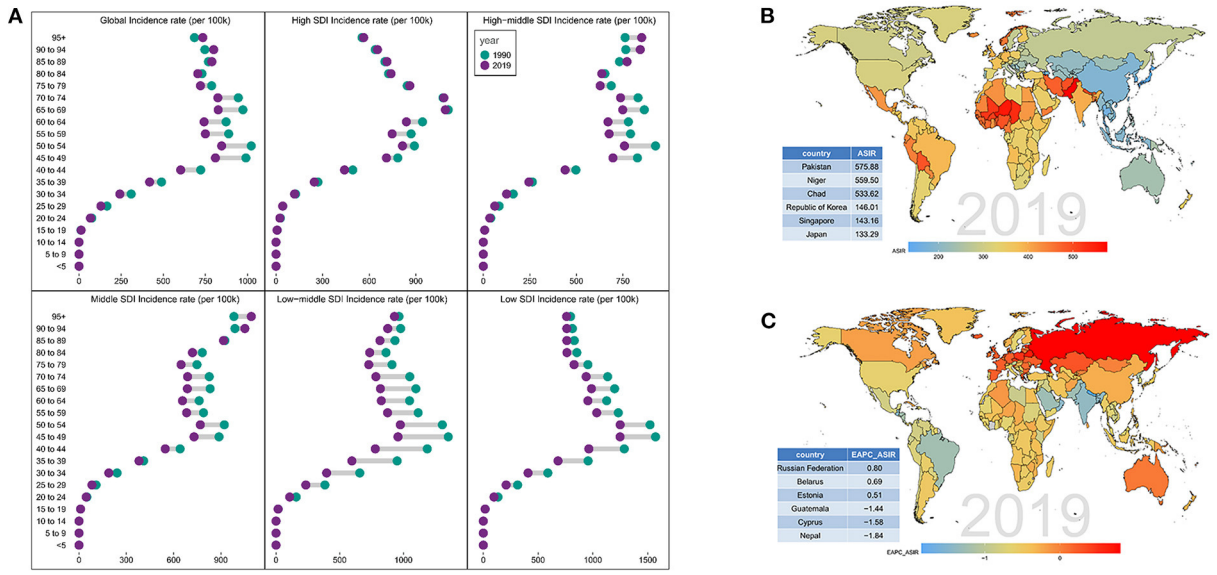

FIGURE 2
Distribution of incidence rate in different SDI regions. **(A)** Age distribution of incidence rate in different SDI regions from 1990 to 2019. Distribution of **(B)** ASIR and **(C)** EAPC-ASIR in various countries and regions in 2019.

50–54 years and 65–69 years age groups (Figure 2). Regarding SDI level analysis, the ASIR in the low SDI region was on the decline with EAPCs of –0.79 (95% CI, from –0.87 to –0.72). The ASIR in the other four SDI regions was stable. In addition, we found that the higher the SDI, the lower the proportion of elderly incidence cases among all POP incidence cases, while the proportion of young incident cases was relatively stable. The proportion of annual young incidence cases decreased year by year, while the proportion of elderly incident cases increased year by year, as shown in Table 1 and Supplementary Figure 1.

On observation from the GBD regions and countries level, the ASIR showed an upward trend in 27 countries, a stable trend in 145 countries, and a downward trend in 23 countries. Among them, the three countries with the highest ASIR were Russian, Belarus, and Estonia; the three countries with the lowest ASIR were Guatemala, Cyprus, and Nepal (Figure 2 and Supplementary Figure 2). As shown in Supplementary Table 1 and Supplementary Figure 3, most countries had an unimodal age distribution, with peak in elderly (≥65) years age groups.

Age-standardized DALY rate trends of POP

At the global level, there were 0.27 million (95% UI: 0.15–0.48) DALYs in 1990 and 0.44 million (95% UI: 0.25–0.76) DALYs in 2019. In the past 30 years, the age-standardized DALY rate decreased significantly with an EAPC of −0.53 (95%CI: from −0.58 to −0.47), dropping from 12.39/100,000 persons (95% UI, 6.81–21.45) in 1990 to 10.37/100,000 persons (95% UI, 5.79–17.99) in 2019, as shown in Table 2.

On analysis from the SDI level, the age-standardized DALY rate in all the SDI regions declined. As for age distribution, the ratio of female incidence among different ages also showed a bimodal distribution, with peaks in 60–64 and 70–74 years age groups (Figure 3 and Supplementary Figure 2). On observation from the GBD regions and countries level, the age-standardized DALY rate in most regions declined and few countries had a rising trend. Among them, the three countries with the highest age-standardized DALY rate were Russian, Belarus, and Estonia; the three countries with the lowest age-standardized DALY rate were Cyprus, Nepal, and Guatemala (Figure 3; Supplementary Table 2; Supplementary Figure 3). Consistent with the trend of ASIR, most countries also showed an unimodal age distribution, with peak in elderly (≥65) years age groups.

Correlation analysis of POP related ASIR, age-standardized DALYs and different SDI

Regarding SDI level analysis of ASIR, as shown in Figure 4 and Supplementary Figure 4, we found a positive correlation between EAPC and SDI ($R = 0.3$, $P < 0.001$) and a negative correlation between EAPC and the ASIR ($R = -0.5$, $P < 0.001$). We also found that the higher the SDI, the lower the proportion

TABLE 1 Trends of incidence and age-standardized incidence rate of POP from 1990 to 2019.

	1990		2019		1990–2019
	Incidence cases No. *10^2 (95% UI)	ASIR per 100,000 No. (95% UI)	Incidence cases No. *10^2 (95% UI)	ASIR per 100,000 No. (95% UI)	EAPC No. (95% CI)
Overall	84,122.61 (68,784.94–101,956.8)	374.13 (304.93–455.87)	134,356.17 (110,470.39–162,580.97)	316.19 (259.84–381.84)	−0.46 (−0.52 to −0.4)
Socio-demographic index					
High SDI	16,005.37 (12,733.72–19,681.84)	309.2 (247.98–379.37)	22,790.44 (18,346.29–27,452.41)	286.75 (234.02–345.28)	−0.24 (−0.29 to −0.19)
High-middle SDI	17,239.01 (14,062.61–20,954.33)	294.9 (241.4–356.99)	25,882.63 (21,158.29–31,201.37)	254.6 (208.21–307.24)	−0.2 (−0.38 to −0.02)
Middle SDI	20,399 (16,780.84–24,700.03)	327.85 (269.43–397.11)	38,191.7 (31,304.14–46,301.37)	279.64 (230.45–338.18)	−0.41 (−0.47 to −0.34)
Low-middle SDI	21,267.98 (17,224.96–25,625.5)	544.75 (443.96–663.8)	31,151.71 (25,371.07–37,953.98)	384.71 (313.01–466.05)	−1.13 (−1.16 to −1.09)
Low SDI	9,167.83 (7,377.82–11,170.26)	573.76 (462.15–704.91)	16,266.27 (13,015.84–20,002.25)	450.56 (363.13–552.97)	−0.79 (−0.87 to −0.72)
Region					
Andean Latin America	752.35 (593.55–935.44)	570.95 (451.81–713.18)	1,406.77 (1,103.42–1,782.06)	451.87 (354.36–572.57)	−0.76 (−0.83 to −0.69)
Australasia	318.23 (244.98–401.76)	274.24 (211.24–348.74)	558.07 (430.09–707.5)	257.9 (198.76–328.94)	−0.01 (−0.16 to 0.14)
Caribbean	691.35 (539.28–868.42)	463.09 (359.65–581.46)	998.7 (782.05–1,267.13)	380.78 (297.54–483.43)	−0.59 (−0.64 to −0.54)
Central Asia	631.8 (476.27–825.04)	236.72 (179.98–308.55)	974.58 (731.89–1,290.72)	209.28 (159.45–272.78)	−0.03 (−0.31 to 0.25)
Central Europe	2,216.68 (1,700.76–2,828.08)	291.54 (226.04–369.79)	2,681.38 (2,078.41–3,339.39)	285.18 (223.88–357.91)	0.2 (−0.15 to 0.55)
Central Latin America	2,491.91 (2,005.08–3,087.69)	481.39 (384.53–595.59)	5,262.08 (4,223.73–6,493.41)	395.48 (317.52–484.57)	−0.87 (−0.97 to −0.78)
Central Sub-Saharan Africa	680.35 (522.39–871.37)	432.06 (334.42–549.5)	1,443.66 (1,107.3–1,866.74)	373.99 (290.29–484.99)	−0.49 (−0.55 to −0.43)
East Asia	10,962.61 (9,022.15–13,225.68)	229.1 (189.06–275.35)	20,434.6 (16,550.46–24,604.78)	187.39 (153.59–224.11)	−0.29 (−0.45 to −0.12)
Eastern Europe	4,498.95 (3,597.33–5,495.37)	282.68 (230.68–341.88)	4,915.26 (3,890.69–5,941.41)	274.03 (222.36–332.86)	0.63 (0.19 to 1.07)
Eastern Sub-Saharan Africa	2,086.69 (1,650.78–2,590.28)	408.1 (325.88–510.5)	4,257.01 (3,362.62–5,273.88)	354.47 (283.99–439.85)	−0.49 (−0.53 to −0.45)
High-income Asia Pacific	1,755.61 (1,390.22–2,183.16)	156.78 (123.95–194.07)	2,655.29 (2,122.98–3,290.68)	137.27 (109.39–168.4)	−0.46 (−0.58 to −0.35)
High-income North America	5,945.08 (4,766.44–7,117.74)	343.81 (275.78–419.16)	8,939.85 (7,286.23–10,580.24)	308.07 (255.82–364.37)	−0.57 (−0.62 to −0.52)
North Africa and Middle East	5,197.59 (4,016.46–6,647.03)	479.89 (375.84–610.31)	11,315.82 (8,689.89–14,482.75)	404.91 (315.66–517.75)	−0.49 (−0.53 to −0.45)
Oceania	45.19 (34.48–58.56)	251.67 (191.61–323.85)	105.37 (79.69–136.77)	238.8 (180.08–308.62)	−0.19 (−0.2 to −0.18)
South Asia	24,520.07 (19,976.26–29,268.47)	641.36 (524.62–778.36)	35,229.59 (28,670.56–42,515.64)	423.87 (345.17–509.44)	−1.35 (−1.39 to −1.32)
Southeast Asia	3,570.08 (2,877.16–4,422.04)	228.24 (183.13–281.89)	6,923.95 (5,509.33–8,571.86)	193.81 (155–239.76)	−0.54 (−0.58 to −0.5)
Southern Latin America	994.51 (757.57–1,265.74)	403.05 (308.07–517.52)	1,347.59 (1,031.83–1,726.17)	328.04 (251.69–421.67)	−0.6 (−0.67 to −0.54)
Southern Sub-Saharan Africa	669.02 (550.71–812.08)	378.31 (307.77–462.2)	1,191.4 (974.93–1,454.48)	329.6 (269.07–400.74)	−0.48 (−0.49 to −0.47)
Tropical Latin America	3,558.47 (2,886.98–4,258.26)	519.18 (423.03–617.64)	5,079.21 (4,205.11–6,011.8)	389.45 (323.24–459.71)	−1.22 (−1.32 to −1.12)
Western Europe	9,448.94 (7,434.98–11,949.92)	363.72 (284.19–461.37)	11,853.66 (9,357.98–14,826.06)	350.41 (276.38–436.77)	0.05 (−0.06 to 0.16)
Western Sub-Saharan Africa	3,087.15 (2,491.08–3,791.73)	575.92 (464.99–712.95)	6,782.33 (5,455.42–8,406.39)	486.24 (392.93–600.38)	−0.57 (−0.62 to −0.52)

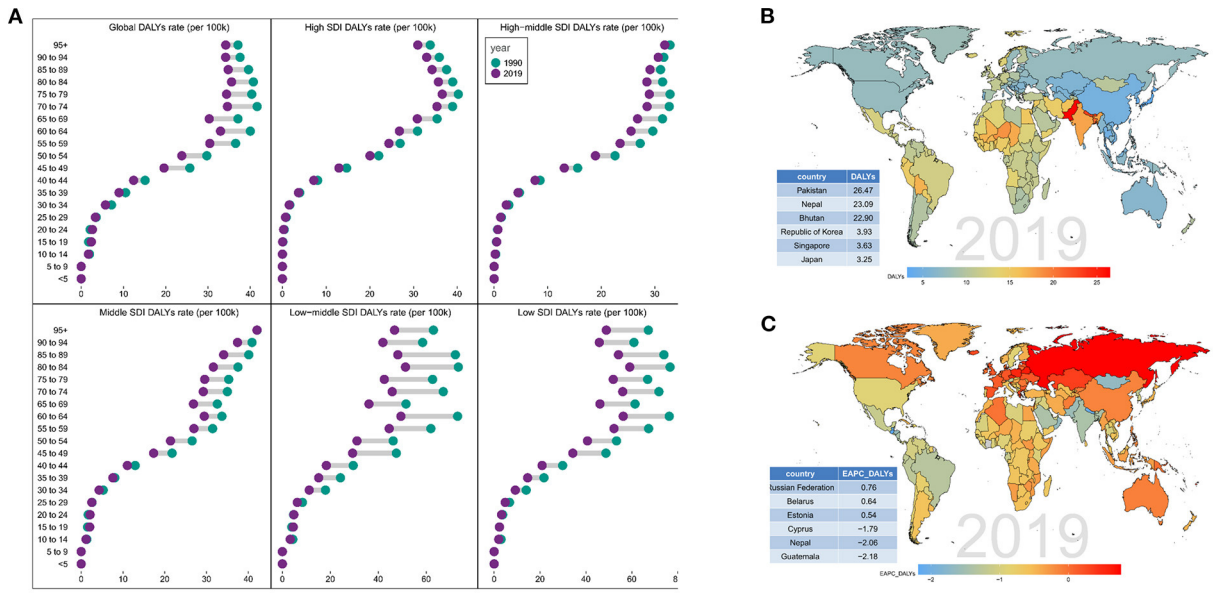

FIGURE 3
Distribution of DALYs in different SDI regions. **(A)** Distribution of DALYs of different age proportions in different SDI regions from 1990 to 2019. Distribution of **(B)** DALY and **(C)** EAPC-DALY in various countries and regions in 2019.

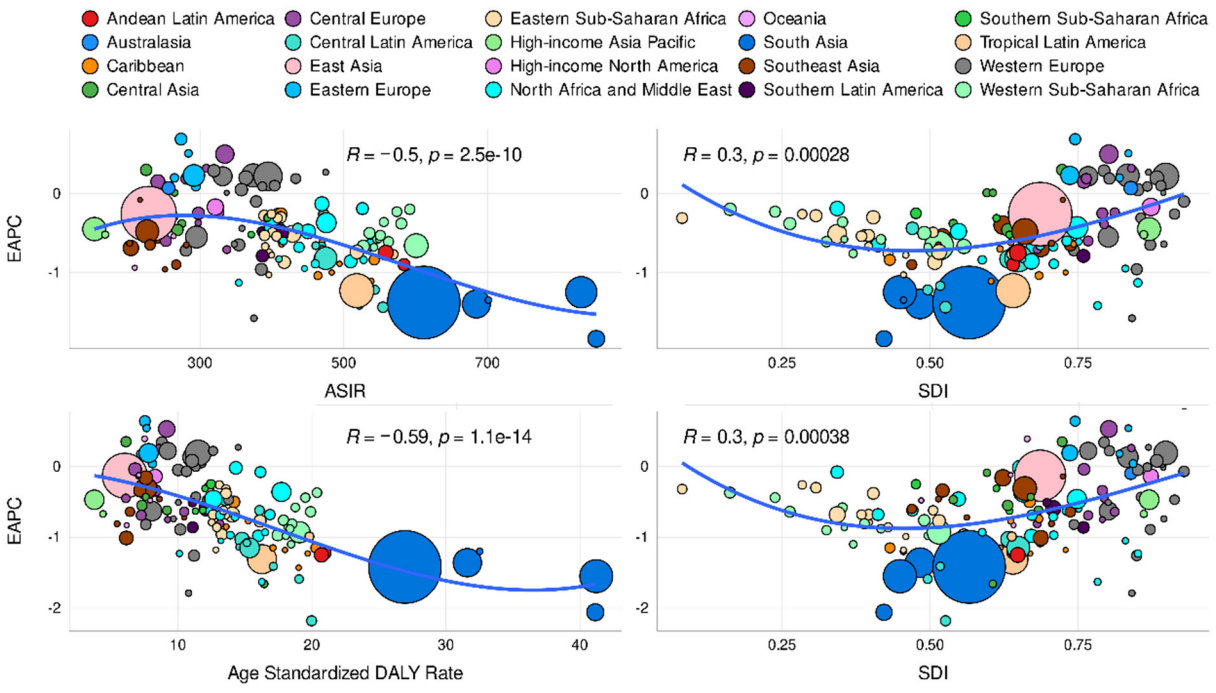

FIGURE 4
Correlation analysis of different SDI regions, age-standardized DALYs and EAPC of global POP from 1990 to 2019.

TABLE 2 Trends in disability adjusted life years and age-standardized disability adjusted life years of POP from 1990 to 2019.

	1990		2019		1990–2019
	DALY No. *10^3 (95% UI)	Age-standardized DALY Rate per 100,000 No. (95% UI)	DALY No. *10^3 (95% UI)	Age-standardized DALY Rate per 100,000 No. (95% UI)	EAPC No. (95% CI)
Overall	275.96 (154.52–475.31)	12.39 (6.81–21.45)	441.77 (245.44–763.52)	10.37 (5.79–17.99)	−0.53 (−0.58 to −0.47)
Socio-demographic index					
High SDI	47.05 (23.53–87.84)	8.58 (4.26–16.01)	67.05 (32.97–125.48)	7.67 (3.75–14.37)	−0.4 (−0.43 to −0.37)
High-middle SDI	49.77 (24.93–92.6)	8.37 (4.17–15.63)	76.74 (38.34–143.43)	7.28 (3.64–13.39)	−0.19 (−0.37 to 0)
Middle SDI	63.6 (35.06–110.72)	10.56 (5.73–18.5)	121.67 (68.03–209.88)	9.04 (5.07–15.77)	−0.42 (−0.49 to −0.36)
Low-middle SDI	82.2 (48.22–136.66)	22.32 (12.99–37.3)	120.19 (70.59–209.16)	15.22 (8.91–26.66)	−1.27 (−1.31 to −1.23)
Low SDI	33.2 (18.74–56.74)	22.7 (12.53–39.13)	55.89 (31.73–94.45)	16.82 (9.49–28.96)	−0.98 (−1.06 to −0.9)
Region					
Andean Latin America	2.59 (1.46–4.52)	20.94 (11.36–37.27)	4.55 (2.33–8.32)	14.95 (7.61–27.59)	−1.17 (−1.3 to −1.03)
Australasia	0.94 (0.47–1.72)	7.72 (3.88–14.32)	1.65 (0.78–3.14)	7.03 (3.3–13.44)	−0.17 (−0.34 to 0.01)
Caribbean	2.3 (1.23–4.11)	16.09 (8.6–28.83)	3.37 (1.79–6.21)	12.63 (6.72–23.23)	−0.79 (−0.84 to −0.74)
Central Asia	2.05 (1.12–3.68)	7.29 (3.99–13.14)	2.88 (1.53–5.14)	6.36 (3.43–11.51)	−0.13 (−0.4 to 0.14)
Central Europe	6.7 (3.32–12.47)	8.21 (4.08–15.14)	8.36 (4.04–16.05)	7.85 (3.77–14.91)	0.14 (−0.24 to 0.52)
Central Latin America	7.4 (3.95–13.28)	15.48 (8.18–28.09)	15.21 (7.47–28.57)	11.65 (5.73–21.86)	−1.19 (−1.32 to −1.05)
Central Sub-Saharan Africa	2.28 (1.19–4.03)	16.1 (8.43–28.68)	4.49 (2.44–7.93)	12.95 (6.87–23.1)	−0.71 (−0.81 to −0.6)
East Asia	28.11 (13.7–53.29)	6.06 (2.93–11.48)	55.12 (27.59–102.93)	5.04 (2.56–9.35)	−0.16 (−0.33 to 0.01)
Eastern Europe	13.33 (6.71–25.06)	7.69 (3.89–14.35)	14.72 (7.31–27.86)	7.39 (3.69–13.99)	0.61 (0.17 to 1.04)
Eastern Sub-Saharan Africa	6.07 (3.26–10.74)	13.24 (7.05–23.87)	11.94 (6.16–21.21)	11.16 (5.71–20.32)	−0.59 (−0.63 to −0.55)
High-income Asia Pacific	4.54 (2.3–8.55)	4.04 (2.07–7.52)	7.46 (3.62–13.96)	3.45 (1.7–6.49)	−0.54 (−0.67 to −0.42)
High-income North America	16.28 (8.01–30.55)	8.9 (4.4–16.84)	24.21 (11.85–44.16)	7.65 (3.7–14.1)	−0.84 (−0.96 to −0.72)
North Africa and Middle East	16.01 (8.29–29.27)	15.49 (7.85–28.71)	33.1 (16.3–61.61)	12.87 (6.41–23.92)	−0.52 (−0.56 to −0.48)
Oceania	0.13 (0.07–0.23)	7.57 (3.93–13.74)	0.31 (0.16–0.55)	7.39 (3.89–13.47)	−0.05 (−0.07 to −0.02)
South Asia	101.89 (60.76–170.99)	28.97 (17.03–47.71)	152.39 (91.65–256.86)	18.87 (11.28–31.68)	−1.44 (−1.47 to −1.41)
Southeast Asia	11.07 (6.15–20.02)	7.11 (3.83–12.93)	21.65 (11.94–38.22)	6.19 (3.41–11.02)	−0.47 (−0.49 to −0.44)
Southern Latin America	2.97 (1.46–5.68)	11.85 (5.81–22.64)	4.11 (1.97–7.77)	9.56 (4.58–18.08)	−0.68 (−0.74 to −0.61)
Southern Sub-Saharan Africa	1.91 (0.98–3.52)	11.44 (5.85–21.22)	3.38 (1.72–6.22)	9.76 (4.97–18.02)	−0.54 (−0.56 to −0.52)
Tropical Latin America	10.09 (4.92–18.44)	16.35 (8.06–29.49)	16.14 (8.02–29.74)	12.16 (6.06–22.36)	−1.3 (−1.41 to −1.19)
Western Europe	29.83 (14.9–55.81)	10.47 (5.15–20.08)	38.38 (18.74–72.16)	10.04 (4.81–19.09)	−0.02 (−0.1 to 0.07)
Western Sub-Saharan Africa	9.5 (4.97–17.21)	18.82 (9.55–34.82)	18.35 (9.04–34.08)	14.89 (7.26–28.09)	−0.82 (−0.87 to −0.78)

of young incidence cases among all POP incidence cases, while the proportion of elderly incident cases was relatively stable. In addition, we found a non-significant correlation between EAPC and SDI ($R = -0.16$, $P = 0.056$). As for DALY analysis, we also found a positive correlation between EAPC and SDI ($R = 0.3$, $P < 0.001$) and a negative association between EAPC and the age-standardized DALY rate ($R = -0.59$, $P < 0.001$). The DALY difference among different age groups showed an unimodal distribution, and the peak appeared after 60 years old.

Discussion

In this study, relying on statistical parameters (ASIR and AS-DALY), we mapped the global epidemic map of POP, which is the first time to obtain authoritative evidence about POP

epidemiology based on GBD database.This analysis of the GBD 2019 study shows that there is a considerable POP disease burden globally and in most regions. In general, the incidence rate of age-standardized points and YLD incidence has declined in the past 30 years. Notably, the absolute number of epidemic cases and YLD has increased, which may be mainly due to the population aging and population growth, as well as the improved survival of patients with long-term diseases known to increase the risk of POP. For example, obesity or chronic respiratory diseases increase the intra-abdominal pressure and then contribute to a person's risk of genital prolapse (32). Overall, these trends indicated that POP still poses a huge global health burden, and the overall burden may continue to rise in the future.

Over the past 30 years, due to variations in data sources and methodological differences from the GBD, a comparison to the GBD 1990 and GBD 2019 is not possible. However, it is still feasible to continuously observe the changing trend of diseases. For example, the decrease observed in the age-standardized incidence of POP from 1990 to 2019 was relatively consistent with our findings, where a 0.85% reduction was observed from 1990 to 2019. In addition, the three countries with the highest ASIR were Russian, Belarus, and Estonia; the three countries with the lowest ASIR were Guatemala, Cyprus, and Nepal. Consistent with previous research reports, the POP incidence is much higher in low-income countries, with about 20% previously reported (33, 34). Meanwhile, different studies have shown that in low- and middle-income countries, the average value of pelvic organ prolapse is 19.7%, and the estimated range is 3.4%−56.4% (35). This study gives us great enlightenment, that is, in the environment of uneven global economic development, the uneven distribution of medical and health resources has also had a great impact on POP related chronic diseases. Especially in underdeveloped areas, POP has a high weight in affecting the quality of life of elderly women, while the medical environment in highly developed areas and equipped with advanced diagnosis and treatment system enable elderly women to enjoy more health benefits.

In this study, our results showed that women over the age of 50 bear the largest burden of POP across the world. About 11% of American women have undergone POP or urinary incontinence surgery before the age of 79 and 29.2% of women may need additional surgery (36). In addition, previous literature has reported that POP is very common in women over 40 years, elderly women, and postmenopausal women, with an estimated prevalence of 41%−50% (37, 38). Similar findings also demonstrated that old age, high parity, obesity, vaginal delivery are the most important risk factors leading to POP (35, 39–41). With the increase of age, these factors can complement each other, so aging is an important force of POP risk factors (Supplementary Table 3). For instance, during a woman's first pregnancy, a significant decrease in all compartments of the vaginal wall and perineum was observed, but the total length of the vagina increased with associated pelvic floor dysfunction (42). As documented here, and in previous studies, the global burden of pelvic floor disorder is increasing due to increasing age of the population.

The current research showed that the proportion of annual young incidences in all POP cases decreased year by year, while the proportion of elderly incidences cases increased, which is comparable with previous studies (43, 44). It is well known that aging and fewer births in developed countries have been a serious concern in recent years. Hence, we observed a phenomenon that the higher the SDI, the lower the proportion of young women and the higher the proportion of the elderly, which confirmed this conjecture. For instance, the incident POP population in the high-income Asia Pacific tended to be aging, compared with other regions in Asia. In addition, the improvement of new treatment plans and supportive care measures in developed countries and regions has led to an unprecedented long-term cure rate of POP treatment, which further promotes this trend. In the future health care, the allocation of medical resources should not only focus on young patients with fertility requirements, but also strengthen the monitoring of elderly women (no fertility requirements, but will have a negative impact on the quality of life). Moreover, for postmenopausal women, due to the growth of age and the decline of estrogen levels, these common factors promote the increase of the incidence of POP, so it is more necessary to investigate it as soon as possible.

Strengths and limitations

Some limitations were unavoidable in this study. First, although GBD includes global pop case data, differences in data collection and coding and data source quality are still inevitable in this analysis model. Second, fluctuations in the incidence rate and DALY annualized rates may partly reflect actual changes in age-related ratios, especially regional differences, which may still be biased. In the future, population-based POP registries must be improved. Third, there are some countries with low socio-economic status and the least data sources, which can also greatly affect the regional burden of estimating POP. Nevertheless, this study presents the latest estimates of the global burden of POP, which will help public health policymakers.

Conclusion

Over the past three decades, the incidence and DALY of POP have been decreasing from 1990 to 2019. The three countries with the highest ASIR were Russian, Belarus, and Estonia; the three countries with the lowest ASIR were Guatemala, Cyprus,

and Nepal. Although the proportion of annual young incidences in all POP cases decreased year by year, the proportion of elderly incidences cases increased. Especially, women over the age of 50 bear the largest burden of POP across the world. Therefore, primary and secondary prevention measures of POP should be integrated into the practice of healthcare professionals dealing with aging women.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary material, further inquiries can be directed to the corresponding author.

Ethics statement

Written informed consent was not obtained from the individual(s) for the publication of any potentially identifiable images or data included in this article.

Author contributions

BW, TW, and MW: study conception and planning, statistical analysis, interpretation of results, manuscript drafting, and final approval of manuscript. XZ, ML, YH, YC, LX, QZ, and XG: interpretation of results and final approval of manuscript. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpubh.2022.975829/full#supplementary-material

SUPPLEMENTARY FIGURE 1
Incidence rate and DALYs development trend of POP in different SDI regions from 1990 to 2019.

SUPPLEMENTARY FIGURE 2
Trends of ASIR and age-standardized DALYs in different SDI regions of global POP from 1990 to 2019.

SUPPLEMENTARY FIGURE 3
EAPC changes of ASIR and age-standardized DALYs in different regions of global POP from 1990 to 2019.

SUPPLEMENTARY FIGURE 4
Correlation analysis between different SDI regions of global POP and ASIR and DALYs from 1990 to 2019.

SUPPLEMENTARY TABLE 1
The incidence rate and age standardized incidence rate of POP and the trend of time changes from 1990 to 2019.

SUPPLEMENTARY TABLE 2
The DALY rate and age standardized DALY rate of POP and the trend of time changes from 1990 to 2019.

SUPPLEMENTARY TABLE 3
The death and age standardized death rate of POP and the trend of time changes from 1990 to 2019.

SUPPLEMENTARY TABLE 4
Literature review on risk factors of POP and its recurrence.

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Parallel randomized controlled feasibility trials of the "Active Brains" digital intervention to protect cognitive health in adults aged 60–85

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Introduction: Multidomain interventions to address modifiable risk factors for dementia are promising, but require more cost-effective, scalable delivery. This study investigated the feasibility of the "Active Brains" digital behavior change intervention and its trial procedures.

Materials and methods: Active Brains aims to reduce cognitive decline by promoting physical activity, healthy eating, and online cognitive training. We conducted 12-month parallel-design randomized controlled feasibility trials of "Active Brains" amongst "lower cognitive scoring" (n = 180) and "higher cognitive scoring" (n = 180) adults aged 60–85.

Results: We collected 67.2 and 76.1% of our 12-month primary outcome (Baddeley verbal reasoning task) data for the "lower cognitive score" and "higher cognitive score" groups, respectively. Usage of "Active Brains" indicated overall feasibility and satisfactory engagement with the physical activity intervention content (which did not require sustained online engagement), but engagement with online cognitive training was limited. Uptake of the additional

brief telephone support appeared to be higher in the "lower cognitive score" trial. Preliminary descriptive trends in the primary outcome data might indicate a protective effect of Active Brains against cognitive decline, but further investigation in fully-powered trials is required to answer this definitively.

Discussion: Whilst initial uptake and engagement with the online intervention was modest, it was in line with typical usage of other digital behavior change interventions, and early indications from the descriptive analysis of the primary outcome and behavioral data suggest that further exploration of the potential protective benefits of Active Brains are warranted. The study also identified minor modifications to procedures, particularly to improve online primary-outcome completion. Further investigation of Active Brains will now seek to determine its efficacy in protecting cognitive performance amongst adults aged 60–85 with varied levels of existing cognitive performance.

KEYWORDS

dementia prevention, behavior change, physical activity, cognitive training, healthy eating

Introduction

Dementia is a major cause of disability and dependency among older adults and places significant burden on the health and social care sector, costing US$ 1.3 trillion dollars globally in 2019 (1). Amongst adults over 60 between 12 and 18% are affected by mild cognitive impairment (MCI); (2), and up to 20% by age-associated cognitive decline (AACD); (3). Up to 10% of MCI and AACD cases progress to dementia annually (3, 4). Better preventative, diagnostic, therapeutic and social care solutions for dementia are public health priorities (1).

An estimated 40% of risk factors for dementia are modifiable, and, if managed proactively, could delay or slow disease (5). People with physically active lifestyles or those following a Mediterranean diet appear less likely to develop cognitive decline and dementia (6, 7). These behaviors also have positive effects on reducing the incidence of other risk factors including hypertension (8). Cognitive training interventions have also demonstrated potential, with reported moderate positive effects on cognitive function for healthy adults (9) and small positive effects for those with MCI (10).

The 'FINGER' trial (n = 1,260) of a multidomain programme targeting diet, physical activity, cognitive training, and vascular risk monitoring, demonstrated modest reductions in cognitive decline (11). Findings suggest that addressing multiple risk factors simultaneously offers a promising strategy. However, reaching large numbers with a face-to-face delivered programme would prove prohibitively resource-intensive (12). More scalable, cost-effective models of delivering multidomain interventions are required (13).

Digital interventions may offer a feasible solution. A meta-analysis of effectiveness of web-based multidomain lifestyle programs to optimize brain health in healthy adults concluded that these interventions show an overall small-to-medium effect on outcomes (14). Whilst this offers promising evidence for the utility of digital multidomain interventions in this field, only three of the 14 identified studies in this review had evaluated interventions using controlled methods. As such there is still need for further research to provide robust Randomized Controlled Trial (RCT) evidence of effectiveness of such interventions which is the intention of the current work. Furthermore, the meta-analysis also indicated that there may be more benefit of such interventions for healthy adults compared to those with existing cognitive decline. The current work will investigate the feasibility (and ultimately effectiveness) of a multidomain intervention amongst both those with and without indications of existing cognitive decline, so could ultimately allow further exploration of whether one group may benefit more than the other. In addition, the fully powered trials of Active Brains are designed to test the effectiveness of the intervention on incidence of dementia diagnosis at 5 years as well as cognitive performance outcomes at 1 year, whereas the majority of interventions to date have only examined impact on cognitive performance. Exploration of the feasibility of Active Brains is needed to prepare appropriately for the fully-powered effectiveness evaluation.

Accordingly, we developed "Active Brains", a multidomain web-based intervention for older adults aged 60–85 years with and without indications of existing cognitive impairment (15). Active Brains aims to reduce cognitive decline, and ultimately long-term incidence of dementia, by promoting physical activity and healthy eating behaviors, and online cognitive training. This paper presents parallel feasibility RCTs of "Active Brains" to determine the feasibility of both the intervention, and the procedures to test its efficacy and cost-effectiveness in fully powered trials.

Our main objective was to evaluate our ability to collect 80% of primary outcome data from both trial groups. The primary outcome measures were the Baddeley verbal reasoning score at 1-year follow-up, and incidence of dementia diagnosis identified from medical notes review for the proposed 5-year follow-up. The Baddeley Verbal Reasoning task was deemed the most appropriate measurement tool for the one-year primary outcome since it has been shown to be an element of cognitive functioning that is sensitive to change, and training in verbal reasoning has significant impact on the ability to maintain activities of daily living (16).

Additional objectives were to explore preliminary estimates of change in outcomes and to evaluate the feasibility and acceptability of: recruitment screening methods; trial procedures; recruitment and attrition rates (specifically the feasibility of scaling these up to the required main trial recruitment); outcome measures; engagement with the Active Brains intervention and the additional human support. We also assessed the feasibility of collecting key resource usage information, and the most suitable quality of life instruments for the full RCTs.

Materials and methods

For further details about study design, measures and analysis, and a full description of "Active Brains" see the published protocol (17). Prospective registration of the work can be viewed here https://www.isrctn.com/ISRCTN23758980.

Study design

We conducted parallel-design 12-month randomized controlled feasibility trials of the Active Brains intervention. Active Brains was trialed amongst two groups of adults aged 60–85 years: (1) those with indications of existing cognitive impairment ("lower cognitive score"; $n = 180$); and (2) those with no indications of existing cognitive impairment ("higher cognitive score"; $n = 180$). Trial allocation was determined by participants' baseline scores on a computerized Baddeley Verbal Reasoning task (18). The Baddeley Verbal Reasoning task offered the most suitable screening tool as it afforded the ability to draw on an extensive existing database of scores from older adults from which a normative score could be used as a meaningful threshold to base our trial allocation on. In line with existing definitions of AACD (19), a score more than one standard deviation below the "normative score" from the PROTECT database - a large (n>15,000) cohort of older adults (20) - determined allocation to the "lower cognitive score" group. The "lower cognitive score" and "higher cognitive score" groups were treated as separate trials for randomization and reporting. In each trial participants were randomized to one of three arms: (1) Active Brains; (2) Active Brains plus brief telephone/email support (telephone support as standard unless email communication preferred by participant); or (3) Usual Care comprising a single-page advice sheet about activities to protect cognitive health.

Study setting and recruitment

Between October 2018 and January 2019, 19 primary care practices in Hampshire, Dorset and Wiltshire completed a database search, screen and mailout in accordance with the study's eligibility criteria. Participating practices recorded age, gender, and postcode of all invitees. Mailout packs provided immediate access to the Active Brains website where invitees could: sign up, provide informed consent, complete additional screening (including the Baddeley Verbal Reasoning Task to determine trial assignment) and, if eligible, complete baseline measures and randomization. Anyone whose score allocated them to the "higher cognitive score" group after 180 participants had been allocated entered a non-randomized "cohort" group with access to Active Brains. This paper focuses only on the RCT participants.

Measures and data collection procedures

Baseline

At baseline, all measures were completed online after initial sign-up and online consent. The cognitive assessment tasks (comprising the Baddeley Verbal Reasoning task, the digit span task, the paired associates learning task and the self-ordered search task) were accessed *via* the PROTECT platform (21). The cognitive assessment tasks have been running for seven years on the PROTECT platform and prior to this have a 35-year history of use. The data flow and management of the cognitive tests is monitored by a cognitive testing expert. The cognitive assessment tasks delivered *via* the PROTECT platform and used in the Active Brains study are well established as a cognitive assessment tool. Several very large studies have demonstrated their validity (21–23). A description of these four cognitive assessment tasks can be found in a prior publication from the PROTECT study team [(22); p992]. In the Baddeley Verbal Reasoning task participants had 3 min to respond to as many statements as possible which referred to the relative size and positional relationship between a changing image of a square and a circle. Examples of these statements include "The square is bigger than the circle," "The circle does not contain the square." These included a mixture of positively or negatively worded, and true or false statements. Participants indicated whether the statement was true or false by clicking on the appropriate button on the page. Correct responses added to their total score, whereas incorrect responses deducted from it. All

other measures were completed *via* the Active Brains website by those eligible.

12-month follow-up

All participants were invited *via* email at 1-year post-randomization to complete online follow-up measures. Participants who had not completed the online cognitive assessment tasks, the Instrumental Activities of Daily Living (IADL); (24) and the EQ5D-5L (25) measures after 3 weeks (including two additional reminder emails) were contacted by paper mail-out and, where necessary, by phone to prompt completion of measures. The cognitive assessment tasks (comprising the Baddeley Verbal Reasoning task, the digit span task, the paired associates learning task and the self-ordered search task) could only be completed online. If these measures remained incomplete after 8 weeks with no participant contact, emails and phone calls were made to the participant's nominated contact person if provided. These requested that the contact person prompted or supported the participant to complete the measures or, if not possible, for the contact person to complete the Informant Questionnaire on Cognitive Decline in the Elderly (IQCODE); (26) and proxy versions of the IADL and EQ-5D.

Notes review

A medical notes review data collection form and accompanying instructions were shared with recruiting primary care practices. These asked practice staff to report for each of their randomized patients: major medical conditions diagnosed before and during the study period; family history of dementia; any record of cognitive impairment complaints; blood pressure and cholesterol readings; medications prescribed at baseline and medication changes during the study period; and healthcare use including primary care consultation, outpatient attendance, A & E visits, and hospitalization during the study period. Should participants have moved and changed practices during the study period, the study team planned to still collect primary care data if they moved to another participating practice. If they moved outside of the participating regions or to a non-participating or non-research active practice, collection of primary care data would not have been possible for this individual.

Analysis

The completeness of the primary outcome data and the other key feasibility outcomes including: intervention uptake, adherence, attrition, retention, and the number of participants recruited per practice, healthcare costs and quality of life were summarized descriptively. Baseline participant characteristics and trial outcomes were descriptively analyzed as randomized (i.e., regardless of level of engagement with the intervention), using number (%), mean (SD) or median (IQR) as appropriate. The pattern and frequency of missing data was also descriptively explored. The completeness of primary outcome and notes review data were used to answer the primary research question about whether we could collect 80% of our outcome data. The recruitment data (uptake rate, total number recruited, recruits per practice and recruitment duration) were used to determine the feasibility of scaling up our recruitment to reach the required sample sizes for the main trials.

Results

From 5,475 study invitations, 1,001 individuals (18.3%) completed online sign-up. Amongst those choosing not to participate, 18.5% ($n = 828$) returned a reply slip indicating why. The most common reasons related to lack of access, or unwillingness to use computers or the internet, or commitments including work and caring responsibilities.

Of 1,001 individuals who signed up, 2% ($n = 21$) did not complete consent, and a further 7% ($n = 70$) did not complete the online screening, leaving 910 individuals who were assessed for eligibility. Overall, 10.2% of invitees ($n = 560$) participated.

Figure 1 illustrates participant flow through the trials.

Sample characteristics

Participant characteristics for each group (Table 1) were generally evenly distributed in each trial. Participants in the "higher cognitive score" trial were slightly younger, with a larger proportion having Higher Education qualifications, compared to those in the "lower cognitive score" trial. Samples were predominantly White (British, Irish or European), living with a partner and regular users of the internet.

Participants were comparable to non-participants in terms of mean age (69.2 years vs. 69.9 years, respectively), demonstrated a similar gender balance (51.7% of participants vs. 49% invited were female), but areas of lower relative deprivation were over-represented (mean index of multiple deprivation (IMD) was 7.5 in participant group vs. 6.8 in non-participants); (27). Indices of Multiple Deprivation (IMD) are the official measure of relative deprivation in England. They collate weighted data from across seven domains of deprivation for each neighborhood in the country to create a rank of most to least deprived areas. IMD is often expressed in deciles, with the top 10% (most deprived areas in the country) being in the first decile (IMD = 1), and the bottom 10% (least deprived areas in the country) being in the tenth decile (IMD = 10) (28).

The remainder of the results section reports our findings relating to the acceptability and feasibility of: (1) the Active

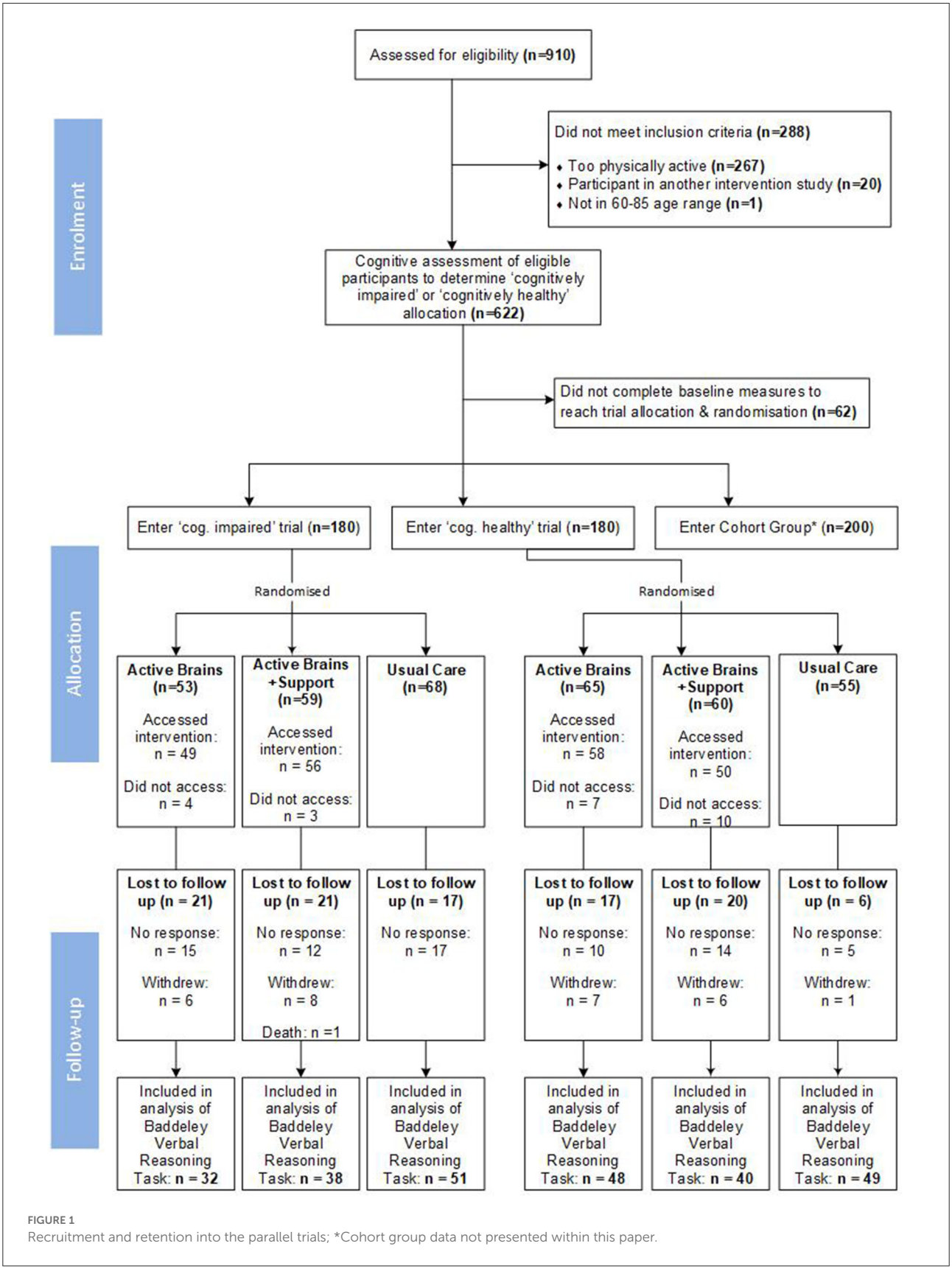

FIGURE 1
Recruitment and retention into the parallel trials; *Cohort group data not presented within this paper.

Brains intervention, and (2) the proposed trial procedures. The study was not powered to perform statistical comparisons. In line with the CONSORT 2010 statement extension to feasibility and pilot studies (29) all reporting of results refers to descriptive statistics and narrative description of apparent trends in the data from visual inspection only. Some of the reporting comments on ostensible differences in the descriptive data over time or between groups. However, we acknowledge that these do not necessarily reflect statistically significant differences at this point and are simply indications of what may be important to explore in fully powered analyses.

Acceptability and feasibility of "Active Brains" – Initial uptake, usage and preliminary indications of change

Initial uptake and usage of active brains

Table 2 below briefly outlines the modules within Active Brains and when these became available to participants in the intervention arms of the trials.

Initial uptake (accessing Active Brains at least once) of the intervention amongst those in the intervention arms (with or without support) appeared to be higher in the "lower cognitive score" trial at 93.8%, compared to 86.4% in the "higher cognitive score" trial. Usage of Active Brains is shown in Table 3.

Across both trials, and regardless of support provision, there was relatively high initial use of Active Brains online content followed by a gradual decline over time. The three main components of Active Brains are released sequentially (Active Lives immediately, Brain Training after 4 weeks, Eat for Health after 8 weeks), and ∼50% of participants were still accessing Active Brains once all content was available. "Getting Active" was the most accessed of the (simultaneously available) physical activity sub-modules. Access to "Breaks from Sitting" (reducing sedentary time) was relatively low across all users but was perhaps slightly higher in the supported group in the "lower cognitive score" trial.

Larger proportions of the supported groups seemed to access the Strength and Balance and Brain Training modules - especially in the "lower cognitive score" trial. Whilst the frequency of use of Brain Training games per participant was low overall, those in the supported groups appeared to access the games more frequently – either with larger proportions of the supported group seeming to access the games (in the "lower cognitive score" trial), or the individuals in the supported group who were accessing the games appearing to do so more frequently (in both trials). However, very few participants in either trial demonstrated the recommended level of use of accessing the Brain Training games 3–5 times per week for the first 6 months. Use of "Eat for Health" was consistent across groups, with ∼50% of users accessing this.

Initial uptake of, and adherence to, human support

Participants randomized to the support groups were offered up to three brief telephone support calls (or email support if they preferred) with a trained facilitator during the first 12 weeks. These appointments only occurred if the participant contacted their designated supporter to arrange them. In addition, all support arm participants received automated emails from their designated supporter at 3- and 7-weeks post-randomization. These provided general encouragement and a reminder of the further support available. Engagement with these support opportunities is shown in Table 4.

More than half of all support arm participants contacted their supporter, and half had at least one telephone support appointment. Initial uptake of support (i.e., any engagement with the designated supporter) appeared to be higher in the "lower cognitive score" trial. Those in this trial also seemed more likely to request multiple appointments. Feedback from supporters was collated *via* email and group discussion and is reported in Supplementary Table 1.

Preliminary estimates of change

Primary outcome data

Although the feasibility trials were not powered to make statistical comparisons between groups, we can comment briefly on possible indicative patterns in the descriptive analysis of primary outcome data (Table 5).

In the "lower cognitive score" trial all trial arms appeared to show higher mean verbal reasoning scores at follow-up, as well as seemingly smaller proportions of respondents meeting AACD/MCI criteria. This potential change in proportion of respondents meeting the AACD criteria appears more pronounced in intervention arms compared to usual care.

In the "higher cognitive score" trial, verbal reasoning scores appeared to remain consistent between baseline and follow-up in the two intervention arms and possibly showed a small decline in the usual care group. Relatedly, the proportion of participants meeting the AACD/MCI criteria at follow-up appeared to increase more sharply in the usual care arm compared to the intervention arms.

An imputed analysis, including auxiliary variables and predictors of missing AACD outcome, gave similar estimates to the observed proportions. This assumes that missing outcomes are missing at random given the observed data.

Intervention-targeted behaviors

Reviewing the descriptive analysis of data relating to behaviors targeted by the intervention gives insight into trends to explore further in fully powered trials. Supplementary Tables 2, 3 report the brain training-related behaviors outside of Active Brains and healthy eating data, respectively, which gave little indication of potential change or

TABLE 1 Participant baseline characteristics in each trial.

	"Lower cognitive score" trial			"Higher cognitive score" trial		
	Active Brains $n = 53$	AB + support $n = 59$	Usual care $n = 68$	Active Brains $n = 65$	AB + support $n = 60$	Usual care $n = 55$
Female	34 (64.2%)	33 (55.9%)	43 (63.2%)	25 (38.5%)	32 (53.3%)	34 (61.8%)
Age (mean, SD)	71.1 (6.8)	70.9 (5.5)	70.8 (5.7)	67.9 (5.3)	67.8 (6.0)	67.5 (5.1)
Living situation						
On my own	10 (18.9%)	12 (20.3%)	25 (36.8%)	9 (13.8%)	13 (21.7%)	9 (16.4%)
With a spouse/partner	40 (75.5%)	45 (76.3%)	39 (57.4%)	54 (83.1%)	45 (75.0%)	45 (81.8%)
With a relative	3 (5.7%)	2 (3.4%)	4 (5.9%)	2 (3.1%)	1 (1.7%)	1 (1.8%)
With a friend	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	1 (1.7%)	0 (0.0%)
Ethnic group						
White	53 (100.0%)	58 (98.3%)	68 (100.0%)	64 (98.5%)	59 (98.3%)	55 (100.0%)
Mixed	0 (0.0%)	0 (0.0%)	0 (0.0%)	1 (1.5%)	1 (1.7%)	0 (0.0%)
Asian	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)
Black	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)
Other	0 (0.0%)	1 (1.7%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)
Education level						
Secondary	20 (37.7%)	22 (37.3%)	27 (39.7%)	11 (16.9%)	11 (18.3%)	15 (27.3%)
Post-secondary	9 (17.0%)	9 (15.3%)	10 (14.7%)	10 (15.4%)	11 (18.3%)	9 (16.4%)
Vocational	16 (30.2%)	12 (20.3%)	16 (23.5%)	17 (26.2%)	13 (21.7%)	14 (25.5%)
Undergraduate	6 (11.3%)	11 (18.6%)	10 (14.7%)	17 (26.2%)	17 (28.3%)	13 (23.6%)
Post-graduate	1 (1.9%)	3 (5.1%)	4 (5.9%)	6 (9.2%)	6 (10.0%)	3 (5.5%)
Doctorate	1 (1.9%)	2 (3.4%)	1 (1.5%)	4 (6.2%)	2 (3.3%)	1 (1.8%)
Internet use						
Every day	43 (81.1%)	40 (67.8%)	51 (75.0%)	55 (84.6%)	54 (90.0%)	46 (83.6%)
A few times each week	10 (18.9%)	19 (32.2%)	15 (22.1%)	10 (15.4%)	6 (10.0%)	8 (14.5%)
A few times a month	0 (0.0%)	0 (0.0%)	1 (1.5%)	0 (0.0%)	0 (0.0%)	1 (1.8%)
Less often	0 (0.0%)	0 (0.0%)	1 (1.5%)	0 (0.0%)	0 (0.0%)	0 (0.0%)

difference between groups. However, reviewing the physical activity descriptive data (Table 6) indicates some trends that may be important to explore further.

The International Physical Activity Questionnaire (IPAQ-E); (30) data indicated high levels of physical activity amongst participants in both trials at baseline. At follow-up, in the "lower cognitive score" trial there seemed to be a more apparent increase in all domains of activity in the Active Brains only group compared to either the supported group or usual care. In the "higher cognitive score" trial there was a similar, but less pronounced pattern. Here the Active Brains group appeared to show smaller increases across physical activity domains than in the "cognitively impaired" trial, but still seemingly larger than in the support and usual care groups.

Uptake of a free pedometer from Active Brains appeared to be slightly higher in the "lower cognitive score" trial (35%, $n = 63$) compared to the "higher cognitive score" trial (29%, $n = 52$).

Acceptability and feasibility of trial procedures

Collection of primary outcome data

Online Baddeley verbal reasoning task

Completion of the Baddeley verbal reasoning data was 76.1% in the "higher cognitive score" trial and 67.2% in the "lower cognitive score" trial. Completion of *some* outcome data regardless of whether the online primary outcome was completed, was 80% in both trials.

In both trials, the highest completion of the primary outcome was in the usual care groups. Supplementary Table 4 provides a breakdown of primary outcome completion by trial and intervention group.

As our primary outcome completion fell short of the 80% target in both trials, we took measures to address identified issues (Table 7).

TABLE 2 Active Brains modules and release schedule.

Active Brains module		Description	Available
Active Lives	Getting active	Advice and support for increasing general physical activity levels	Immediately – as soon as participant is randomized to Active Brains or Active Brains plus support group
	Strength and balance	Support for building strength and balance exercises into daily routines	
	Breaks from sitting	Advice and support for breaking up sedentary time	
Brain training		Advice about keeping the brain active and access to brain training games [described here (22); Table 1] with advice to aim for 3–5 sessions of brain training per week for first 6 months	4 weeks after randomization – 6 Brain training games available immediately, 1 additional game added every 4 weeks up to maximum of 12 games
Eat for Health		Advice and support for modifying eating patterns toward a healthier diet, with a particular focus on elements of a Mediterranean style diet (e.g., nuts, leafy green veg, oily fish)	8 weeks after randomization
Active Brains "Booster" content		Access to all existing modules, plus some modified/additional content: - Recommendations to carry out Brain Training 3–5 times a week for 1 month, every 3 months - Additional links to recipes/resources for meal planning aligned to healthy eating recommendations - Additional links to external resources for finding activities within community/local area.	7 months after randomization

TABLE 3 Usage of Active Brains components by trial and trial arm.

	% of people (and number) from each workstream and group who accessed at least once					
Section	**Lower cognitive score ($n = 112$)**		**Higher cognitive score ($n = 125$)**		**Combined ($n = 237$)**	
	AB ($n = 53$)	AB + S ($n = 59$)	AB ($n = 65$)	AB + S ($n = 60$)	AB ($n = 118$)	AB + S ($n = 119$)
Overall uptake (any use)	92.5% (49)	94.9% (56)	89.2% (58)	83.3% (50)	90.7% (107)	89.1% (106)
Active Brains introduction	92.5% (49)	93.2% (55)	87.7% (57)	83.3% (50)	89.8% (106)	88.2% (105)
Active Lives (AL) intro	84.9 % (45)	84.7% (50)	78.5% (51)	75% (45)	81.4% (96)	79.8% (95)
AL: Getting active	56.6% (30)	57.6% (34)	61.5% (40)	61.7% (37)	59.3% (70)	59.7% (71)
AL: Strength and balance	49.1% (26)	61% (36)	46.2% (30)	50% (30)	47.5% (56)	55.5% (66)
AL: Breaks from sitting	32.1% (17)	45.8% (27)	40% (26)	35% (21)	36.4% (43)	40.3% (48)
Brain Training (BT)[a]	58.5% (31)	72.9% (43)	58.5% (38)	65% (39)	58.5% (69)	68.9% (82)
Number of BT sessions[b]	848	838	1,113	1,062	1,961	1,900
Median BT sess. per user	3	5	3	5	3	5
Participants meeting BT recommendations[c]	3.8% (2)	0	4.6% (3)	1.7% (1)	4.2% (5)	0.8% (1)
Eat for Health	52.8% (28)	47.5% (28)	46.2% (30)	53.3% (32)	49.2% (58)	50.4% (60)

[a]Brain Training (BT), proportion (number) of participants who accessed the Brain Training module; [b]BT sessions, number of separate occasions Brain Training games were accessed across all individuals in this group; [c]Brain Training module recommended that participants accessed BT games 3–5 times per week for first 6 months.

Notes review

We collected notes review data for 94.4% of participants across both trials. Data were analyzed to inform any amendments required to the notes review data collection form and choice of instruments to measure quality of life. Detailed collection of medication use both at baseline and follow up proved too complex and time-intensive. We simplified the data form by collecting information only if any medication changes occurred during the study. Additional data about health service resource use is provided in Supplementary Table 5.

We explored use of three quality life and well-being measures –EQ5D-5L, the SF-12 (31) and the Index of Capability

TABLE 4 Uptake and use of support provision.

Support type	Lower cognitive score support arm ($n = 59$)	Higher cognitive score support arm ($n = 60$)	Combined support arm across both trials ($n = 119$)
Participant made email contact	68% (40)	53% (32)	**61% (72)**
At least one phone appointment	54% (32)	47% (28)	**50% (60)**
At least two phone appointments	27% (16)	13% (8)	**20% (24)**
All three phone appointments	7% (4)	0	**3% (4)**
Requested additional phone appointment	2% (1)	0	**1% (1)**

TABLE 5 Baddeley Verbal Reasoning task scores and number meeting AACD/MCI criteria.

Lower cognitive score Trial	**Active Brains ($n = 53$)**		**Active Brains + support ($n = 59$)**		**Usual care ($n = 68$)**	
	Baseline	**Follow up**	**Baseline**	**Follow up**	**Baseline**	**Follow up**
Baddeley Verbal Reasoning score Mean (SD)	16.4 (4.9)	18.7 (6.6)	15.2 (5.8)	19.1 (8.7)	14.7 (5.8)	19.45 (7.3)
AACD flag *n* (%) (1 SD below norm verbal reasoning)	53 (100%)	23/32 (71.9%)	59 (100%)	25/38 (65.8%)	68 (100%)	39/51 (76.5%)
MCI flag (1.5 SD below norm verbal reasoning)	27(50.9%)	13/32 (40.6%)	35 (59.3%)	15/38 (39.5%)	45 (66.2%)	20/51 (39.2%)
Missing score (*n*, %)	0 (0.0%)	21 (39.6%)	0 (0.0%)	21 (37.3%)	0 (0.0%)	17 (25.0%)
Higher cognitive score Trial	**Active Brains ($n = 65$)**		**Active Brains + support ($n = 60$)**		**Usual care ($n = 55$)**	
	Baseline	**Follow up**	**Baseline**	**Follow up**	**Baseline**	**Follow up**
Baddeley Verbal Reasoning score Mean (SD)	31.4 (6.2)	32.1 (8.1)	31.6 (6.7)	32.2 (8.1)	30.4 (4.9)	28.8 (7.8)
AACD flag (1 SD below norm verbal reasoning)	0 (0.0%)	5/48 (10.4%)	0 (0.0%)	5/40 (12.5%)	0 (0.0%)	12/49 (24.5%)
MCI flag (1.5 SD below norm verbal reasoning)	0 (0.0%)	1/48 (2.1%)	0 (0.0%)	1/40 (2.5%)	0 (0.0%)	5/49 (10.2%)
Missing score (*n*, %)	0 (0.0%)	17 (26.2%)	0 (0.0%)	20 (33.3%)	0 (0.0%)	6 (10.9%)

for Older Adults [ICECAP-O; (32)]; response rates were similar at both baseline and 1-year follow-up. EQ5D-5L and SF12 were more sensitive to QoL variation compared with ICECAP-O and feedback from Patient and Public Involvement Contributors (PPI) that ICECAP-O's items may be difficult or off-putting to answer led us to removing this measure. The EQ-5D-5L and SF-12 were deemed sufficient to capture quality of life and well-being data in the trial population.

Evaluating trial procedures

We evaluated the acceptability of the study's: screening methods, recruitment strategies, randomization process, study materials, outcome measures, notes review process, and recruitment and attrition rates. Our screening methods appeared largely feasible to operationalize and were effective in recruiting eligible samples for each trial. Throughout the screening process, several minor issues were identified and addressed as described in Supplementary Table 6.

Our key findings regarding trial procedures and the associated implications for the main trial are shown in Table 8.

Minor changes to measures

We identified potential issues with two measures; the IPAQ-E and the IADL.

IPAQ-E

The IPAQ-E scores indicated very high baseline levels of physical activity across all groups. Given our exclusion of highly active individuals [using the Godin Leisure Time Exercise Questionnaire (33)], this was unexpected, leading to concerns about the IPAQ-E's validity. Despite considering potential alternatives, the IPAQ-E was still considered the most accessible self-report instrument with a level of granularity that should permit detection of small changes. This is pertinent given

TABLE 6 Baseline and follow-up IPAQ-E (physical activity) data in each trial.

Lower cognitive score Trial	Active ($n = 53$)		AB + Support ($n = 59$)		Usual care ($n = 68$)	
	Baseline	Follow up	Baseline	Follow up	Baseline	Follow up
IPAQ mean (SD) MET min per week	4,238.2 (2,670.2)	5,414.9 (3,475.6)	3,459.8 (2,551.9)	3,656.2 (3,121.8)	4,302.7 (2,709.3)	4,577.4 (2,676.2)
Mean (SD) min per week walking	753.5 (423.3)	825.1(444.8)	604.9(372.0)	617.7 (395.7)	625.8 (389.9)	671.2 (411.0)
Mean (SD) min per week moderate	463.8 (371.0)	632.7(441.4)	379.1(265.6)	429.0 (346.3)	465.9 (335.6)	461.6 (347.7)
Mean (SD) min per week vigorous	137.8 (110.7)	217.0(162.9)	206.6(166.5)	213.8 (166.2)	220.3 (185.7)	254.5 (201.5)
Mean (SD) min per week strength/balance[a]	93.6 (54.7)	247.5(306.0)	107.6 (99.5)	118.6 (148.4)	149.3 (175.4)	149.5 (118.4)
Missing IPAQ (n, %)	0 (0.0%)	25 (47.2%)	0 (0.0%)	29 (49.2%)	0 (0.0%)	20 (29.4%)
Higher cognitive score Trial	**Active Brains ($n = 65$)**		**AB + Support ($n = 60$)**		**Usual care ($n = 55$)**	
	Baseline	Follow up	Baseline	Follow up	Baseline	Follow up
IPAQ mean (SD) MET min per week	3,362.2 (1,853.2)	4,157.0 (2,944.8)	3,488.3 (2,457.5)	3,607.2 (2,052.9)	4,449.2 (2,647.5)	4,004.1 (2,413.7)
Mean (SD) min per week walking	625.1 (389.6)	673.0(393.0)	612.0(401.5)	588.3 (383.0)	694.1 (432.8)	647.7 (401.3)
Mean (SD) min per week moderate	302.7 (238.3)	396.0(310.4)	339.4(327.5)	366.3 (309.0)	537.3 (415.2)	390.6 (313.8)
Mean (SD) min per week vigorous	155.6 (141.4)	249.3(308.2)	96.7 (65.5)	94.3 (71.2)	118.2 (80.4)	194.7 (160.6)
Mean (SD) min per week strength/balance[a]	93.5 (88.5)	127.4(113.7)	72.1 (43.6)	123.5 (137.6)	91.4 (54.3)	101.6 (78.7)
Missing IPAQ (n, %)	0 (0.0%)	20 (30.8%)	0 (0.0%)	20 (33.3%)	0 (0.0%)	9 (16.4%)

[a]An item relating to frequency and duration of strength and balance was added for the present study in the format of the IPAQ questionnaire but does not typically feature in the validated version of this survey.

that Active Brains advocates small, gradual change in physical activity behavior.

IADL

Through feedback from PPI, participants, and team discussion, we identified some potential issues with the wording of the IADL items. Each item in the IADL has two parts asking the respondent to report: (a) how much assistance they have with that specific activity, (b) and how difficult they find the activity. The first part of the question did not appear to distinguish between activities that were not performed because the individual was not capable of performing it and those that were not performed because the activity was not relevant to the individual (i.e., because it was not an activity they need to do - e.g., taking medications, or not one that they took responsibility for within their household - e.g., managing finances). Furthermore, the second part of the question asked the participant to report how difficult they found the activity, even if they had previously reported that the activity was not performed or was done with full assistance which respondents reported finding confusing. Accordingly, we made some minor wording and formatting changes to these questions so that respondents could: (1) indicate whether they were unable to complete an activity themselves or if that activity was not relevant to them, and (2) indicate how much difficultly they had or would have with conducting the activity – even if not one they complete themselves.

To check that our modifications did not systematically affect participant responding on the IADL, we only modified the paper version sent to those who did not complete measures online. This allowed comparison between the data collected with the original version and our modified version. The distributions of the two data sets were broadly similar indicating no cause for concern, so these changes were applied to the online version.

Discussion

This study provides insight into engagement with the Active Brains intervention; provides preliminary interpretations of ostensible trends in outcomes at 1 year and evaluates the feasibility and acceptability of study procedures. These investigations were conducted amongst adults aged 60–85 with, and without, indications of existing AACD or MCI. The findings are important for determining the feasibility of planned future work to evaluate Active Brains.

Uptake and engagement with active brains

Initial uptake of the study invitation (18.3%) was in line with expectations for a UK primary care mail-out study to older adults even without an online aspect to the study (34, 35).

TABLE 7 Issues with primary outcome collection and mitigating measures.

Problem identified	Mitigation measures(s) implemented
Less than 80% completion of online primary outcome task – especially amongst participants in "lower cognitive score" trial.	• Reordered follow-up process: moved phone call ahead of sending paper measures (to avoid completion of paper measures without primary outcome) • Changed focus of call to prompting/supporting participants to complete online measures (by focusing the call on asking people if we could talk them through accessing the online tasks whilst we were on the phone to them, or providing additional instruction verbally or *via* email, instead of trying to collect other measures over the phone as previously planned) • Added step to follow-up process between automated emails and phone call: postal reminder to complete follow-up online with detailed instructions about how to access and complete online tasks. This sought to give participants who may have been unsure about how to access the online tasks additional written instructions they could refer to that were not part of originally planned procedures.
Message possibly not clear that online tasks were the most important element and could be completed quickly	• Changes to PIS documents and automated email prompts to emphasize importance of completing online task even if no time for other parts • Provided a time estimate for completion of tasks (10 min) to illustrate they could be completed quickly • Adaptation of paper follow-up packs splitting into very brief "primary outcomes" (IQCODE, IADL and EQ5D), plus additional longer pack of secondary measures. Accompanying letter stresses importance of online tasks, and signposts to this.
Possibility of automated emails being ignored/spam filtered so people miss request to complete online measures	• Amended emails to be sent from named email account; more clearly distinguishes them from other emails from Active Brains that don't require action
Higher withdrawal rate from intervention groups limiting maximum possible follow-up	• Clarified existing "partial withdrawal" (for participants wanting to cease use of Active Brains/ receiving intervention emails, but happy to be contacted to complete follow-up measures) option: made it clear to participants they can choose "partial withdrawal" even if only happy to complete the online primary outcome task. • Amended online system to allow participants more control over self-selecting level of withdrawal. Aim to maximize partial (primary) outcome data from those who would otherwise provide none.

Although a commonly reported reason for non-participation was lack of access to, or willingness to engage with the internet, only 15% of those invited reported a reason for non-participation, and many selected other reasons alongside these such as working or caring responsibilities. As such, this did not raise undue concerns about the potential future application and accessibility of Active Brains amongst UK older adults. In the 7 years between 2013 and 2020, internet use amongst over 75s in the UK nearly doubled from 29% to 54% (36). Older adults are the most rapidly growing users of the internet, and whilst there is inevitably some within this age group who do not currently use the internet, it is likely that this will continue to rapidly decline. As time goes on, we believe that digital interventions such as Active Brains will become increasingly accessible amongst large proportions of UK older adults.

Whilst the Active Brains usage data indicated that use of the online components was fairly modest, there was still evidence of the intervention being feasible and acceptable for participants in both trials to access and use, with 50% still accessing it at 2 months. Such levels of online usage are very much in line with that of other web-based health behavior change interventions (37). Furthermore, the online usage statistics alone do not

TABLE 8 Acceptability of study processes - key findings and implications for trial.

Key findings	Implications for main trial
Recruitment strategies	
• Primary care recruitment proved feasible to recruit to target ($n = 360$) within timeframe (3 months)	Primary care recruitment only feasible
• Practices reported database search criteria easy to operationalise • Practices identified screening process as the most resource intensive aspect, and determinant of maximum mailout size. • Average mailout size = 288 • Average number of participants recruited per practice = 29	Based on need to recruit $n = 21,455$ across both trials, will need to recruit approx. 740 GP practices
• Alternative routes explored (e.g., Join Dementia Research, Dementia Platforms UK, poster recruitment) not feasible for various reasons: ○ no clear pathway to access participants' medical notes for review at the end of the study; ○ administrative procedures required far too resource intensive at the scale required; ○ screening out ineligible invitees not possible/easy	
Randomization	
• Pure randomization • Performed automatically 'behind the scenes' by the Active Brains website, allowing participants seamless transition from baseline measures to notification of group allocation • Resulted in relatively evenly balanced groups even in small sample • No reported issues with randomization	Randomization method will be taken forward to main trial unchanged
Study materials	
• Participant facing materials and instructional documents for GP practices generally accessible and easy to follow • Clarifications required to information sheet/ follow-up questionnaires/ cover letter to maximize completion of online primary outcome	Modifications to participant facing documentation detailed in Table 6
Outcome measures	
• Overall good completion – 80% in both trials provided some follow-up data • Little missing data due to online completion automatically flagging missed responses • Slightly lower than hoped completion of primary outcome – particularly in "lower cognitive score" trial • Some issues identified with IPAQ-E and IADL measures	Modifications to participant facing documentation detailed in Table 6 to facilitate improved completion of primary outcome Continued use of IPAQ-E to measure physical activity. Minor modifications to IADL measure.
Notes review	
• Highly successful in collecting required data – 94.4% of whole sample notes review data collection; 100% of the data requested • Instructional document ensured form was easy to complete, but practice staff expressed concerns that it was too time consuming per patient, especially re. medical conditions and medications.	Removed baseline medications and medical conditions questions and only record any changes/ additions since baseline. Added questions on these items to participants' baseline measures.
Recruitment and attrition rates	
• 10.2% randomization rate – 560 participants from 5,475 invites	Confirms need for 730–740 GP practices.

(Continued)

TABLE 8 (Continued)

Key findings	Implications for main trial
• 92.2% retention rate – 28 withdrew, 14 from each trial	Amendments to ensure: 1) clear to participants they could withdraw from use of the intervention without leaving the trial; and 2) participants could more easily self-action withdrawal *via* the website.
• Across both trials, withdrawal rate from intervention substantially higher than Usual Care - 0.8%; Active Brains - 10.2%, Active Brains Plus Support - 12.6%	
• Loss to follow-up (i.e., no completion of primary outcome amongst those who remained in the study) higher in "lower cognitive score" trial (24.4%) than in "higher cognitive score" trial (16.1%)	Changes to follow-up materials to facilitate completion of primary outcome online documented in Table 6.

necessarily reflect all engagement with the recommendations of the intervention, as discussed further below. Exploring the impact of engagement with intervention content, and adherence to intervention recommendations will be a key part of the process evaluations conducted alongside the main trials, as recommended by recent guidance (38). If the slightly higher proportion of "lower cognitive score" participants accessing Active Brains overall (94% vs. 86% of the "higher cognitive score" participants) reflects a real difference, this may indicate a greater perceived relevance of the intervention amongst this group. Previous research has demonstrated that self-perceived cognitive deficit predicts willingness to invest time in interventions to protect cognition (39).

Usage of the online brain training element of Active Brains was low and, amongst nearly all participants in both trials, did not reflect the intervention's recommendations (3–5 times per week for an initial 6-month period). Across all groups, the median number of brain training sessions per user indicates lower usage than in a previous trial of the same cognitive training tasks that demonstrated a significant benefit for older adults' cognitive function (22). Our qualitative process data (to be reported elsewhere) indicated that many participants got bored of the games quite quickly which may explain low continued engagement. This may partially be explained by a programming error early in the feasibility trials which meant that the intended release schedule of the games (i.e., an initial six games with one additional game every 4 weeks up to a total of 12 games) was sped up meaning that all games became available to users within a much shorter period of time. This has been resolved for the main trials and so may facilitate more prolonged engagement with the novelty of available games lasting longer. Whilst sufficient engagement with the brain training games is important, exactly what "sufficient engagement" is in the context of a multi-domain intervention such as Active Brains is complex. For example, participants may have only accessed components they felt they needed support with. Recent evidence from a study examining dose-response in a multi-domain dementia prevention intervention suggests that higher number of sessions engaged with was not necessarily optimal for cognitive outcomes (40). Active Brains may also have prompted users to engage in other brain training activities – i.e., other online games, or pursuing "offline" activities.

Despite this lower than anticipated engagement with the online brain training, the behavioral data gives very preliminary indications that some aspects of the physical activity recommendations may have been better engaged with – more likely those from the Getting Active and Strength and Balance sub-modules given that these appeared to be more widely engaged with. Although recognized that the IPAQ-E can over-estimate time spent across all activity intensities and underestimate sedentary time amongst older adults (41), inflation of physical activity estimates here are likely to be present at both baseline and follow-up and so higher scores at follow-up could still be indicative of actual change. The IPAQ-E data seemed to indicate possible increases in physical activity behavior in the Active Brains group – particularly in the "lower cognitive score" trial. Active Brains was developed with the intention of minimizing users' need to regularly access online content and to instead build activity into daily routine and habits. Accordingly, sustained online engagement with the online content prompting physical activity was not considered necessary to support "effective engagement" (42) with the intervention. The suggestion of a possible increase in physical activity in the Active Brains groups is promising given that recent syntheses of the evidence about modifiable dementia risk factors indicate that interventions to enhance physical activity behavior point toward small beneficial effects for cognition overall, whereas those for cognitive training are somewhat less conclusive (5). If reflective of a significant statistical difference in a larger sample, the possible larger IPAQ-E increases in the Active Brains only groups compared to the supported groups could indicate that brief human support may not be beneficial (or may even be detrimental) in relation to independently sustaining physical activity behavior. These speculations can be further explored in the fully powered trials.

About half of those offered additional support in each trial had at least one telephone appointment, with larger numbers making at least email contact with their supporter. This is comparable to support uptake amongst digital behavior change interventions with similar models of brief additional support

(43, 44) and even to those that have demonstrated better intervention usage and trends toward better outcomes with only modest uptake of support (45). It possible that, amongst those who did not actively engage with their supporter, email reminders of the availability of support calls should they want them may have offered a sufficient level of perceived support. Indeed, our qualitative process data (to be published elsewhere) also indicated that even amongst those who did not take up the offer of support, they found it useful to know it was there if they needed it. In terms of the feasibility of scaling up support provision for the main trials, brief telephone support will continue to be provided by centralized supporters employed and trained by the study team. Assuming approximately equal allocation of participants to study arms, ∼7,150 participants will be allocated to the support arms. With a similar uptake of support as the feasibility trials, we would estimate that between 3,575 and 5,000 of these participants will take up the offer of support requiring between one and three 10-min phone calls each. For the feasibility trial eight supporters delivered all of the support and all reported having additional capacity, so although we will of course need to scale up the numbers of supporters, this should not be an unfeasibly large number required. This is especially the case given that participants will be recruited over a period of 2 years compared to 3 months in the feasibility trial, so the need for/provision of this support will be spread over a much longer period. Furthermore, as the support model primarily delivers support within the first 12 weeks of participants' use of Active Brains, some participants will reach the end of their support window by the time newly recruited participants begin theirs, meaning that the same supporter will be able to provide support for multiple practices without their workload becoming overwhelming. We estimate that around 15 supporters will be sufficient to deliver support to start with and we will have capacity to increase this number if required as more participants are recruited.

There were some indications that those in the "lower cognitive score" trial may have used the additional support more than those in the "higher cognitive score" trial – particularly in terms of having multiple telephone appointments. This might indicate greater perceived need for additional support amongst this group. Regular telephone support is advocated for maintaining engagement with complex interventions for those with cognitive impairment (46). Possible indications of differences in usage between the supported and non-supported groups, suggest that the support may have acted differently in the two trials. In the "lower cognitive score" trial, it appeared that a larger proportion of those in the support group accessed brain training compared to in the non-supported group and also appeared to access the games more frequently. In the "higher cognitive score" trial, although it seemed that similar proportions of the supported and non-supported groups accessed brain training, individuals in the supported group appeared to access it more frequently per person. However, in both trials there were early indications that the additional support may have enhanced engagement with brain training. Within the "lower cognitive score" trial, it also appeared that those in the supported group may have been more likely to access the full range of physical activity sub-sections than those in the non-supported group.

Preliminary indications about intervention outcomes

Potential patterns identified in the primary outcome data suggest that testing of Active Brains in fully powered effectiveness trials is warranted for both groups. In the "lower cognitive score" trial, the indication of higher Baddeley verbal reasoning scores and fewer individuals meeting the AACD/MCI criteria at 1 year was seen in all trial arms including the usual care group. Whilst the apparent improvement in the usual care group may suggest any actual change was not due to the intervention, this might be partly a consequence of the study procedures. All participants entering this trial were advised that their score on the baseline cognitive tests was slightly lower than the average. This may have prompted them to take action over the following year; those allocated to the usual care arm may have sought external advice or interventions beyond the brief advice sheet they were provided with, which may have led to improved scores. This message is no longer presented as it was not deemed acceptable by participants. In the "higher cognitive score" trial, the seemingly minimal change in the Baddeley verbal reasoning scores and proportions meeting the AACD/MCI criteria in the intervention arms compared to indications of sharper decline in the usual care groups gives a provisional indication of a protective effect of Active Brains. It is possible that the higher withdrawal rates from the intervention arms in both trials may account for the patterns seen. However, assuming that the AACD outcomes are missing at random given the observed data, we would expect this apparent protective effect to remain. This would be reduced under the extreme assumption that all of those missing meet the AACD criteria.

Feasibility and acceptability of study procedures

The findings indicated that the trial procedures were generally feasible, but also highlighted elements that required refining. Whilst there were imbalances of some participant characteristics between trial groups this is not unexpected given relatively small groups and should be overcome in larger main trial samples. Although successful in collecting 94% of the notes review data, our findings indicated that changes were required to facilitate sufficient response to the online

Baddeley verbal reasoning task – particularly amongst those in the "lower cognitive score" trial who may have found this more challenging. Cognitive decline may detrimentally affect participant retention or follow-up within research given that it can make completion of research tasks more difficult, time consuming, and frustrating (47). In this case, the effect may be compounded by our primary outcome requiring online completion, therefore not offering the usual paper alternative. However, following recommendations by Mody et al. (47), the subsequent changes to our materials and procedures offer participants more guidance and support about completing the online primary outcomes, and provide further explanation and encouragement. The greater completion of the primary outcome in the usual care groups compared to intervention groups likely reflects a combination of higher withdrawal rates in the intervention arms of both trials comparative to usual care, and possible fatigue with, or overlooking of, study emails within the intervention arms. The changes to automated emails and withdrawal process are anticipated to improve primary outcome completion in the intervention arms.

Recruitment and retention of sufficient numbers of participants within the trials was another important factor for being able to collect sufficient follow-up data. We recruited to target (n=180) in each trial within 3 months from 19 primary care practices in just one Clinical Research Network (CRN) within England. Projecting forward to the main trial, this will inevitably require extensive scaling up of recruitment to reach our target sample sizes of n = 10,940 for the "lower cognitive score" trial and n = 10,515 for the "higher cognitive score" trial. These sample sizes have been calculated on the basis of detecting a 5% difference in incidence of dementia at 5 years in the "lower cognitive score" trial, and of detecting a mean difference of 0.1 in the Baddeley Verbal Reasoning score in the "higher cognitive score" trial. They assume 70% completion of primary outcomes at 1 year, and 60% completion at 5 years. Full details of the trial sample size calculations are provided in Supplementary Table 7. Whilst we acknowledge that these are ambitious recruitment targets, we have allowed a 2-year recruitment period, and will be working with all 15 CRNs in England to identify primary care practices to participate across the country. We will also expand recruitment into Wales and Scotland for the main trial. Working with England's CRNs during study set up, we have identified that there are over 2,800 research-active (i.e., already engaged in research study activity) primary care practices in England alone. Given that we estimate the need for ∼740 practices (based on having recruited an average of 29 participants per practice in these feasibility trials) this indicates that whilst such large recruitment targets will be challenging, there should be sufficient practices to invite to achieve them.

Across both feasibility trials, withdrawal was relatively low, but disproportionately from the intervention arms. Those in the intervention arms naturally had more contact from the study team and therefore more opportunity to request withdrawal. After randomization, the usual care participants were only contacted when 12-month follow-up was due. We considered whether the higher withdrawal from the intervention arms indicated that Active Brains was too burdensome for participants. However, there was no requirement for participants in the intervention arms to engage any more than they wanted and chose to do so. Whilst they would occasionally receive email reminders about new content or suggestions about features of the intervention to try, there was no obligation for them to act on these, and they also had full control over how many emails they received and could stop these if preferred. The changes aimed to make it clearer and easier for participants to stop engaging with the intervention without leaving the trial, and also reassured them that completion of the primary outcome only was sufficient if that's all they could manage. Whilst we anticipate these changes to improve participant retention and primary outcome completion in the main trials, even in this feasibility study neither trial fell substantially below collection of 70% of the primary outcome follow-up data overall. This was the prior agreed criteria with our funder that may indicate lack of feasibility for proceeding to the main trial unless there was a clear and plausible plan to increase responses rates or reduce missing data.

Strengths and limitations

The study's parallel design allowed us to explore study objectives amongst older adults with and without existing indications of cognitive decline. This has allowed optimization of the intervention and procedures amongst both groups. We can now trial the intervention to determine its effectiveness for both groups. In-depth qualitative work conducted alongside these feasibility trials will be published separately providing further insight into participants' engagement with Active Brains.

A key limitation of this study was the lack of diversity in our sample with regards to ethnicity and relative deprivation. A predominantly white sample, largely from areas of low relative deprivation may not represent the outcomes or engagement we might have seen with a more diverse sample. It is possible, for example, that a more diverse sample may have different requirements or preferences for intervention support, tailoring, or functionality. Our recruitment region is likely to have contributed to our sample's lack of diversity. The average IMD score of all invitees was 6.9, indicating lower than average relative deprivation amongst all those invited. Furthermore, the South West region of England has the UK's lowest proportion of non-white residents (48). For the main trials, we will employ a nationwide recruitment strategy to encourage invitation of more diverse groups in terms of both ethnicity and relative deprivation. Furthermore, we will

consider other strategies to maximize recruitment of a diverse sample– for example, targeting areas with higher proportions of non-white residents and/or higher relative deprivation indices. We will also aim to engage with PPI contributors with a more diverse range of characteristics, perspectives, and experiences to ensure our recruitment strategies are accessible and engaging to a diverse audience. For example, this may include reviewing our recruitment materials and procedures with a more diverse group of PPI contributors to ensure that the content, tone and delivery of these is also appropriate, appealing and relevant for individuals from communities with higher relative deprivation and from a range of ethnic backgrounds. Where possible we will also explore the potential for community-based recruitment routes whereby researchers may be able to visit community groups, networks and institutions to introduce and explain the study, have the opportunity to answer questions and invite people directly.

Inevitably, an intervention that necessitates (even brief or occasional) access to a computer/the internet will not always be accessible to all, and we acknowledge that those from more deprived communities may have disproportionately fewer opportunities access to Active Brains. The process evaluation of the main trials will provide an opportunity to explore the reach of recruitment and sign-up to understand this better in the context of a nationwide recruitment study. However, by trialing such a digital resource for those who can access it, if effective it could potentially free up other "in person" resources for those who cannot. In the meantime, it offers a scalable, relatively low-cost way of identifying which recommendations/strategies etc. may be most beneficial which could then be further developed to be accessible non-digitally too.

Conclusions

This study investigated whether a multi-domain digital behavior change intervention to protect cognitive health is feasible and acceptable amongst adults aged 60–85 both with and without existing indications of cognitive decline. The proposed trial procedures were largely feasible and confirmed that a nationwide primary care recruitment strategy, whilst challenging, should be a suitable approach. Minor modifications to recruitment and follow-up materials and procedures were deemed important for providing participants with additional support and encouragement to complete the online primary outcome measures. Whilst initial uptake and engagement with the online intervention was modest, it was in line with typical usage of other digital behavior change interventions, and early indications from the descriptive analysis of the primary outcome and behavioral data suggest that further exploration of the potential protective benefits of Active Brains are warranted. Large-scale fully powered effectiveness trials amongst older adults with (n = 10,940) and without (n = 10,515) indications of existing cognitive decline will now investigate whether Active Brains is effective in reducing cognitive decline.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving human participants were reviewed and approved by National Health Service Research Ethics Committee (reference 17/SC/0463). The patients/participants provided their written informed consent to participate in this study. Written informed consent was obtained from the individual(s) for the publication of any potentially identifiable images or data included in this article.

Author contributions

PL and LY conceived of the study and secured funding. PL, LY, RE, and KB led the research and RE drafted the first version of this manuscript with input from SP. RE, MW, EG, SP, KS, FM, JS-B, JD-D, KB, AF, LY, and PL all contributed to the design, iterative development, and conduct of study procedures and collection of study data. JK, VH, and JS managed and coordinated the feasibility trials and provided administrative support. JZ, KS, and JD-D provided technical support and expertise in building and amending the digital intervention. HB and CB provided and coordinated access to the cognitive training and assessment tasks. BS and TB conducted the quantitative analysis. GY and SZ conducted the health economic analysis. TK, SG, NM, SRo, MR, HB, CB, LR, GG, JG, SRa, BG, RP, TS, and JN are members of the research management group and provided regular input on study processes, data, and write-up throughout. All co-authors reviewed, commented on, edited or approved this manuscript.

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Conflict of interest

LY is a member of the NIHR Health Protection Research Unit in Behavioral Science and Evaluation at University of Bristol, and the NIHR ARC West. KB's research portfolio is part funded by NIHR ARC Wessex.

The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpubh.2022.962873/full#supplementary-material

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Multimorbidity resilience and health behaviors among older adults: A longitudinal study using the Canadian Longitudinal Study on Aging

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Objective: There has been a growing interest in examining why some individuals adapt and bounce back from multimorbidity (resilience) better than others. This paper investigates the positive role of protective health behaviors on multimorbidity resilience (MR) among older adults focusing on older persons with two or more concurrent chronic conditions, and separately for three multimorbidity chronic illness clusters.

Methods: Using Baseline and Follow-up One data from the Comprehensive Cohort of the Canadian Longitudinal Study on Aging, we studied 10,628 participants aged 65 years and older who reported two or more of 27 chronic conditions, and three multimorbidity clusters: Cardiovascular/metabolic, Musculoskeletal, and Mental health. Associations between health behaviors and MR were evaluated using Linear Mixed Models, adjusting for socio-demographic, social/environmental, and illness context social determinants of health.

Results: Among older adults with two or more illnesses, smoking, satisfaction with sleep, appetite, and skipping meals were associated with MR in the expected direction. Also, obesity (compared to normal weight) and skipping meals showed longitudinal interaction effects with survey wave. Most of the results were replicated for the physical multimorbidity clusters (Cardiovascular/metabolic and Musculoskeletal) compared to the full 2+ multimorbidity analyses; however, for the Mental health cluster, only satisfaction with sleep was supported as a lifestyle predictor of MR.

Discussion: Several modifiable health behaviors identified in the broader health and aging literature are important in affecting levels of multimorbidity resilience in older age. These factors are important strength-based areas to target. Additionally, several social determinants of health are also supported and parallel research on multimorbidity risk. The effects of lifestyle factors for resilience among older adults is dependent on the type of multimorbidity

measured. We conclude that the results have significant public health, program intervention, and clinical implications for healthy aging among persons coping with multimorbidity.

KEYWORDS

multimorbidity, resilience, aging, health behaviors, CLSA

Introduction

In response to the dominant pathogenic approach to understanding health, researchers have begun to examine salutogenic responses to illness-related adversities by which individuals maintain and regain a sense of wellness in their lives through positive adaptation processes (1). There has also been a recognition that the majority of individuals experience illness adversity in older age, and that definitions of successful aging have not recognized the strength-based responses among individuals who may have been considered as "not aging well" (2, 3). This has led to interest in understanding one's ability and resources needed to cope with and navigate stress-inducing experiences—termed *resilience* (4, 5). Resilience models have been applied to numerous forms of adversity across the lifecourse, including disasters, aging-related functional loss, mental illness and multimorbidity (6–16), the latter of which is the focus of this paper (17).

In most economically advanced countries, approximately two-thirds of older adults have multimorbidity (two or more concurrent chronic conditions) and these rates increase with advanced age (18, 19). Living with multimorbidity represents a particularly unique and potentially potent form of adversity, since it can compound the synergetic deleterious effects of individual chronic conditions that shape symptom burden, functional ability, quality of life, and result in higher health care costs (20–24). Thus, a robust body of research has arisen addressing forms of multimorbidity from a resilience perspective (15, 19, 25, 26). The broad set of adaptations, including partial recovery and potentially reintegration (functional roles, identity, etc.), have been termed *multimorbidity resilience* (MR) (15, 25). However, there remains a gap in research knowledge pertaining to predictors of multimorbidity resilience, in particular, longitudinal analyses of health behaviors that have significant public health implications. These are important since they are mutable predictors of coping and adaptation to multimorbidity. Our primary research question is: what are the modifiable behavioral protective/risk factors that are associated with multimorbidity resilience over time?

Conceptualizing multimorbidity resilience

The science of resilience has identified a number of levels within which processes of adaptation and recovery can be manifested through interaction across psychological, emotional, spiritual, physical/functional, economic, cultural, and complex system domains (6, 16, 27–29). Specifically, in gerontology, the availability and accessibility of resources and the ability for older individuals to harness them constitute resilience and can shape multimorbidity trajectories. Yet some individuals are more likely to possess various protective factors, such as healthy lifestyle routines, social support systems, economic resources, and social-psychological strengths that may enable them to cope better than others with multimorbidity deficits (25, 30).

Given the focus of this research, we utilize the Lifecourse Model of Multimorbidity Resilience (LMMR) to frame the analyses [for full description, see (31)]. The LMMR uses three primary resilience domains: (A) *Functional resilience* which is necessary for completing tasks of daily living, social roles, and remaining physically active (27, 32). (B) *Social resilience* for the maintenance of positive social and community connectedness (10, 25, 33), as well as protection against feelings of loneliness and experiences of social isolation (34–36). (C) *Psychological resilience* which is needed to mentally cope with stressors linked to multimorbidity, rooted in stress theory and the cognitive appraisal process (37). The LMMR forms the basis for framing the analyses and developing the measurement strategy (see Section Methods).

Health behaviors and multimorbidity resilience

Research into precursors of multimorbidity and associated morbidity and mortality outcomes has identified a number of important modifiable health behaviors that we expect to predict MR (38, 39). Evidence has established that smoking, physical activity, obesity, eating habits, nutrition and alcohol consumption are associated with multimorbidity, although findings are equivocal for some of these behaviors (30, 38–42). In a cohort analysis, Canizares et al. (42) showed that there were successive cohort increases in multimorbidity inflated by being

obese, a smoker, and engaging in a sedentary lifestyle. Other studies found associations between smoking and multimorbidity (43, 44); and poor eating habits and obesity and multimorbidity (40). However, studies have uncovered inconsistent findings for physical activity (41, 42, 45), and alcohol consumption (39). Additionally, while sparse, research has shown a positive influence of sleep patterns for recovery (46), and that individuals with sleep disturbances progress to multimorbidity more rapidly over the life span (47). Health behaviors assist in the management and adaptation to illness-related stressors, foster stronger social connections and support, and enhance wellbeing (48–51). We hypothesize that the above health behaviors will be positively (protective factors) or negatively (risk factors) associated with levels of MR in older adults.

There are a number of other social determinants of multimorbidity that need to be adjusted to test the above hypotheses, including age, sex, education, income, marital status, immigration status, social support, housing and urban/rural residence (25, 30, 33, 38, 39, 42, 52). Additionally, perceptions of pain, medication use, and perceived health are indicators of the type and severity of multimorbidity that also should be included as covariates (25). This is because perception of pain is expected to have an inverse association with MR, due to its debilitating effect on functioning (26), while perceived health has been anticipated to be positively related to MR (9, 21, 53). Finally, medication use is associated with severity of illness but may also mitigate illness symptoms (26).

Methods

Data and sample

Participants were drawn from the Baseline and Follow-up 1 (FUP1) data of the Comprehensive cohort of the Canadian Longitudinal Study on Aging (CLSA). The CLSA is a national-level population-based longitudinal survey collecting social, psychological, biological, and clinical data from 51,338 Canadians aged 45–85 years old when recruited starting in 2011. Currently, two waves of CLSA data are available: Baseline data on 51,338 participants (2011 to 2015), and Follow-up One (FUP1) with 44,817 participants (2015 to 2018), separated by ∼3 years. The CLSA is comprised of two cohorts of participants, the Comprehensive cohort who were randomly selected among population residing within 25 km (or 50 km in a lower population density area) of the 11 data collection sites across Canada, and the Tracking cohort who were randomly selected from the ten provinces by the computer-assisted interview system. Detailed information about the CLSA has been published elsewhere (54–56). Researchers can access the de-identified data, and information on weighting through the CLSA website (www.clsa-elcv.ca).

The current study was conducted based on the Comprehensive cohort only, since several physiological measures essential to the multimorbidity resilience index measure (see below) are only available in this cohort. There are 30,097 comprehensive participants at Baseline of whom 27,765 (92.3%) are included in FUP1. There were 10,628 participants aged 65 years and older with two or more chronic health conditions at the Baseline included in the present analyses (refer to Figure 1 for the process of sample selection). During data collection, participants were asked whether they have been told by a doctor that they had the following 27 types of chronic conditions, including Alzheimer's disease, back problems, bowel incontinence, cancer, cataracts, diabetes, epilepsy, glaucoma, heart attack, heart disease, high blood pressure, irritable bowel syndrome, kidney disease, Parkinson's disease, peripheral vascular disease, lung disease, macular degeneration, multiple sclerosis, osteoarthritis, osteoporosis, migraine headaches, rheumatoid arthritis, stroke, thyroid problem, transient ischemic attack, ulcer, and urinary incontinence. In our study, participants diagnosed with two or more chronic illnesses were deemed multimorbid.

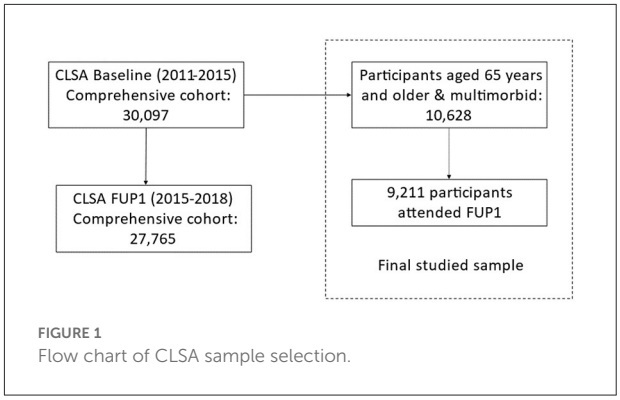

FIGURE 1
Flow chart of CLSA sample selection.

Additional sub-sample analyses were conducted based on sub-sets participants (65+) with two or more conditions within three exclusive multimorbidity clusters: (1) Cardiovascular/Metabolic cluster (heart disease, diabetes, and high blood pressure) (3,033), (2) Musculoskeletal cluster (osteoarthritis, osteoporosis, and lower back problem) (2,417), and (3) Mental health cluster (mood disorder, anxiety disorder, and migraine headache) (753). The three chronic illnesses within each cluster have been found to occur concurrently and share similar symptoms (57–62). These grouping were based on review of the cluster literature and the likely co-occurrence of particular chronic illness groupings.

Measurement

Dependent variable

The multimorbidity resilience index (MRI) is the dependent variable in this study. The MRI was developed by Wister et al. (15) based on the LMMR using CLSA Comprehensive cohort Baseline data. The MRI contains three resilience domains

essential to aging-related adversity and adaptation, including functional, social, and psychological multimorbidity resilience domains. In each resilience domain, three adversity challenges or positive adaptation variables were selected to calculate the sub-index score. The functional resilience domain includes the Summary Performance Score of Functional Ability Scale (63), the Older Americans Resources and Services Activities of Daily Living (ADL) Scale, and Instrumental Activities of Daily Living (IADL) Scale (64). The social resilience domain contains the total Medical Outcomes Study (MOS) Social Support Survey (65), a social participation measure related to the frequency of participation in activities with family and friends, and a single item measuring perceived loneliness over the past week (from the Center for Epidemiological Studies Depression - CES-D scale). The psychological resilience domain variables are the (CES-D) 9 item Scale (66) with the loneliness item removed, the Kessler Psychological Distress K10 Scale (67), and the Diener Satisfaction with Life Scale (68). The removal of the loneliness item from the CES-D has been used in research on loneliness, depression, and aging using the revised CES-D scale (69). This research demonstrated that the removal of a single item in the CES-D scale had a minimal effect, although comparisons made to the full 10 item CES-D should be made with caution.

A mapping system was applied to standardize different measurement types and skewed distributions of measures by converting all of the index related variables into a score between 0 and 10. For a full description of this index and the mapping system, see (15). This mapping system with normalization procedure has been used to develop other validated indices, such as a frailty index (70). The total MRI score was calculated by adding the three sub-index scores and dividing by three to produce a measure with the same range (0–10). Higher MRI scores mean greater multimorbidity resilience. The initial analyses have established good concurrent validity of the MRI (15). MRI total scores were associated with perceived health (OR = 1.68, CI 1.59–1.77); sleep quality (OR = 1.34, CI 1.30–1.38); perceived pain (OR = 0.80, CI 0.77–0.83); hospital overnight stays (OR = 0.87, CI 0.83–0.91); and emergency department visits (OR = 0.90, CI 0.87–0.94), after adjusting for socio-demographic factors, and number of chronic conditions. In the present study, at Baseline, the MRI mean was 6.47 (standard deviation = 1.64).

Socio-demographic variables

Six socio-demographic covariates based on the CLSA Baseline data included: age, gender, education, household income, marital status, and immigration status. Participants' age was measured in single years and ranged from 65 to 86. Sex was measured as "male" and "female." The highest educational attainment was coded at four levels from "no post-secondary education", "trade certificate or diploma or equivalent," "bachelor's degree," to "university degree above bachelor's degree." The annual household income was categorized into five groups, including "<$20,000," "$20,000–49,999," "$50,000–99,999," "$100,000–149,000," and "$150,000 and over." Marital status was originally collected based on five categories, and further recoded into two groups as "not married" (single, never married, widowed, divorced, separated) and "married/common-law." Immigration status was based on participants' country of birth and grouped into "immigrants" and "born in Canada."

Social and environmental variables

Four social and environmental covariates were included: number of friends, number of relatives, housing problems, and residential area. In the CLSA, participants were asked about the number of people they considered as close friends with whom they shared personal matters (ranging from 0 to 90), and the number of living relatives (ranging from 0 to 100). For those participants who reported at least one of the seven housing-related problems (noise, leaking, condensation, electrical wiring or plumbing, heating, maintenance or repairs, and infestations) were grouped into "with housing problem(s)," and others into "no housing problem." Residential areas were coded dichotomously as "rural area" and "urban area."

Behavioral and lifestyle variables

Six primary health behavior variables were of interest for these analyses, including physical inactivity, alcohol consumption, smoking, sleep, appetite, and skipped meals. Physical inactivity was measured using a measure of sedentary behavior from the Physical Activity Scale for the Elderly (PASE) (71). Participants were asked about the daily amount of time for sitting activities, ranging from "<30 min," "30 min but <1 h," "1 h but <2 h," "2 h but <4 h," and "4 h or more." Alcohol consumption is an aggregated variable based on a series of variables capturing participants' consumption (by drinks) of beer, wine, liquor, and other types of alcohol during both weekdays and weekends. The National Institute on Alcohol Abuse and Alcoholism (72) guidelines were used to group the variable at two levels: "14 or less drinks per week" and "15 or more drinks per week," since this cut-off reflects potentially problematic alcohol consumption. Smoking was measured based on participants' smoking activities during the past 30 days before taking the survey. A dichotomous variable was created as "smoked" and "not smoking in the last 30 days." Participants evaluated their sleeping quality at five levels: "very dissatisfied," "dissatisfied," "neutral," "satisfied," and "very satisfied." Appetite was similarly self-reported and measured as "poor," "fair," "good," and "very good." An additional variable was available capturing frequency of skipped meals. This variable was recoded as: "all the time to sometimes," and "rarely or never." Both the Baseline and FUP1 data of these variables were used in the data analysis.

Health context variables

Four main health related variables were examined, including Body Mass Index (BMI), self-rated health, pain, and number of medications. BMI was categorized into four levels: "underweight" (18.49 or below), "normal" (18.5–24.9), "overweight" (25–29.9), to "obese" (30 or higher). Self-rated health was measured using a single ordinal scale categorized as "poor," "fair," "good," "very good," and "excellent." Pain was measured based on responses to the usual intensity of pain or discomfort: "none," "mild," "moderate," and "severe." The number of medications variable is an aggregated variable based on ten questions related to medication taken or not for ten highly prevalent chronic conditions, including arthritis, diabetes, hypertension, ischemic heart disease, osteoporosis, Parkinson's disease, respiratory problems, stroke, thyroid, and transient ischemic attack. Responses to these questions were combined into a continuous variable with possible scores ranging from 0 to 10 with 10 reflective of a higher number of medications taken. The data from both Baseline and FUP1 were included for the self-rated health and pain variables, but only Baseline data were available for the number of medications.

Data analytic procedure

Data analyses were performed using SPSS version 26. The descriptive statistics for all variables at both Baseline and FUP1 waves are illustrated in Table 1. Linear Mixed Models [LMM; (73)] were applied to the longitudinal analysis of MRI from Baseline to FUP1 among aging participants with multimorbidity, as well as among the three multimorbidity clusters. LMM has been widely used to analyze panel data as it can control for random effects due to repeated measures on the same participant, and account for within-subject and between-subject variability (74). Additionally, use of LMM allows for both time-invariant (e.g., sex) and time-variant (e.g., age, number of chronic conditions) factors to be included in the same model.

Four hierarchical models representing the four blocks of variables (socio-demographic factors, social and environmental factors, behavioral and lifestyle factors, and the health context factors) were added sequentially into the models. In order to capture the change of MRI from Baseline to FUP1, survey wave analysis was used to test for time-related interaction effects. A random intercept was included to model the variation in the dependent variable outcomes across participants. Likelihood ratio tests based on the Akaike Information Criterion (AIC) were performed to compare the model fit, where a lower value of AIC indicates a better model fit. As recommended by the CLSA methods group (https://www.clsa-elcv.ca/), the trimmed weights were applied for descriptive analysis, and the analytic weights were applied for bivariate and multivariate analyses. We used the LMM function to handle the missing data for different waves on the outcome variables *via* restricted maximum likelihood estimation; and listwise deletion was used for independent variables (e.g., demographic factors) with missing cases. The only exception is the household income variable, which contains 6.4% missing values (over the 5% threshold), and therefore, missing cases were replaced with "not stated."

Results

A total of 10,628 participants aged 65 years and older reported two or more chronic conditions at Baseline. The average age was 73. More female older adults were multimorbid than their male counterparts (56 vs. 44%). The majority (89%) of participants reported post-secondary education, with half of them having received university degrees. About three quarters (74%) of participants reported household income between $20,000 and 99,999, and most (65%) were married or living with a partner in common-law relationship. Almost eight in ten (78%) were born in Canada (see Table 1).

The comparative results across survey time periods are also presented in Table 1, and only statistically significant results are described below. Participants reported lower MRI scores at the FUP1 than Baseline (6.22 vs. 6.47, $p < 0.001$). Participants had fewer relatives from Baseline to FUP1 (29.96 vs. 28.37, $p < 0.001$), but no change in the number of close friends. Compared to Baseline, a higher proportion of participants at FUP1 experienced housing problem(s) (19 vs. 18%, $p < 0.001$), and lived in urban area (93 vs. 91%, $p < 0.001$). Also, a higher percentage of participants at FUP1 spent four or more hours in sitting-based activities every day (59 vs. 46%, $p < 0.001$), and rated their appetite as fair to poor (11 vs. 7%, $p < 0.001$) when compared to Baseline. A higher proportion of participants at FUP1 did not smoke in the past 30 days (96 vs. 95%, $p < 0.001$), consumed 14 or less drinks every week (93 vs. 92%, $p < 0.001$), and rarely or never skipped a meal (23 vs. 19%, $p < 0.001$), comparing to Baseline. In addition, the proportion of participants rating their health as poor or fair was higher at FUP1 than Baseline (14 vs. 11%, $p < 0.001$). Satisfaction with sleep decreased, and the pattern of BMI shifted, with a higher proportion in the obese group at FUP1. Finally, a higher proportion of participants reported no pain at the FUP1 than Baseline (62 vs. 56%, $p < 0.001$).

The results of LMM of MRI score among participants with multimorbidity and additional three multimorbidity clusters are presented in Table 2. Only full model in each analysis with all variables included are discussed. As shown in Table 2, participants reported a lower MRI score at FUP1 than Baseline [estimate = −0.77, 95% CI: (−1.42, −0.13)]. Age was significantly related to MRI scores negatively [estimate= −0.03, 95% CI: (−0.04, −0.03)]. Male participants had a significantly higher MRI score than female participants [estimate = 0.34, 95% CI: (0.27, 0.41)]. Only participants with bachelor's degree

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TABLE 1 Socio-demographic, social and environmental, behavioral and lifestyle, and health contextual information among participants.

Variables	Baseline	Follow-up 1	χ^2(df)/*t*-test (df)
Age	73.17 (5.67)	–	
Gender			
Male	43.68	–	
Female	56.32		
Education level			
No post-secondary education	10.60	–	
Trade certificate or diploma or equivalent	39.96		
Bachelor's degree	23.93		
University degree above bachelor's degree	25.51		
Household income			
<$20,000 per year	7.70	–	
$20,000–49,999 per year	35.71		
$50,000–99,999 per year	38.40		
$100,000–149,000 per year	12.26		
$150,000 and over per year	5.92		
Marital status			
Not Married	34.57	–	
Married/Common law	65.43		
Immigration status			
Immigrants	21.71		
Born in Canada	78.29		
Number of friends	5.25 (6.39)	5.51 (7.07)	−1.08
Number of relatives	29.96 (25.77)	28.37 (24.26)	4.19***
Housing problems			
Yes	18.11	19.21	380.02 (1)***
No	81.89	80.79	
Urban, rural status			
Rural area	8.68	6.74	2,439.89 (1)***
Urban area	91.32	93.26	
BMI			
Underweight	0.89	0.97	9,046.38 (9)***
Overweight	41.74	39.02	
Obese	29.42	31.78	
Normal	27.95	28.23	
Physical inactivity			
1 h to <2 h	10.68	6.81	587.98 (9)***
2 h to <4 h	41.97	33.50	
4 h and more	45.52	58.50	
Siting < 1 h	1.82	1.19	
Alcohol consumption			
14 drinks or less per week	92.50	93.44	1,620.64 (1)***
15 drinks or more per week	7.50	6.56	
Smoking			
Not in the last 30 days	94.87	96.10	4,130.26 (1)***
Smoked	5.13	3.90	
Sleep			
Very satisfied	20.89	22.70	2,422.16 (16)***
Satisfied	40.89	37.55	

(Continued)

TABLE 1 (Continued)

Variables	Baseline	Follow-up 1	χ^2(df)/*t*-test (df)
Neutral	14.11	16.32	
Dissatisfied	19.93	18.05	
Very dissatisfied	4.18	5.39	
Appetite			
Very good	50.54	12.37	2,483.89 (9)***
Good	40.95	20.23	
Fair	6.38	5.07	
Poor	2.13	62.33	
Skipped meals			
Rarely or never	19.08	23.32	1,470.10 (1)***
All the time to sometimes	80.92	76.68	
Self-rated health			
Excellent	16.44	14.79	3,254.94 (16)***
Very good	39.05	37.99	
Good	33.79	33.60	
Fair	9.12	11.08	
Poor	1.60	2.54	
Pain			
Mild	15.78	12.37	1,652.51 (9)***
Moderate	22.98	20.23	
Severe	5.21	5.07	
None	56.03	62.33	
Number of medications$^+$	1.46 (1.14)	–	
Multimorbidity resilience index	6.47 (1.64)	6.22 (1.82)	7.86***

*p < 0.05; **$p < 0.01$; ***$p < 0.001$.
$^+$This variable is only available at the Baseline wave.

reported higher MRI scores than that of participants without any post-secondary education [estimate = 0.13, 95% CI: (0.01, 0.25)]. All the income groups above $20,000 per year reported higher MRI scores than participants with an annual household income < $20,000 [estimate= 0.32, 95% CI: (0.19, 0.45) for $20,000–49,999; estimate = 0.49, 95% CI: (0.35, 0.63) for $50,000–99,999; estimate = 0.66, 95% CI: (0.50, 0.83) for $100,000–149,000; estimate = 0.74, 95% CI: (0.55, 0.93) for $150,000 and over]. The MRI scores of unmarried participants were lower than married or partnered participants [estimate = −0.37, 95% CI: (−0.45, −0.30)]. Immigration status was not significantly associated with the MRI.

Among the social and environmental factors, number of friends, number of relatives, and housing problems were significantly associated with MRI, but not urban/rural residence. Number of friends had a positive association with MRI (estimate = 0.02, 95% CI: (0.01, 0.02)], and this effect was attenuated between Baseline to FUP1 longitudinally [estimate = −0.01, 95% CI: (−0.01, −0.002)]. Number of relatives was also positively related to MRI score at Baseline [estimate = 0.001, 95% CI: (0.001, 0.002)], and the relationship was strengthened over time [estimate = 0.003, 95% CI: (0.002, 0.004)]. Participants with housing problem(s) reported lower levels of MRI [estimate = −0.31, 95% CI: (−0.39, −0.24)] than those without housing problem(s), although the longitudinal effect was not supported.

Three of the seven behavioral and lifestyle factors were significantly related to MRI scores. Participants who did not smoke in the past 30 days prior to Baseline survey reported a higher MRI score [estimate = 0.27, 95% CI: (0.12, 0.41)]. Sleep was also correlated to the MRI score at Baseline, with higher levels of satisfaction of sleep leading to higher MRI scores [estimate = 0.93, 95% CI: (0.77, 1.09) for very satisfied; estimate = 0.69, 95% CI: (0.53, 0.84) for satisfied; estimate = 0.38, 95% CI: (0.21, 0.55) for very neutral; estimate = 0.25, 95% CI: (0.09, 0.41) for dissatisfied, compared to very dissatisfied]. Also, participants with either very good or good appetite reported higher MRI scores than those with poor appetite at Baseline [estimate = 0.40, 95% CI: (0.17, 0.63) for very good; estimate = 0.25, 95% CI: (0.03, 0.48) for good]. No longitudinal effect of sleep or appetite on MRI score was supported. Skipping meals had both main effect and interactive effect with survey wave on MRI score. Participants who skipped meals sometimes to all the time

TABLE 2 Linear mixed models of multimorbidity resilience score in full multimorbidity sample, the cardiovascular/metabolic cluster, the musculoskeletal cluster, and the mental health cluster.

	Multimorbidity sample		Cardiovascular/metabolic cluster		Musculoskeletal cluster		Mental health cluster	
	Estimate	**95% CI**	**Estimate**	**95% CI**	**Estimate**	**95% CI**	**Estimate**	**95% CI**
Survey wave								
Follow-up 1	−0.77*	−1.42, −0.13	−0.75	−1.93, 0.43	−0.97	−2.29, 0.36	−0.59	−1.90, 3.07
Baseline (ref.)								
(1) Sociodemographic model								
Age	−0.03***	−0.04, −0.03	−0.04***	−0.05, −0.03	−0.04***	−0.05, −0.02	−0.04***	−0.06, −0.02
Gender								
Male	0.34***	0.27, 0.41	0.44***	0.30, 0.58	0.37***	0.20, 0.54	0.25	−0.06, 0.55
Female (ref.)								
Education level								
Trade certificate or diploma or	0.06	−0.05, 0.17	−0.14	−0.36, 0.07	0.12	−0.12, 0.36	0.19	−0.23, 0.61
equivalent	0.13*	0.01, 0.25	0.10	−0.14, 0.34	−0.02	−0.28, 0.24	0.05	−0.41, 0.51
Bachelor's degree	0.07	−0.05, 0.20	−0.10	−0.34, 0.15	0.01	−0.25, 0.27	0.06	−0.40, 0.52
University degree above bachelor's degree								
No post-secondary education (ref.)								
Household income								
$20,000–49,999 per year	0.32***	0.19, 0.45	0.29*	0.03, 0.54	0.50***	0.24, 0.76	0.63**	0.22, 1.03
$50,000 to $99,999 per year	0.49***	0.35, 0.63	0.53***	0.26, 0.80	0.71***	0.43, 0.99	0.75***	0.31, 1.20
$100,000 to $149,000 per year	0.66***	0.50, 0.83	0.80***	0.48, 1.12	0.83***	0.48, 1.18	0.83**	0.21, 1.44
$150,000 and over per year	0.74***	0.55, 0.93	0.76***	0.39, 1.13	0.66**	0.25, 1.08	0.39	−0.34, 1.11
<$20,000 per year (ref.)								
Marital status								
No married	−0.37***	−0.45, −0.30	−0.32***	−0.48, −0.17	−0.33***	−0.48, −0.18	−0.24	−0.52, 0.04
Married/Common law (ref.)								
Immigration status								
Immigrants	−0.04	−0.11, 0.03	0.03	−0.12, 0.18	−0.04	−0.19, 0.12	−0.13	−0.45, 0.19
Born in Canada (ref.)								

(Continued)

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TABLE 2 (Continued)

	Multimorbidity sample		Cardiovascular/metabolic cluster		Musculoskeletal cluster		Mental health cluster	
	Estimate	**95% CI**	**Estimate**	**95% CI**	**Estimate**	**95% CI**	**Estimate**	**95% CI**
(2) Social/environmental model								
Number of friends	0.02***	0.01, 0.02	0.01*	0.002, 0.02	0.02***	0.01, 0.03	0.04**	0.01, 0.06
Number of friends × survey wave	−0.01**	−0.01, −0.002	−0.01	−0.02, 0.01	−0.01	−0.02, 0.01	−0.02	−0.04, 0.01
Number of relatives	0.001*	0.001, 0.002	0.002	−0.01, 0.004	0.001	−0.01, 0.003	0.001	−0.003, 0.01
Number of relatives × survey wave	0.003***	0.002, 0.004	0.005**	0.002, 0.008	0.01***	0.002, 0.01	0.01	−0.001, 0.01
Housing problems								
Yes	−0.31***	−0.39, −0.24	−0.29***	−0.44, −0.14	−0.31***	−0.46, −0.15	−0.34*	−0.61, −0.06
No (ref.)								
Housing problems × survey wave								
No × survey wave	−0.01	−0.11, 0.10	−0.03	−0.24, 0.18	0.01	−0.21, 0.23	0.26	−0.12, 0.64
Yes × survey wave (ref.)								
Urban, rural status								
Rural area	0.07	−0.03, 0.18	0.16	−0.06, 0.37	0.11	−0.12, 0.34	−0.21	−0.64, 0.22
Urban area (ref.)								
Urban, rural status × survey wave								
Rural area × survey wave	0.05	−0.10, 0.20	−0.09	−0.40, 0.21	−0.20	−0.54, 0.13	0.18	−0.39, 0.75
Urban area × survey wave (ref.)								

(Continued)

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TABLE 2 (Continued)

	Multimorbidity sample		Cardiovascular/metabolic cluster		Musculoskeletal cluster		Mental health cluster	
	Estimate	95% CI	Estimate	95% CI	Estimate	95% CI	Estimate	95% CI
(3) Behavioral/lifestyle model								
Inactivity								
1 h to <2 h	−0.02	−0.27, 0.22	0.05	−0.45, 0.55	0.25	−0.28, 0.78	0.33	−0.93, 1.61
2 h to <4 h	−0.07	−0.30, 0.17	0.15	−0.33, 0.62	0.20	−0.30, 0.71	0.59	−0.63, 1.82
4 h and more	−0.12	−0.36, 0.11	−0.001	−0.47, 0.47	0.27	−0.24, 0.77	0.58	−0.64, 1.80
Siting < 1 h (ref.)								
Inactivity × survey wave								
1 h to <2 h × survey wave	0.07	−0.36, 0.50	−0.03	−0.93, 0.86	0.04	−0.94, 1.01	−0.03	−2.03, 1.96
2 h to <4 h × survey wave	0.20	−0.20, 0.61	−0.15	−0.97, 0.68	0.12	−0.78, 1.03	−0.32	−2.21, 1.57
4 h and more × survey wave	0.17	−0.23, 0.57	−0.07	−0.90, 0.75	0.01	−0.89, 0.91	−0.68	−2.56, 1.20
Siting < 1 h × survey wave (ref.)								
Alcohol consumption								
14 drinks or less per week	0.04	−0.07, 0.15	−0.04	−0.27, 0.19	−0.04	−0.33, 0.25	0.27	−0.23, 0.78
15 drinks or more per week (ref.)								
Alcohol consumption × survey wave								
14 drinks or less per week × survey wave	0.05	−0.11, 0.20	0.25	−0.05, 0.55	0.05	−0.33, 0.43	−0.57	−1.33, 0.20
15 drinks or more per week × survey wave (ref.)								
Smoking								
Not in the last 30 days	0.27***	0.12, 0.41	0.57***	0.28, 0.85	0.36*	0.04, 0.67	0.30	−0.17, 0.77
Smoked (ref.)								
Smoking × survey wave								
Not in the last 30 days × survey wave	0.08	−0.10, 0.27	−0.10	−0.48, 0.27	0.31	0.10, 0.73	0.43	−0.20, 1.06
Smoked × Survey wave (ref.)								

(Continued)

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TABLE 2 (Continued)

	Multimorbidity sample		Cardiovascular/metabolic cluster		Musculoskeletal cluster		Mental health cluster	
	Estimate	**95% CI**	**Estimate**	**95% CI**	**Estimate**	**95% CI**	**Estimate**	**95% CI**
Sleep								
Very satisfied	0.93***	0.77, 1.09	0.76***	0.44, 1.08	0.80***	0.48, 1.13	1.27***	0.73, 1.81
Satisfied	0.69***	0.53, 0.84	0.59***	0.28, 0.90	0.61***	0.31, 0.91	0.97***	0.49, 1.45
Neutral	0.38***	0.21, 0.55	0.34	−0.002, 067	0.23	−0.10, 0.55	0.41	−0.12, 0.95
Dissatisfied	0.25**	0.09, 0.41	0.12	−0.20, 0.44	0.24	−0.07, 0.55	0.44	−0.04, 0.93
Very dissatisfied (ref.)								
Sleep × survey wave								
Very satisfied × survey wave	0.02	−0.19, 0.23	0.14	−0.27, 0.55	−0.01	−0.43, 0.42	−0.20	−0.89, 0.50
Satisfied × survey wave	0.04	−0.16, 0.25	0.04	−0.35, 0.44	−0.05	−0.45, 0.35	−0.17	−0.85, 0.50
Neutral × survey wave	0.16	−0.06, 0.37	0.15	−0.29, 0.58	0.30	−0.14, 0.74	−0.001	−0.76, 0.76
Dissatisfied × survey wave	0.10	−0.12, 0.32	0.13	−0.30, 0.56	0.16	−0.27, 0.58	0.18	−0.51, 0.86
Very dissatisfied × survey wave (ref.)								
Appetite								
Very good	0.40***	0.17, 0.63	0.46*	0.09, 0.83	0.38	−0.09, 0.85	0.26	−0.40, 0.93
Good	0.25*	0.03, 0.48	0.29	−0.07, 0.66	0.30	−0.16, 0.77	0.22	−0.43, 0.87
Fair	−0.04	−0.29, 0.21	0.07	−0.34, 0.48	0.004	−0.51, 0.51	−0.22	−0.95, 0.51
Poor (ref.)								
Appetite × survey wave								
Very good × survey wave	−0.08	−0.38, 0.22	−0.10	−0.58, 0.39	−0.13	−0.74, 0.49	−0.07	−0.92, 0.78
Good × survey wave	−0.21	−0.50, 0.09	−0.19	−0.68, 0.29	−0.27	−0.88, 0.34	−0.30	−1.14, 0.55
Fair × survey wave	−0.15	−0.49, 0.19	−0.10	−0.67, 0.46	−0.18	−0.86, 0.50	0.29	−0.69, 1.27
Poor × survey wave (ref.)								
Skipped meals								
All the time to sometimes	−0.31***	−0.39, −0.23	−0.18*	−0.33, −0.03	−0.33***	−0.50, −0.17	−0.20	−0.47, 0.07
Rarely or never (ref.)								
Skipped meals × survey wave								
All the time to sometimes × survey wave	0.16**	0.07, 0.26	−0.10	−0.30, 0.09	0.16	−0.05, 0.37	0.06	−0.30, 0.42
Rarely or never × survey wave (ref.)								

(Continued)

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TABLE 2 (Continued)

	Multimorbidity sample		Cardiovascular/metabolic cluster		Musculoskeletal cluster		Mental health cluster	
	Estimate	**95% CI**	**Estimate**	**95% CI**	**Estimate**	**95% CI**	**Estimate**	**95% CI**
(4) Illness context								
BMI								
Underweight	−0.05	−0.39, 0.29	1.66*	0.03, 3.29	0.05	−0.54, 0.65	−0.28	−0.94, 0.39
Overweight	0.01	−0.06, 0.09	−0.08	−0.26, 0.10	−0.03	−0.19, 0.14	0.21	−0.10, 0.62
Obese	−0.08	−0.17, 0.005	−0.16	−0.35, 0.02	−0.30**	−0.49, −0.12	−0.06	−0.39, 0.28
Normal (ref.)								
BMI × survey wave								
Underweight × survey wave	−0.13	−0.54, 0.29	−2.07*	−4.03, −0.11	−0.21	−0.96, 0.55	0.64	−0.98, 2.25
Overweight × survey wave	0.02	−0.07, 0.11	0.12	−0.10, 0.34	−0.09	−0.30, 0.11	−0.13	−0.53, 0.27
Obese × survey wave	−0.13*	−0.23, −0.03	−0.004	−0.22, 0.21	−0.14	−0.36, 0.08	−0.12	−0.53, 0.29
Normal × survey wave (ref.)								
Self-rated health								
Excellent	1.47***	1.18, 1.75	1.41***	0.98, 1.84	1.73***	1.21, 2.25	1.38**	0.50, 2.27
Very good	1.21***	0.93, 1.49	1.19***	0.80, 1.59	1.44***	0.94, 1.94	1.40***	0.59, 2.21
Good	0.82***	0.54, 1.09	0.87*** 0.26	0.48, 1.26	0.96***	0.47, 1.45	0.88* 0.32	0.09, 1.17
Fair	0.17	−0.11, 0.46		−0.14, 0.67	0.18	−0.33, 0.68		−0.49, 1.13
Poor (ref.)								
Self-rated health × survey wave								
Excellent × survey wave	0.47*	0.11, 0.83	0.64*	0.07, 1.20	0.65	−0.002, 1.30	0.48	−0.64, 1.60
Very good × survey wave	0.37*	0.02, 0.72	0.44	−0.07, 0.96	0.56	−0.05, 1.17	0.04	−0.94, 1.02
Good × survey wave	0.26	−0.09, 0.60	0.23	−0.28, 0.74	0.43	−0.17, 1.03	−0.22	−1.18, 0.73
Fair × survey wave	0.25	−0.11, 0.62	0.23	−0.31, 0.77	0.52	−0.11, 1.16	−0.24	−1.22, 0.75
Poor × survey wave (ref.)								
Pain								
Mild	−0.15***	−0.23, −0.07	−0.21*	−0.38, −0.04	−0.08	−0.26, 0.10	−0.14	−0.48, 0.20
Moderate	−0.29***	−0.36, −0.21	−0.27***	−0.41, −0.13	−0.27***	−0.43, −0.12	−0.22	−0.50, 0.06
Severe	−0.44***	−0.58, −0.30	−0.77***	−1.03, −0.51	−0.37**	−0.63, −0.11	−0.54*	−0.97, −0.11
None (ref.)								
Pain × survey wave								
Mild × survey wave	−0.10	−0.23, −0.07	0.10	−0.16, 0.35	−0.37**	−0.63, −0.10	−0.05	−0.54, 0.45
Moderate × survey wave	−0.10	−0.20, 0.01	−0.08	−0.28, 0.12	−0.17	−0.39, 0.05	−0.15	−0.54, 0.24
Severe × survey wave	−0.16	−0.37, 0.05	0.20	−0.16, 0.57	−0.39*	−0.75, −0.04	0.06	−0.57, 0.68
None × survey wave (ref.)								
Number of medicines (baseline)	−0.03*	−0.05, −0.001	−0.05	−0.10, 0.01	−0.08**	−0.13, −0.02	−0.11*	−0.22, −0.01
AIC	40,587.05		10,999.68		9,926.39		3,173.71	

*$p < 0.05$; **$p < 0.01$; ***$p < 0.001$; The reference group in the analysis is indicated by (ref.).

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reported lower MRI scores than those who rarely or never skipped meal [estimate = −0.31, 95% CI: (−0.39, −0.23)], while the difference of MRI scores between these two groups was attenuated over time [estimate = 0.16, 95% CI: (0.07, 0.26)].

All four health contextual factors were significantly associated with MRI scores. The main effect of BMI on the MRI score was not supported, but when compared to participants with normal BMI scores, those who were obese tended to have a greater decease in MRI scores between Baseline and FUP1 [estimate = −0.13, 95% CI: (−0.23, −0.03)]. Participants rated their health as good, very good, and excellent reported significant higher MRI scores than those rated health as poor at Baseline [estimate = 0.82, 95% CI: (0.54, 1.09) for Good; estimate = 1.21, 95% CI: (0.93, 1.49) for Very good; estimate = 1.47, 95% CI: (1.18, 1.75) for Excellent]. In addition, the interactive effect between self-rated health and survey wave was also supported, indicating that participants with very good and excellent levels of health had significantly greater increases in MRI scores than those with poor health over time [estimate = 0.37, 95% CI: (0.02, 0.72) for Very good; estimate = 0.47, 95% CI: (0.11, 0.83) for Excellent]. Pain was also related to MRI in the expected direction, where participants with all three levels of pain reported lower scores in the MRI than participants with no pain at Baseline [estimate = −0.15, 95% CI: (−0.23, −0.07) for Mild; estimate= −0.29, 95% CI: (−0.36, −0.21) for Moderate; estimate = −0.44, 95% CI: (−0.58, −0.30) for Severe]. The number of medications at Baseline was negatively related to MRI scores [estimate = −0.03, 95% CI: (−0.05, −0.001)].

Cardiovascular/metabolic cluster: Health behavior findings

There were 3,033 participants who identified with two or more Cardiovascular/metabolic illnesses. Given that most of the covariates showed similar patterns with MRI, and our focus is on health behaviors, we only present below the results for the behavioral and lifestyle factors shown in Table 2.

Four out of seven behavioral and lifestyle factors, including smoking status, skipped meals, sleep, and appetite, were significantly related to MRI scores among the Cardiovascular/metabolic cluster. Not smoking was related to higher MRI scores [estimate = 0.57, 95% CI: (0.28, 0.85)], and skipped meal (all the time to sometimes) was associated with lower MRI scores [estimate = −0.18, 95% CI: (−0.33, −0.03)]. Additionally, participants with very satisfied sleep [estimate = 0.76, 95% CI: (0.44, 1.08)] and satisfied sleep [estimate= 0.59, 95% CI: (0.28, 0.90)] reported higher scores in the MRI compared to those with very dissatisfied sleep. Participants with very good appetite were also associated with MRI when compared with those with poor appetite [estimate = 0.46, 95% CI: (0.09, 0.83)].

In addition, participants who were underweight reported higher MRI scores than those who were normal in BMI at Baseline [estimate = 1.66, 95% CI: (0.03, 3.29)]. The significant interactive effect between BMI and survey wave indicated that participants who were underweight had lower MRI scores at FUP1 compared to those who were normal in BMI [estimate = −2.07, 95% CI: (−4.03, −0.11)].

Musculoskeletal cluster: Health behavior findings

A total of 2,417 participants (65+) belonged to the Musculoskeletal cluster with two or more osteo-related diseases. Table 2 presents the results yielded from the LMM analysis. Among the behavioral and lifestyle factors, the relationship between smoking, satisfaction with sleep, and skipped meals were replicated compared to the Cardiovascular/Metabolic cluster (see Table 2). However, for BMI, only participants who were obese reported lower MRI scores than those who were normal in BMI [estimate = −0.30, 95% CI: (−0.49, −0.12)] at Baseline.

Mental health cluster: Health behavior findings

There were 753 participants (65+) with two or more mental health conditions. As shown in Table 2, among the behavioral and lifestyle factors, only the satisfaction with sleep was associated with MRI scores, where participants reporting very satisfied sleep [estimate = 1.27, 95% CI: (0.73, 1.81)] and satisfied sleep [estimate = 0.97, 95% CI: (0.49, 1.45)] reported higher MRI scores than those with very dissatisfied sleep at Baseline. See Table 2 for full results, including all covariates.

Discussion

A growing body of resilience and aging literature is developing in numerous sub-fields within gerontology multimorbidity (25, 27, 30, 38, 41, 42, 44). This paper is the first to employ longitudinal data separated by ∼3 years (2011–2015, and 2015–2018) to investigate the association between a comprehensive set of modifiable health behaviors and multimorbidity resilience (MR) among older adults. Our results provide evidence that behavioral lifestyle factors may be modified to act as resources for those experiencing the multimorbidity processes to enhance resilience.

Among older adults with multimorbidity, higher scores on the MRI were associated with not smoking, higher satisfaction with sleep, better appetite, and fewer skipped meals. In addition, being obese decreased multimorbidity resilience over time, although an association at baseline was not observed.

Further, the association for skipped meals with MRI was attenuated between the survey time periods. This research adds to prior research in several unique ways by demonstrating that health behaviors play an important role in the ways in which older adults adapt to multimorbidity resilience *over time*, which is often missing in research studies on resilience and aging processes.

Our results on smoking status parallel a large body of research showing that smoking increases multimorbidity risk [for example, (38, 42, 44, 75, 76)]. Moreover, this study also establishes that not smoking fosters resilience fortitude, which is consistent with an earlier study using the MRI but based on cross-sectional data (30). Looking at the risk side of the equation, smoking compromises MR due to its addictive properties among smokers coupled with its adverse effect on quality of life and psychological wellbeing (77). The importance of sleep quality as a positive health behavior for MR underscores its influence for illness recovery as well as role and identity reintegration, and is consistent with research demonstrating the salience of good sleep for better general resilience and lower health care utilization (30, 46, 78). Additionally, having a good appetite and not skipping meals appear to enhance levels of resilience among those with multimorbidity and is consistent with a growing number of studies showing the importance of food security in patterns of multimorbidity (76, 79), as well as resilience (30). Yet, the association between obesity and MR was only found when examining this relationship longitudinally. This is consistent with past research that has shown an increased risk of multimorbidity associated with obesity over time (42, 76). Taken together, our results on multimorbidity resilience are consistent with the broader research focusing on predictors of multimorbidity, which can provide a useful benchmark upon which we can validate the findings on resilience. For example, Skivington et al. (76) found support for similar behavioral lifestyle factors on multimorbidity (2+ conditions) in a Scottish longitudinal study. After controlling for socio-demographic covariates, multimorbidity risk was higher among smokers compared to non-smokers (OR 1.38, 95% CI 1.20–1.60); for those with BMI 30–35 (OR 1.57, 95% CI 1.22–2.01) and >35 (OR 2.21, 95% CI 1.40–3.48) compared to BMI 20–25; and for those with poor diet (OR 1.28, 95% CI 1.05–1.57). Although BMI is considered to be a health factor, we consider it to be an indicator of eating habits and physical activity level, similar to other studies [e.g., (30, 42, 80)].

However, our study did not support an association between physical inactivity and multimorbidity resilience. Previous research pertaining to the influence of physical inactivity on multimorbidity has been equivocal. Studies have reported positive associations among older adults with multimorbidity (75), support only for older men in others (41), and non-support in others, including longitudinal studies [e.g., (42, 45, 76)]. The inconsistent findings for physical inactivity may be the result of difference in design, age of the target population, and measurement, suggesting the need for more studies. It is also possible that physical activity, rather than sedentary time, may bolster multimorbidity resilience, since each exert independent effects on health (81, 82). Thus, physical activity has multipotent effects on physical function and mental health (83) that may improve resilience. Additionally, the absence of support for drinking patterns as a predictor of MR is aligned to many other findings based on research in the health and aging literature, some of which uses cross-sectional designs that can convolute the direction of the association since many individuals with multimorbidity reduce drinking, which does not mean that drinking is a protective factor [e.g., (39)].

Supplementary analyses were conducted on the associations of all health behaviors and covariates for the three multimorbidity clusters: Cardiovascular/metabolic, Musculoskeletal and Mental health. For the two physical multimorbidity clusters (Cardiovascular/metabolic, and Musculoskeletal), most of the findings reported for the 2+ multimorbidity group were replicated (see Table 2). The exception is the Mental-health cluster, where only sleep satisfaction was found to be associated with MR. Another notable exception was that obesity related to MRI in the musculoskeletal cluster only, which may reflect the additional loading demands of obesity on the musculoskeletal system (84). Additionally, being underweight related to lower MRI in the cardiovascular/metabolic disease cluster only, both at baseline and over time. Underweight BMI has previously been associated with increased mortality in Canadian seniors (85). It is possible that trajectories of body weight changes may have disease-specific impacts on health outcomes and resiliency. However, these results should be interpreted with caution.

This study also identified relationships between several socio-demographic resources and health care factors and multimorbidity resilience. Among the full 2+ multimorbidity group, increased resilience scores were observed among those with lower age, being male compared to female, having post-secondary education, higher income levels, being married or partnered, having larger support networks, and fewer housing problems. These social determinants are consistent with studies on multimorbidity as well as formative resilience research among older adults (6, 14, 25, 30, 36, 38, 42, 76). Turning to the health context measures, higher multimorbidity resilience was associated with better perceived health, less perceived pain, and fewer medications. These findings concur with other research on both multimorbidity and resilience (10, 21, 30, 53).

A number of limitations of these analyses are notable. First, the measures incorporated in the analyses are restricted to those available in the CLSA data sets. Additional modifiable health behaviors (e.g., meditation, sexuality, etc.) may also influence MR. Second, the MR index is a new measure that has only been validated in one study and used in a small cluster of studies to date, thus requiring further analyses and

comparisons to other resilience measures (5, 10, 30). For instance, established measures, such as the Connor-Davidson Resilience Score (86), or the Brief Resilient Coping Scale (87), or a priori statistical methods of estimating resilience (16), could be employed to further validate these findings and advance the literature surrounding multimorbidity resilience. Third, given that multimorbidity is variable due to differing symptom presentation and illness severity (e.g., hypertension, cancer, diabetes, etc.), research that incorporates additional illness context factors, such as onset, severity, and duration, and examines interactions with health behavior may help to specify the treatable, or modifiable moments in illness trajectories (88). Fourth, research may benefit by examining the cumulative effects of modifiable health behaviors over time, which has been useful in the broader multimorbidity risk literature (44, 75). This could include combinations of not smoking, physical activity, maintaining positive eating habits and a healthy weight, and quality sleep. Finally, this work needs to be extended to additional sub-groups, such as diverse racial/ethnic groups (89), those without health care insurance (6, 33), and at a community or system level (25, 28), especially during the COVID-19 pandemic (8, 17, 90, 91).

Conclusion

The ability to adapt, bounce back or reintegrate from multiple chronic illnesses, termed multimorbidity resilience, is fundamental to healthy aging and is receiving increasing attention in the literature (2, 6, 11, 12, 14, 26, 27, 30, 31, 91), including pandemic research (88, 90). Our findings indicate that there are several mutable health behaviors that are associated with MR and worthy of considering for intervention. The health behaviors found to be important in this study can be used to tailor and target health promotion and public health programs and policies. Innovations in the delivery of interventions for older adults with multimorbidity may utilize these findings to develop and implement innovative health promotion approaches (e.g., multifactor telehealth counseling, digital behavioral monitoring devices, community support programs, peer support groups, tailored cognitive therapy, etc.). Indeed, proactive, strength-based approaches to enhance resilience may prove to be valuable in enhancing aging well. Finally, several known social determinants of multimorbidity also have been found to be important, including age, gender, socio-economic deprivation factors and social support, which may also be low hanging fruit in the development of interventions targeting MR. The present study serves to advance important findings for other studies to build upon regarding the complex ways in which resilience can be elucidated and enhanced among persons experiencing multimorbidity over the life course.

Data availability statement

Publicly available datasets were analyzed in this study. This data can be found here: https://www.clsa-elcv.ca/data-access.

Ethics statement

This current project received ethics approval at two levels. Consent to participate was obtained for all participants under the CLSA harmonized multi-university ethics process approved by the Hamilton Integrated Research Ethics Board (HiREB), Hamilton Health Sciences/McMaster University. Written consent was obtained from all CLSA participants prior to enrollment. Individuals who were not deemed to be cognitively functional were excluded from the CLSA study. Simon Fraser University (SFU) was a participating institution in the CLSA data collection, and the SFU Office of Research Services Ethics Committee reviewed all consent material prior to data collection (SFU ORS #2010s0281). The patients/participants provided their written informed consent to participate in this study.

Author contributions

AW wrote the manuscript. LL conducted analyses of data, drafted methods, and results sections. CW, JF, KK, and IL reviewed and edited the manuscript. All authors have read and approved the final version of the manuscript, and have agreed to be accountable for all parts.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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What are the acceptances and associated influences of hospice care in Mainland China? A national cross-sectional study

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Background: China ranks 53rd out of 81 countries in the Quality of Death Index for 2021. Although hospice care demand is increasing, the progress remains slow. It is of great significance to explore the acceptances and associated influencing factors of hospice care.

Methods: A cross-sectional survey by quota sampling was conducted in China from July 10th to September 15th, 2021. We collected demographic data and hospice care acceptance. A stepwise linear regression analysis was used.

Results: This survey contained 11,031 valid questionnaire results to investigate the hospice care acceptance. It was found that individuals with undergraduate or above ($\beta = 0.04$), more properties [2 ($\beta = 0.02$), 3 ($\beta = 0.01$)], and higher reimbursement types of medical insurance [employee health insurance and commercial health ($\beta = 0.03$), government insurance ($\beta = 0.04$)] had higher hospice acceptance willingness, while males ($\beta = -0.02$) were less willing to accept than females. Psychological conditions [mild anxiety ($\beta = 0.03$), moderate anxiety ($\beta = 0.01$), moderate stress ($\beta = 0.05$), and severe stress ($\beta = 0.06$)] also played an important role. The Self-Management Scale (SHMS) ($\beta = 0.12$), EuroQol Five Dimensions Questionnaire (EQ-5D) ($\beta = 0.05$), EuroQol Visual Analog Scale (EQ-VAS) ($\beta = 0.21$), Short-Form Family Health Scale (FHS-SF) ($\beta = 0.12$), higher scores of the Short-Form Health Literacy Instrument (HLS-SF12) ($\beta = 0.16$), and Perceived Social Support Scale (PSSS) ($\beta = 0.10$) also contributed. Gender subgroup showed that in the male group, age, highest educational level, marital status, number of properties, whether having children, psychological conditions, the SHMS, EQ-5D, EQ-VAS, HLS-SF12, and PSSS

showed significant difference. Urban and rural subgroups showed that age, highest educational level, number of properties, whether having chronic disease or psychological conditions, the SHMS, EQ-VAS, HLS-SF12, and PSSS were contributing factors in rural areas.

Conclusion: The average score of acceptance of hospice care was 65.02 points. Gender, house, anxiety, pressure, social support, and health literacy were the main influencing factors on residents' attitudes.

KEYWORDS

hospice care, personal intention, affecting factors, cross-sectional study, China, public education

Background

In 2021, a study on the Quality of Death Index showed that China ranked 53rd out of 81 countries, indicating that there is still much room for improvement in the quality of death in China (1). China is a large developing country with a population of more than 1.4 billion, accounting for one-fifth of the world (2). In recent years, the growing elderly population has led to a demographic change (3). The growing trend of population aging, especially later in life, magnifies the need for hospice services.

Hospice care services can improve quality of life, save costs, and shorten hospital stays. Generally, high-income countries have higher access to hospice care but are also affected by geographical differences, such as the England and Canada (4). Hospice care is generally lower in developing countries and is more influenced by economics, education, and national policies (3). In China, the aging population has led to greater demand for hospice care services (5). However, the development of hospice care progresses very slowly and the supply of hospice care is limited in Mainland China, while hospice care services are widely provided in Western countries. Another obstruction is that death has long been a taboo in traditional Chinese culture, which may result in the concept that death is a failure caused by medical treatment (6). In a multicenter cross-sectional study, only 10.5% of 1,084 patients preferred a hospice facility (7). Besides, the economic and cultural conditions vary a lot in different parts of China, which may also affect the acceptance of hospice care. A previous study reported that attitudes toward hospice care are crucial to end-of-life decisions and that different individual characteristics influence preferences for hospice care (8). Nevertheless, there is no nationwide sample of the Chinese population to explore the factors associated with hospice care.

Hence, our study investigates people's attitudes toward palliative and hospice care and analyzes the associations between attitudes and potential explanatory variables based on the nationwide population sample in China. Given what we know, this study is the first to discuss the general intention of hospice care. This is likely to contribute to the development of hospice care by promoting global access to hospice care and quality of death.

Methods

Ethics statements

This study scheme was approved by the Institutional Review Committee of Jinan University, Guangzhou, China (JNUKY-2021-018). The questionnaire survey (Chinese Family Health Index survey, 2021) for the study was formally sponsored by China Family Newspaper and designed by Peking University, Jinan University, and Beijing Jiaotong University. All respondents volunteered to participate in the survey.

Survey design

The survey was carried out from July 10th, 2021 to September 15th, 2021, which involved 22 provinces, 5 autonomous regions, and 4 municipalities all over China's mainland. There were 120 cities, including the capital city, and 2–6 other prefecture-level cities of each province and autonomous region chosen by random number table method. The investigators or investigator teams were openly recruited in each chosen city to obtain the samples by quota sampling of the citizens, whose gender, age, and urban and rural distribution are in line with the demographic characteristics of the 7th National Census in 2021 (1–3). Each city was assigned at least 1 investigator (or team) by using the wenjuanxing platform (https://www.wjx.cn/, a professional online questionnaire survey platform). Moreover, we conduct a rigorous training for the investigators we recruited for the questionnaire survey, which included the standardized process and emergency measures to cope with the survey. The investigators imported the survey questionnaire into the wenjuanxing system and

created a link. Then they only need to share the link with the respondents through the online platform. Each investigator needs to collect 30–90 questionnaires (100–200 for each team) according to the set requirements. After giving informed consent to the survey, these respondents could answer the questionnaire and had the right to abandon it during the survey, and all the respondents remained anonymous.

Specific quota sampling criteria (every 100 samples) include: (1) Age criteria: under 18: 8 ± 5 (samples); between 19–24: 12 ± 5; between 25–30: 12 ± 5; between 31–40: 16 ± 5; between 41–50: 18 ± 5; between 51–60: 18 ± 5; between 51–60: 18 ± 5; between 61–70: 10 ± 5; over 71: 18 ± 5. (2) Gender criteria: the proportion between male and female is close to 1:1. (3) Urban and rural distribution criteria: the proportion between urban and rural samples is close to 3:2.

Inclusion criteria for this study include: (1) Age ≥ 12 years. (2) The nationality of the People's Republic of China. (3) China's permanent resident population (annual travel time ≤ 1 month). (4) Participate in the study voluntarily and fill in the informed consent form. (5) Participants can complete the network questionnaire survey by themselves or with the help of investigators. (6) Participants can understand the meaning of each item in the questionnaire. The reasons why we chose teenagers aged above 12 for our study are as follows. Firstly, we found that teenagers as well as adults have already accepted death education due to the improvement in education quality and social milieu (9, 10). Most teenagers aged above 12 have the conditions and circumstances to form their own outlooks of life and death, so they may also have mature ideas about hospice care. Secondly, those teenagers are fully capable of reading the questionnaire and answering it online with their smartphone (if they have). Taking these two points into consideration, it was believed that those teenagers would finish the survey rationally. Exclusion criteria include: (1) Those with mental disorders or insanity. (2) Those involved in other similar research projects. (3) Those unwilling to cooperate.

A total of 1,1709 questionnaires were collected and we screened 1,1031 valid questionnaires, with the 94.2% effective rate. In the process of the survey and analysis, we held 3 expert meetings to discuss and modify our research approach, which was advised by experts in different fields. Also, the final structure and data of the survey was rigorously screened and audited by those experts, and proved to be valid and meaningful.

Research instrument

Hospice care is a particular therapeutic method that provides physical, psychological and humanistic care for terminal and elderly people at their dying time. It may relieve their pain and discomfort and improve the quality of their lives, leading them to a peaceful and serene death. To discover more valuable information, the study focused on the relevance between residents' intentions for hospice care (according to what the investigators interpreted for the respondents) and their health status. After consulting professionals, we used a visual analog scale (VAS) scoring from 0 to 100 to assess their intention toward hospice care, with a higher score representing a stronger willingness to accept hospice care. Besides, based on the previous literature and information from other studies (11), the study mainly analyzed some sociodemographic characteristics (gender, age, house properties and so on) and health indicators (self-management ability, life quality, social support degree and so on) as the representative health metrics to assess their health status.

In this study, in addition to commonly used demographic and sociological characteristics, we added some health-related scales to measure the correlation between the respondents' multi-faceted health status and their willingness to accept hospice care. The Self-Management Scale (SHMS) can reflect the respondents' health management ability, and show the importance of the respondents to health. A previous study showed that the EuroQol Five Dimensions Questionnaire (EQ-5D), a simple and effective quality-of-life assessment tool, can serve as a useful predictor of survival in advanced cancer patients receiving hospice care (12). And for EQ-VAS, it can reflect the respondents' perception of their own health status and have an impact on the respondents' attitudes toward health. Social support also plays an important role in end-of-life care (13), and the Perceived Social Support Scale (PSSS) will reflect the support that the respondents feel. Both the Short-Form Health Literacy Questionnaire (HLS-SF) and Short-Form Family Health Scale (FHS-SF) can reflect the health literacy of respondents and their home environment. It has been confirmed that health literacy is related to respondents' knowledge, attitudes and decisions about end-of-life care (14). Besides, a scale measuring the psychological state of the respondents was also added to observe the influence of psychological state on the willingness to accept hospice care.

SHMS was used to measure self-management ability. The SHMS is made up of 3 sub-scales and they assess exercise frequency, cognitive symptom management, and communication ability with doctors. According to their personal conditions, respondents choose the corresponding options and those options would be rated from 0 to 5 (Likert-type). Then all the items would be summed up for a total score between 6 and 75, with higher scores indicating better self-management ability. The Cronbach's alpha of the SHMS was 0.79 (15).

EQ-5D was used to measure life quality and a sense of self-health. For this study, we used the five-level version (EQ-5D-5L). There are 5 items in the questionnaire that assess the action, self-care, daily activities, pain or discomfort and depression of respondents. Items would also be rated from 1 to 5 (Likert-type) and summed up. The total score is between 5 and 25 with higher scores indicating lower life quality. Additionally, EQ-VAS is also used to assess the sense of self-health. The VAS

scales range from 0 to 100, with a higher score indicating a better sense of self-health. The respondents input a number that reflects their health conditions from their own perspective. The Cronbach's alpha of the EQ-5D-5L was 0.87 (16).

A 3-item self-made scale was used to measure the sense of self-pressure. The scale includes the following items: (1) How would you evaluate your ability to cope with stress? (2) How would you evaluate the stress level in your life (at home and at work) over the last two weeks? (3) How would you evaluate the stress level in your life (at home and at work) over the last year? For each item, respondents inputted a number from 1 to 6 which indicated their stress levels on both family and work. The summed scale has a total score of between 3 and 18, with a higher score indicating more significant stress perception. The total score was used to classify the stress status of the respondents: a score of 3–6 means mild pressure, 7–15 means moderate pressure, and 16–18 means severe pressure.

PSSS was used to assess the degree of social support. PSSS assesses the perception of emotional support from social relationships through 12 items. Items are rated from 0 to 6 (Likert-type), based on the options from "very strongly disagree" to "very strongly agree." The summed items have a total score between 0 and 72, with a higher score indicating a higher degree of the perception of social support. The Cronbach's alpha of the PSSS was 0.91 (17).

HLS-SF was used to measure health literacy. For the study, we used the 12-item version (HLS-SF12). HLS-SF12 assesses the ability to find, understand, assess and apply health-related information. Items are rated from 1 to 4 (Likert-type), based on the options from "very hard" to "very easy". The summed items have a total score of between 0 and 72, with a higher score indicating a better health literacy. The Cronbach's alpha of the HLS-SF12 was 0.87 (18).

FHS-SF was used to measure family health degree. FHS-SF assesses 4 influencing factors including social and emotional health processes, health lifestyle, health resources, and external social support of a family through 10 items. The total score is summed up by rating each item from 1 to 5. The final score is between 10 and 50, with a higher score indicating a higher family health degree (19).

The Generalized Anxiety Disorder-7 (GAD-7) was used to measure anxiety status. 7 items are included to assess the frequency of anxiety symptoms by scoring each item from 0 to 3, and the total score ranges from 0 to 21. According to the reference standard, a score of 0-4 reflects no anxiety, 5–9 reflects mild, 10–14 reflects moderate, and 15–21 reflects severe symptoms. The Cronbach's alpha of the GAD-7 was 0.87 (20).

The Patient Health Questionnaire (PHQ-9) used nine items scored on their frequency from "not at all" to "nearly every day" resulting in a score between 0 and 27 (higher scores representing greater depressive symptoms) to assess depressive disorders. The Cronbach's alpha of the PHQ-9 was 0.84 (21).

Statistical methods

We used SPSS™ for Windows, Version 26.0 (SPSS, Inc., Chicago, IL, USA) for our data analysis. The descriptive analysis includes the mean value, standard deviation (SD) of continuous variables, and the *p*-value of each variable. The ANOVA analysis and t-test were used to compare differential factors for the scores of hospice care intention. Furthermore, a stepwise regression analysis was used to assess those differential variables associated with the intention of hospice care (Inclusion and exclusion criteria were: $P = 0.05$ and $P = 0.01$).

Results

Basic characteristics of the 1,1031 respondents

In this survey, a total of 1,1031 valid questionnaire survey results from 22 provinces, 5 autonomous regions, and 4 municipalities all over China's mainland (Figure 1) were shown. 50.87, 25.85, and 23.29% were from the east, central, and western China, respectively. Among the respondents, 54.27% were female, 72.60% lived in urban areas, 42.29% were under the age of 30, 45.71% were undergraduate or above, and 48.52% had resident medical insurance.

The average score of the PSSS of the survey target group was 48.22 ± 13.03 points, the short-form of the FHS-SF was 37.99 ± 6.64 points, the EQ-5D was 5.84 ± 1.82 points, the HLS-SF12 was 36.70 ± 6.04 points, and the SHMS was 26.49 ± 9.79 points. The average score for willingness to accept hospice care was 65.02 ± 29.82 points. The average willingness to receive hospice care varied across regions (Figure 2). Most of the respondents had a high acceptance rating (Figure 3).

Acceptance and associated influences of hospice care

To study the factors related to the acceptance of hospice care, we first conducted a chi-square univariate analysis of the variables, and the results showed that the differences in gender, permanent residence, age, highest education level, marital status, number of houses, occupational status, medical insurance type, whether having children, debt, or history of smoking, number of medications taken daily, frequency of drinking, anxiety state, stress state, and depression state were all statistically significant (Table 1). These variables and scales were further analyzed by multiple stepwise linear regression (Table 2). The results showed that among the survey respondents, males ($\beta = -0.02$) were less willing to accept than females. Those with undergraduate or above ($\beta = 0.04$), more properties [2 ($\beta = 0.02$), ≥3 ($\beta = 0.01$)], and higher reimbursement types of

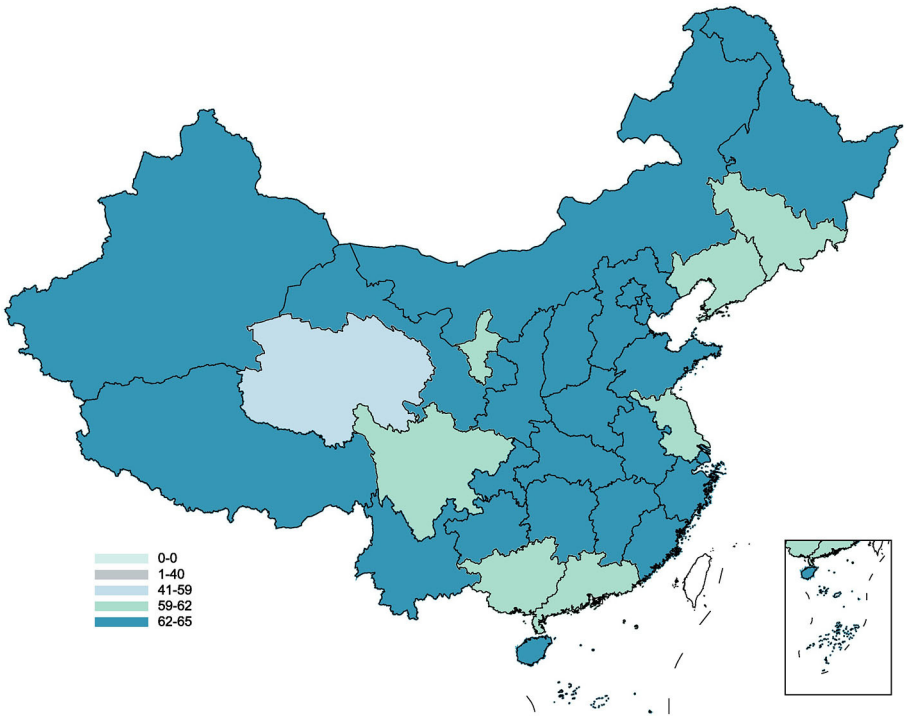

FIGURE 1
The distribution of acceptance of hospice care in China.

medical insurance [employee health insurance and commercial health (β = 0.03), government insurance (β = 0.04)] had a higher willingness to accept. The results showed that the psychological state of the respondents also had a great influence on the acceptance level. Compared with the respondents with no anxiety, those with mild anxiety (β = 0.03) and moderate anxiety (β = 0.01) had higher acceptance willingness, while there existed no significant difference in severe anxiety. Compared with respondents with mild stress, those with moderate stress (β = 0.05) and severe stress (β = 0.06) also showed better willingness to accept. SHMS (β = 0.12), EQ-5D (β = 0.05), EQ-VAS (β = 0.21), FHS-SF (β = 0.12), HLS-SF12 (β = 0.16), and PSSS (β = 0.10) also contributed to the results.

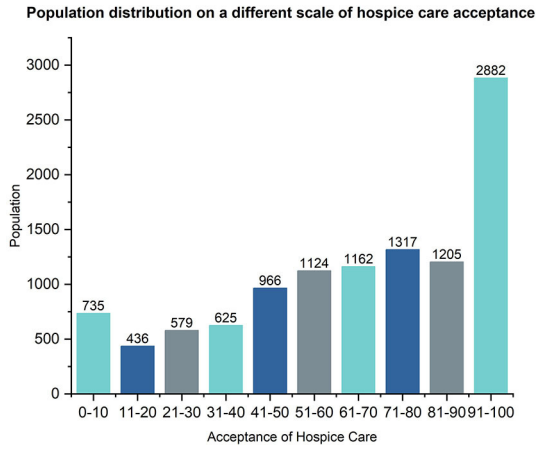

FIGURE 3
Population distribution on a different scale of hospice care acceptance.

Subgroup analysis of hospice care acceptance of different genders

In view of the statistical differences in gender (Figure 4), we further performed a stepwise regression analysis of gender subgroups (Table 3). In the female group, similar to the overall population, the highest educational level [undergraduate or above (β = 0.05)], psychological status [mild anxiety (β = 0.03), moderate anxiety (β = 0.02), moderate stress (β = 0.04) and severe stress (β = 0.05)], and the six scales [SHMS (β = 0.10), EQ-5D (β = 0.06), EQ-VAS (β = 0.18), FHS-SF (β = 0.15), HLS-SF12 (β = 0.23), and PSSS (β = 0.09)] also revealed correlations.

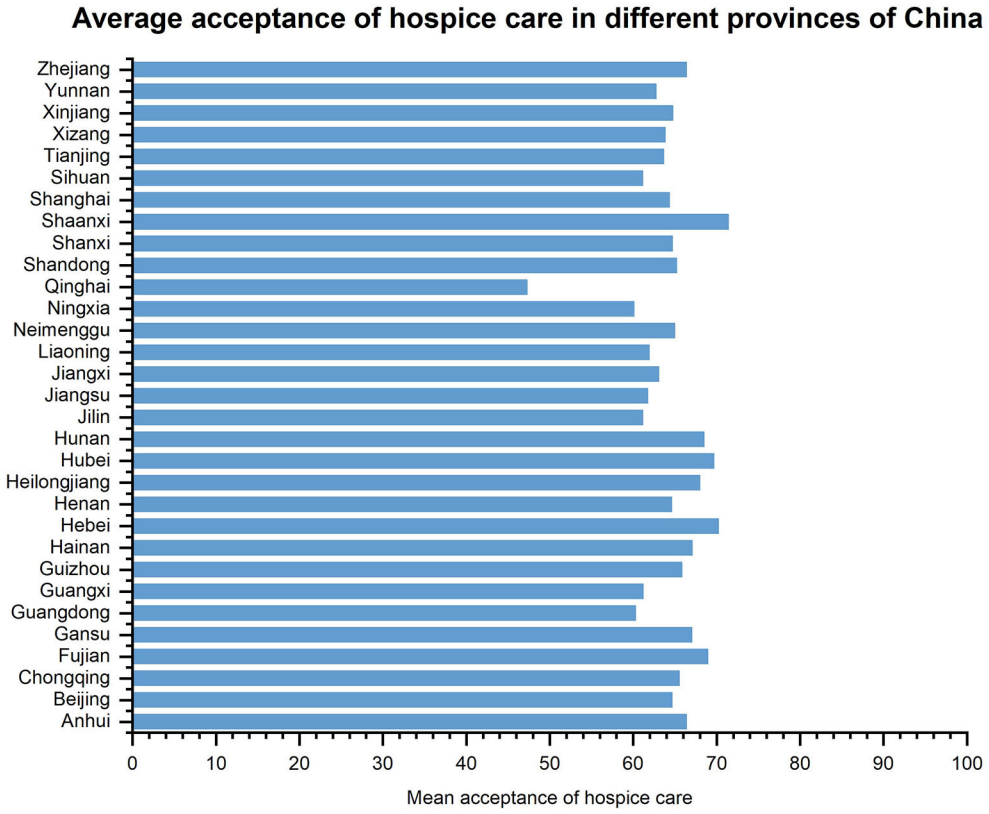

FIGURE 2
Average acceptance of hospice care in different provinces of China.

In the male group, except for the highest educational level [undergraduate or above (β = 0.03)], psychological state [mild anxiety (β = 0.02), moderate anxiety (β = 0.01), severe anxiety (β = −0.02), moderate stress (β = 0.06) and severe stress (β = 0.08)] and the five scales [SHMS (β = 0.15), EQ-5D (β = 0.04), EQ-VAS (β = 0.26), HLS-SF12 (β = 0.12), PSSS (β = 0.14)], those with an age of over 60 years old (β = 0.03) were more willing to accept it than those under 30 years old. Furthermore, being married (β = 0.08) and having 3 or more properties (β = 0.02) were also associated with a higher willingness to accept. The male group with children (β = −0.04) showed a lower willingness to accept.

Subgroup analysis of hospice care acceptance in urban and rural areas

Although the difference between urban and rural permanent residence was not significant in the multivariate regression results, the analysis of different groups of people in urban and rural areas may be conducive to the promotion of hospice care programs in urban and rural areas (Figure 5). For this reason, we further conducted a stepwise regression analysis of the urban and rural subgroups (Table 4). In the rural subgroup, the highest educational level [undergraduate or above (β = 0.04)], psychological status [mild anxiety (β = 0.03), moderate anxiety (β = 0.02), moderate stress (β = 0.08) and severe stress (β = 0.07)], and the four scales [SHMS (β = 0.08), EQ-VAS (β = 0.23), HLS-SF12 (β = 0.30), and PSSS (β = 0.11)] were consistent with the overall situation. Those with the age of 30–44 (β = 0.02) or 60 years old and above (β = 0.04), 3 or more properties (β = 0.02), and those diagnosed with chronic diseases (β = 0.02) showed a higher willingness to accept.

In the urban subgroup, gender [male (β = −0.03)], highest education level [senior high or specialty (β = 0.02), undergraduate or above (β = 0.06)], medical insurance type [employee health insurance and commercial health (β = 0.04), government insurance (β = 0.05)], psychological state [mild anxiety (β = 0.03), moderate anxiety (β = 0.01), moderate stress (β = 0.04) and severe stress (β = 0.06)], and six scales [SHMS (β = 0.13), EQ-5D (β = 0.05), EQ-VAS (β = 0.20), FHS-SF (β = 0.16), HLS-SF12 (β = 0.12), and PSSS (β = 0.10)] also showed correlations consistent with the general trend.

TABLE 1 Descriptive statistics of hospice acceptance among study subjects.

Variate	Number	Proportion	Mean	*SD*	*F*	*P*
Total	11031	100.00%	65.02	29.82	NA	NA
Gender						
Male	5033	45.63%	63.62	29.97	20.26	<0.001
Female	5998	54.37%	66.19	29.65		
Place of residence						
Urban	8008	72.60%	65.81	29.67	20.73	<0.001
Rural	3023	27.40%	62.91	30.12		
Age group						
<30	4665	42.29%	66.15	29.85	10.89	<0.001
30–44	3001	27.21%	65.76	28.61		
45–59	2218	20.11%	63.61	30.09		
≥60	1147	10.40%	61.17	31.86		
Region						
Eastern China	5611	50.87%	64.92	30.21	1.46	0.232
Central China	2851	25.85%	65.76	29.38		
Western China	2569	23.29%	64.40	29.44		
Highest educational level						
Junior high or below	2566	23.26%	60.92	31.36	51.10	<0.001
Senior high or specialty	3423	31.03%	63.83	29.26		
Undergraduate or above	5042	45.71%	67.91	29.09		
Marital status						
Unmarried	4805	43.56%	66.19	29.87	9.38	0.002
Married	6226	56.44%	64.25	29.64		
Number of propertes owned						
0	1083	9.82%	62.82	30.05	14.15	<0.001
1	6598	59.81%	64.02	29.67		
2	2440	22.12%	67.22	29.86		
≥3	910	8.25%	68.94	29.85		
Occupational status						
Student	3314	30.04%	66.82	29.74	18.52	<0.001
Incumbency	4637	42.04%	65.88	29.25		
Retire	884	8.01%	60.39	31.89		
No fixed occupation	2196	19.91%	62.32	29.91		
Occupation type						
Personnel of government agencies	1050	9.52%	67.50	29.52	7.16	<0.001
Professional and technical personnel	850	7.71%	65.71	29.93		
Medical staff	501	4.54%	70.09	29.70		
Labor service personnel	1729	15.67%	63.44	28.89		
Other	6901	62.56%	64.58	30.04		
Type of medical insurance						
Self-pay	2299	20.84%	64.05	29.57	3.22	0.012
Resident insurance	5352	48.52%	64.54	29.83		
Employee health insurance	2937	26.62%	66.17	30.07		
Commercial health insurance	237	2.15%	67.68	28.17		
Government insruance	206	1.87%	68.50	30.15		
Whether having children						
YES	5969	54.11%	63.78	29.95	13.31	<0.001
NO	5062	45.89%	66.47	29.60		
Whether having debts (including car loans, mortgages)						
YES	4251	38.54%	65.87	29.48	5.62	0.018
NO	6780	61.46%	64.48	30.02		
Whether having chronic disease						
NO	8984	81.44%	65.25	29.79	3.09	0.079
YES	2047	18.56%	63.97	29.93		

(Continued)

TABLE 1 (Continued)

Variate	Number	Proportion	Mean	*SD*	*F*	*P*
Whether having a history of smoking						
YES	2186	19.82%	63.41	30.44	7.94	0.005
NO	8845	80.18%	65.41	29.65		
Number of medications taken daily						
0	8996	81.55%	65.40	29.75	4.13	0.016
1–2	1540	13.96%	63.55	29.88		
≥3	495	4.49%	62.67	30.69		
Anxiety						
No anxiety	6170	55.93%	63.67	31.25	12.49	<0.001
Mild anxiety	3364	30.50%	66.23	28.09		
Moderate anxiety	1198	10.86%	66.95	26.35		
Severe anxiety	299	2.71%	71.50	29.89		
Pressure						
Mild pressure	2719	24.65%	63	34	82.15	<0.001
Moderate pressure	7653	69.38%	65	28		
Severe pressure	659	5.97%	79	27		
Depression						
No depression	5031	45.61%	63.57	31.46	8.00	<0.001
Mild depression	3801	34.46%	65.78	28.67		
Moderate depression	1148	10.41%	65.54	27.85		
Moderate to severe depression	803	7.28%	67.81	26.57		
Severe depression	248	2.25%	71.07	30.14		

Discussion

This study is the first to examine the acceptance level of Chinese residents for hospice care and its influencing factors. The average score of residents in this study was 65.02, which is relatively high. It was found that most residents intended to receive hospice care. In addition, the study identified some significant factors that may influence attitudes, providing a reference for targeted hospice care promotion strategies.

Firstly, gender is a factor that influences the attitude of residents. Our study discovered that women were more willing to accept hospice care. This result was consistent with the cross-sectional study about receptivity to palliative care in New York (22), while other studies have found no association between gender and hospice care (23). Secondly, our research indicated that educational level is the critical factor in hospice care. The higher education people receive, the greater the acceptance of hospice care they have (24). This result was similar to that of a previous study, which reported that patients with an educational level of a college degree or above are evidently more willing to accept hospice care (25). Thirdly, when compared to residents who did not own a house property, those who owned two or more house properties expressed greater concerns for hospice care. In most regions of China, house property equals economic status, which is positively associated with people's health literacy. Meanwhile, our research also found that health literacy plays a significant role in the population's attitude toward hospice care. Residents with higher HLS-SF12, EQ-5D, and EQ-VAS scores were more likely to develop an intention, indicating that higher health attention is positively related to hospice care. Therefore, it was deduced that better economic conditions and higher levels of knowledge are positively associated with hospice care appeals.

Furthermore, when we analyzed the data by gender, we discovered some other intriguing predictors of hospice acceptance. Compared to women, age, marital status and house properties showed a positive correlation with hospice care in men. The factor of whether having children was just the opposite. These results specifically revealed differences in health and thanatopsis between men and women in China. Previous research has reported that men have higher occupational risks and lower health literacy than women (26). Therefore, when Chinese men's marriage demands, economic demands, and child-rearing demands are satisfied, they will give more priority to their demands for hospice care. What's more, better family atmosphere will help people choose palliative care when dying in the intensive care unit (27). In our research, the FHS-SF score was an important factor influencing women's choice of hospice care but not for men. It indicated that family health is essential for Chinese women when choosing hospice care.

As a traditional agricultural country, the exploration of urban-rural differences in hospice acceptance is also of great significance. The FHS-SF score was found to be a specific factor in urban areas, which may be due to more family-centered care in urban areas (28). Rural residents have limited health literacy

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TABLE 2 Stepwise regression analysis of factors related to acceptance of hospice care.

Variables	Unstandardized coefficients		Standardized coefficients	*t*	*P*	95%*CI*	
	B	*SE*	*Beta*			Lower limit	Upper limit
Gender (Ref: Female)							
Male	−2.44	0.56	−0.02	−4.39	<0.001	−3.53	−1.35
Highest educational level (Ref: Junior high or below)							
Undergraduate or above	4.21	0.74	0.04	5.65	<0.001	2.75	5.67
Number of propertes owned (Ref: 0)							
2	2.98	1.07	0.02	2.78	0.005	0.88	5.08
≥3	3.28	1.32	0.01	2.49	0.013	0.70	5.86
Type of medical insurance (Ref: Self–pay and resident insurance)							
Employee health insurance and commercial health insurance	3.79	1.76	0.03	2.15	0.031	0.34	7.23
Government insruance	3.65	1.68	0.04	2.17	0.030	0.35	6.94
Anxiety (Ref: No anxiety)							
Mild anxiety	3.66	0.67	0.03	5.47	<0.001	2.35	4.98
Moderate anxiety	2.94	1.05	0.01	2.80	0.005	0.88	4.99
Pressure (Ref: Mild pressure)							
Moderate pressure	4.42	0.68	0.05	6.48	<0.001	3.08	5.76
Severe pressure	17.87	1.34	0.06	13.33	<0.001	15.25	20.50
SHMS	0.30	0.03	0.12	9.51	<0.001	0.24	0.36
EQ−5D	0.63	0.15	0.05	4.15	<0.001	0.33	0.93
EQ–VAS	0.18	0.02	0.21	10.63	<0.001	0.14	0.21
FHS–SF	0.21	0.05	0.12	3.98	<0.001	0.11	0.32
HLS–SF12	0.31	0.05	0.16	5.97	<0.001	0.21	0.41
PSSS	0.14	0.03	0.10	5.14	<0.001	0.09	0.20

because of some structural barriers like a shortage of specialist doctors, which leads to their lower scores for hospice care (29). As a result, younger people with relatively higher health literacy show higher scores for hospice acceptance than the aged (30). However, in the rural areas of China, older residents were more willing to accept hospice care when dying. This may not mean they are more health-literate than the young, but rather that they would prefer to die with a lighter burden on their children.

Notably, our results may provide helpful advice for healthcare providers to know more about patients' concerns. In our research, people with higher EQ-5D, FHS-SF and PSSS scores had a more acceptable intention toward hospice care. It was revealed that individual life support and emotional companionship are considered major factors in a good death (31). Another research found that higher PSSS scores mean higher psychological mediating ability, which may be the reason for accepting hospice care before death. Hospice care, as we know, involves providing people with adequate social support at the end of their lives. Most patients with cancer had supportive attitudes toward hospice care in a cross-sectional study in Mainland China. They wanted to know their diagnosis or prognosis of the disease, and wished to improve their life quality rather than prolong their life expectancy (32). In the countries with developed specialist hospice care, factors affecting people' preference are summarized as follows: available services, notably community support and hospice care units (33). Therefore, enhancing positive individual and social support may help alleviate the pain of dying people.

At the same time, our study reported that residents with high SHMS scores had a higher willingness to receive hospice care. Similarly, residents with higher anxiety and pressure levels were also more likely to accept hospice care. These people didn't have a greater health status, but showed a more urgent willingness for hospice care. The hypothesis of health behavior theory also showed that residents who are opposed to their own health risks are more likely to seek medical help (34). Pain caused by chronic

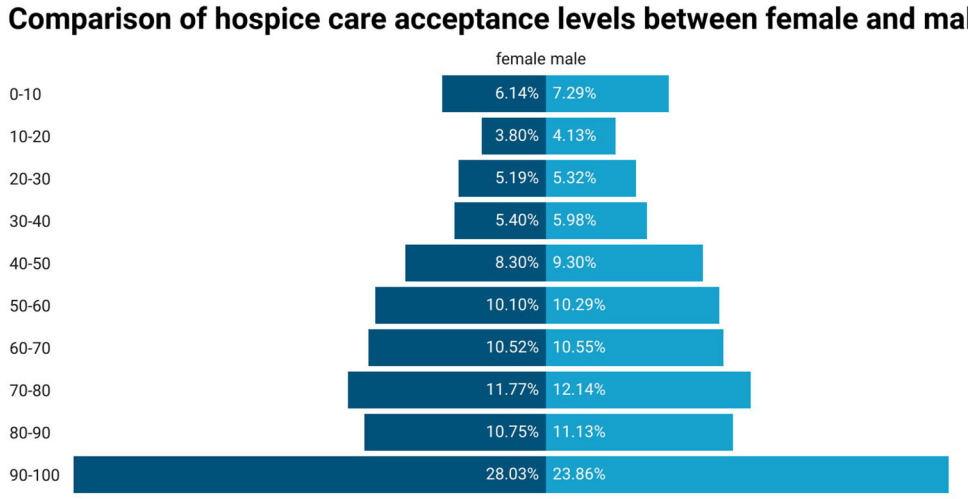

FIGURE 4
Comparison of hospice care acceptance levels between female and male.

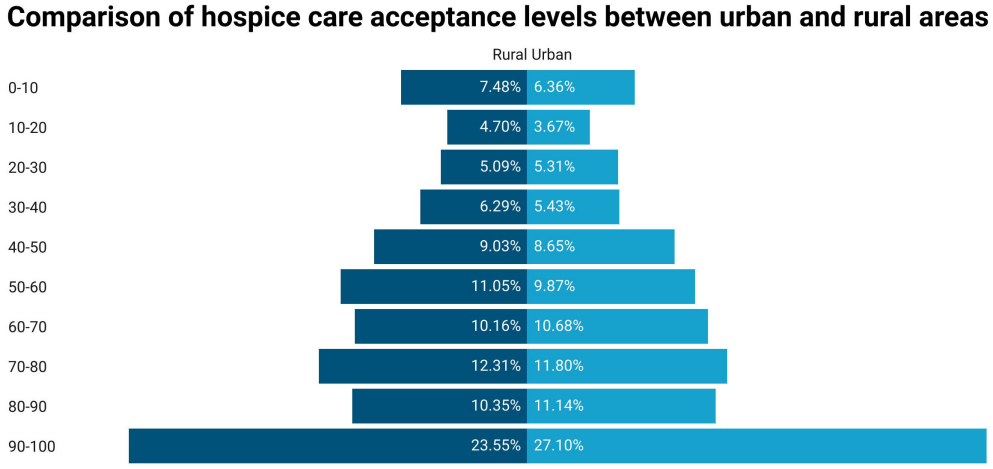

FIGURE 5
Comparison of hospice care acceptance levels between urban and rural areas.

disease, anxiety, and depression are other key components of palliative care (35). So reducing negative individual pains and social burden may prove to be necessary for clinicians.

One of our study's strengths is the large sample size, which slashes the influence of existing bias. It is the first time to discuss the public attitudes and explore the related factors on hospice care among a nationwide sample of the Chinese population. The perspective of this study can provide some valuable insight and reference for future research on hospice care policy theory. It can help researchers understand the process of accepting hospice care promotion better.

Despite some significant outcomes in hospice care, there are also limitations. Firstly, reporting bias was possible because of the self-reported information and the self-assessed scales in the study. Moreover, we could not know the number of participants who reviewed the online poster or survey but decided not to complete the survey, and thus could not assess non-response bias. Secondly, it is difficult to establish causality among the variables for the cross-sectional design of this study (27). Future research could explore more longitudinal studies to evaluate the relationship between various influencing factors and the acceptance of hospice care among residents. Besides, the distribution of the participants was imbalanced across the regions which might not be representative of the population. In addition, disparities in medical policy among different regions may exert an influential effect when people choose hospice care

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TABLE 3 Hierarchical stepwise regression analysis of predictors of hospice acceptance by gender.

Variables	Unstandardized coefficients		Standardized coefficients	*t*	*P*	95%*CI*	
	B	*SE*	*Beta*			Lower limit	Upper limit
Female							
Highest educational level (Ref: Junior high or below)							
Undergraduate or above	5.21	0.98	0.05	5.32	<0.001	3.29	7.14
Anxiety (Ref: No anxiety)							
Mild anxiety	4.33	0.89	0.03	4.86	<0.001	2.58	6.07
Moderate anxiety	3.66	1.45	0.02	2.53	0.012	0.82	6.51
Pressure (Ref: Mild pressure)							
Moderate pressure	3.81	0.92	0.04	4.15	<0.001	2.01	5.61
Severe pressure	14.95	1.89	0.05	7.91	<0.001	11.24	18.66
SHMS	0.27	0.04	0.10	6.09	<0.001	0.18	0.35
EQ−5D	0.75	0.20	0.06	3.68	<0.001	0.35	1.15
EQ–VAS	0.16	0.02	0.18	7.17	<0.001	0.11	0.20
FHS–SF	0.28	0.07	0.15	3.97	<0.001	0.14	0.42
HLS–SF12	0.45	0.07	0.23	6.49	<0.001	0.31	0.58
PSSS	0.14	0.04	0.09	3.52	<0.001	0.06	0.21
Male							
Age group (Ref: <30)							
≥60	5.60	1.88	0.03	2.98	0.003	1.92	9.29
Highest educational level (Ref: Junior high or below)							
Undergraduate or above	3.64	1.17	0.03	3.11	0.002	1.35	5.94
Marital status (Ref: Unmarried)							
Married	3.42	1.35	0.08	2.54	0.011	0.78	6.06
Number of propertes owned (Ref: 0)							
≥3	4.84	1.91	0.02	2.54	0.011	1.10	8.59
Whether having children (Ref: No)							
YES	−4.20	1.57	−0.04	−2.67	0.008	−7.28	−1.12
Anxiety (Ref: No anxiety)							
Mild anxiety	2.89	1.01	0.02	2.86	0.004	0.91	4.87
Moderate anxiety	1.53	1.50	0.01	1.02	0.308	−1.41	4.46
Severe anxiety	−6.58	2.69	−0.02	−2.45	0.015	−11.86	−1.30
Pressure (Ref: Mild pressure)							
Moderate pressure	5.40	0.99	0.06	5.45	<0.001	3.46	7.34
Severe pressure	20.39	1.90	0.08	10.74	<0.001	16.67	24.12
SHMS	0.35	0.05	0.15	7.52	<0.001	0.26	0.44
EQ−5D	0.51	0.21	0.04	2.42	0.016	0.10	0.92
EQ–VAS	0.22	0.02	0.26	9.42	<0.001	0.17	0.27
HLS–SF12	0.23	0.07	0.12	3.18	0.001	0.09	0.37
PSSS	0.19	0.04	0.14	5.48	<0.001	0.12	0.26

during their last days of life (36). More local and deep research a waits our exploration in the future.

Conclusion

The study found that Chinese residents' acceptance of hospice care scored 65.02 points. Gender, house properties, educational level, anxiety, pressure, health care type, health literacy and social support were the main influencing factors of residents' attitudes. Governments and medical institutions should take targeted measures to increase social support and improve the mental health of the population. This can facilitate the popularization of death education and the implementation of hospice policies in hospitals.

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TABLE 4 Hierarchical stepwise regression analysis of predictors of hospice acceptance by place of residence.

Variables		Unstandardized coefficients		Standardized coefficients	*t*	*P*	95%*CI*	
		B	*SE*	*Beta*			Lower limit	Upper limit
Rural								
Age group (Ref: <30)								
	30–44	3.27	1.48	0.02	2.20	0.028	0.36	6.18
	≥60	6.07	1.94	0.04	3.14	0.002	2.28	9.87
Highest educational level (Ref: Junior high or below)								
	Undergraduate or above	5.20	1.54	0.04	3.37	<0.001	2.18	8.23
Number of propertes owned (Ref :0)								
	≥3	8.85	3.14	0.02	2.82	0.005	2.69	15.01
Whether having chronic disease (Ref: No)								
	YES	3.79	1.61	0.02	2.35	0.019	0.62	6.95
Anxiety (Ref: No anxiety)								
	Mild anxiety	3.12	1.27	0.03	2.47	0.014	0.64	5.60
	Moderate anxiety	4.73	1.91	0.02	2.47	0.013	0.98	8.48
Pressure (Ref: Mild pressure)								
	Moderate pressure	6.44	1.29	0.08	5.01	<0.001	3.92	8.96
	Severe pressure	20.22	2.52	0.07	8.02	<0.001	15.28	25.16
SHMS		0.20	0.06	0.08	3.08	0.002	0.07	0.32
EQ–VAS		0.19	0.03	0.23	6.59	<0.001	0.14	0.25
HLS–SF12		0.58	0.09	0.30	6.49	<0.001	0.40	0.75
PSSS		0.16	0.05	0.11	3.50	<0.001	0.07	0.25
Urban								
Gender(Ref: Female)								
	Male	−2.71	0.65	−0.03	−4.17	<0.001	−3.98	−1.43
Highest educational level (Ref: Junior high or below)								
	Senior high or specialty	2.73	0.98	0.02	2.77	0.006	0.80	4.66
	Undergraduate or above	5.56	0.94	0.06	5.93	<0.001	3.72	7.41
Type of medical insurance (Ref: Self–pay and resident insurance)								
	Employee health insurance and commercial health insurance	4.76	1.95	0.04	2.44	0.015	0.94	8.57
	Government insruance	4.48	1.88	0.05	2.38	0.017	0.79	8.17
Anxiety (Ref: No anxiety)								
	Mild anxiety	4.00	0.78	0.03	5.11	<0.001	2.47	5.53
	Moderate anxiety	2.71	1.23	0.01	2.20	0.028	0.30	5.12
Pressure (Ref: Mild pressure)								
	Moderate pressure	3.79	0.80	0.04	4.76	<0.001	2.23	5.36
	Severe pressure	17.09	1.58	0.06	10.84	<0.001	13.99	20.18
SHMS		0.33	0.04	0.13	8.83	<0.001	0.25	0.40
EQ−5D		0.61	0.18	0.05	3.32	<0.001	0.25	0.97
EQ–VAS		0.17	0.02	0.20	8.99	<0.001	0.14	0.21
FHS–SF		0.30	0.06	0.16	4.79	<0.001	0.17	0.42
HLS–SF12		0.24	0.06	0.12	3.85	<0.001	0.12	0.36
PSSS		0.14	0.03	0.10	4.28	<0.001	0.08	0.21

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding authors.

Ethics statement

The studies involving human participants were reviewed and approved by the Institutional Review Committee of Jinan University, Guangzhou, China (JNUKY-2021-018). The patients/participants provided their written informed consent to participate in this study.

Author contributions

XinZ, XunZ, YL, TC, YinW, and XY contributed to the conceptualization and methodology. YibW, YuW, XS, and W-KM contributed to investigation. YL, TC, and XY contributed to the design of the study and the data analysis. XinZ, XunZ, YL, TC, LS, YinW, and XY contributed to the writing of the manuscript. JW, YibW, and ZX critically revised the manuscript. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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Design and process optimization of combined medical and elderly care services: An integrated service blueprint–TRIZ model

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China's increasingly aging population is resulting in an imbalance between supply and demand for elderly care resources. The theory of "combined medical and elderly care" (CMEC) has introduced a new perspective in the conception of China's elderly care problems. This study employed the service blueprint, fuzzy failure mode and effects analysis (Fuzzy-FMEA), and the theory of inventive problem solving (TIPS or the Russian acronym TRIZ) for the process optimization of CMEC services in three phases. In the first phase (service process analysis), potential service failure points in the service process were analyzed using the service blueprint technique. In the second phase (service failure diagnosis), Fuzzy-FMEA was applied to diagnose the service failure modes and explore the possible causes and effects. The service failure modes were then prioritized based on fuzzy numbers and the cumulative fuzzy risk priority number (Fuzzy-RPN). Finally, in the third phase (generation of service optimization solutions), the TRIZ parameters, inventive principles, and contradiction matrix were first employed to select TRIZ inventive principles. The selected TRIZ inventive principles were then used to inspire inventive solutions for new service processes. Finally, a case study was conducted on the service processes of elderly care institutions to demonstrate the applicability of the optimization solutions.

KEYWORDS

service blueprint (SB), Fuzzy-FMEA, theory of inventive problem solving (TRIZ), combined medical and elderly care, service innovation

Introduction

According to the 14th Five-Year Plan of the Chinese government, in order to cope with the problems caused by an aging population, it is necessary to strengthen the health services for the elderly, promote "combined medical and elderly care" (CMEC) services and meet the demand for care services of elderly people with disabilities and dementia. The aging population has led to a surge in demand for elderly care services (1).

According to the 2019 National Bureau of Statistics data, the number of people over 60 years old in China reached 254 million, accounting for nearly 20% of the total population (1). Furthermore, this trend of aging is expected to increase in the future. China's elderly population aged over 60 years is projected to exceed 400 million in 2035 and 500 million by 2055. Against the backdrop of an aging population and longer life expectancy, the number of elderly people living alone in China is gradually increasing, and it is insufficient to rely solely on their children for elderly care and meet their multifaceted needs (2). China's elderly care services face the risk of an imbalance between supply and demand. According to the literature, China has an average of only two beds per 100 elderly people, which is far below the elderly care standard of 5–8 beds per 100 elderly people in developed countries (3). Families of the elderly are also faced with different forms of pressure, including the provision of medical care and rehabilitation, imposing new demands on the country and society when it comes to dealing with the manifold aspects of an aging society. According to the 14th Five-Year Plan, to cope with the problems of an aging population, it is necessary to strengthen health services for the elderly, promote CMEC services, and meet the demand for elderly care services for people with disabilities and dementia, which are crucial in alleviating the associated pressures.

Owing to the lack of a robust management system in the Chinese government and the relative scarcity of professional caregivers for CMEC services in the country, problems with the design of CMEC services in relevant elderly care institutions need to be addressed. In the implementation process, there are one or more factors (e.g., service capacity, service flexibility, number of care providers, quality of care services, facilities, and equipment) that can have a decisive impact on the quality of CMEC services (2, 4, 5). Therefore, the potential of elderly care services can be fulfilled by optimizing service processes and improving and upgrading service factors. To this end, many elderly care institutions require a service design approach to analyze service failures and develop new service solutions to meet the care needs of the elderly and alleviate the imbalance and conflicting pressures on resources (4, 5).

Researchers have previously conducted studies on healthcare services similar to the concept of CMEC, such as nursing care in Japan, long-term care (LTC) in the United States, and integrated care in the United Kingdom. These studies have explored the concepts of LTC in the United States with respect to understanding the nature, determinants, social processes, and impacts of LTC (6–8); examined the rationale for integrated services in primary care settings in the UK and proposed the Rainbow Model of Integrated Care (9)[7]; and studied Integrated Funding Models (IFM) of sustainable integrated care for chronic conditions in Ontario, Canada (10). However, there is a lack of research on the optimization of specific service processes in CMEC.

Based on previous research, this study combined the application of service blueprint, fuzzy failure mode and effects analysis (Fuzzy-FMEA), and the theory of inventive problem solving (TRIZ) to form an integrated service blueprint-TRIZ model. The advantage of this model is that it replaces the reliance on the service designer's intuition and personal experience with a quantifiable scientific method to systematically identify failures in the service process and perform optimization. The application of this method to research on the CMEC service process may successfully fill the gaps of current research.

Literature review

Based on the findings of previous research, this study employed the service blueprint technique to map the CMEC service delivery process to identify the CMEC points and their service failure points, aiming to improve the CMEC service process design. The possible causes and effects of failure points were then analyzed using Fuzzy-FMEA, and the Fuzzy Risk Priority Number (Fuzzy-RPN) was calculated from the fuzzy numbers obtained for prioritization. In addition, by combining TRIZ with the service blueprint technique, the causes and effects of service failures were mapped and adapted to the innovative principles and methods of TRIZ. Relevant optimization solutions were then designed to optimize the service process and support policies of CMEC. A literature review of relevant concepts is provided as follows.

Definition of CMEC

CMEC (combined medical and elderly care) is a Chinese term, and similar concepts can be found in the healthcare services of other countries, including nursing care in Japan, LTC (long-term care) in the United States, and integrated care in the United Kingdom (4–6, 10). In the United States, Kane was the first to introduce the concept of LTC in 1987, which was defined as the provision of medical care, personal care, and social services for people with congenital or acquired disabilities (11). In 2002, the National Health Service (NHS) of the United Kingdom introduced the Integrated Care Trust to better provide integrated health services for the elderly, disabled, mentally ill, and other groups.

For LTC in China, it needs different care service deliveries, such as home care, community care, and institutional care. These care services need to be intergraded by CMEC coping with the healthy development of the aging society (12, 13). CMEC is unlike the traditional home care model in China, it focuses on integrating optimization, medical care, and pension resources for the elderly, which includes providing daily care, nursing care, medical services, and other forms from the new

LTC service to achieve healthy aging (4). In China, CMEC is a new concept of elderly healthcare that combines medical service technology with elderly care services. This was proposed by professionals in various fields based on the special needs of the elderly population to improve their quality of life and adapt to the trends of an aging population. Its goal is to achieve an in-depth integration between two completely different but interrelated services, namely, medical and elderly care services (2, 4, 5). CMEC not only seeks to enhance the medical capacity of elderly care institutions, but also to relieve the pressure on elderly care resources, improve the scope and level of medical care and nursing care services for the elderly, and meet the complex needs of older adults in this era. Thus, by creating a new approach to provide elderly care through the combination of hospital care and elderly care resources, CMEC aims to achieve spatial accessibility and time continuity of medical services in the face of new demand for elderly care.

Wei and Zhang (4) explored the influence of different factors on the elderly's preferences in CMEC services by using Andersen Model for predicting the elderly's real needs, this study helps the government to better plan the elderly's pension and care services for giving full play to the important supplementary role of institutional care. Yang et al. (2) conducted a cross-sectional survey aiming at six elderly care institutions in a city in Central China according to the national guidelines for combined medical and elderly care. Their result indicated CMEC service system should increase managers' specialized training and salary for improving their elderly care skills and care service quality to deal with the diversified demands from CMEC. A long-term care education system should be integrated into CMEC by expanding the enrollment scale of the nursing school, carrying out training about elderly care skills, and issuing vocational skills certificates to those who pass the examination, the number of local nurses for the elderly will be increasing, and the quality of CMEC will be improving (14).

Service blueprint

The service blueprint is a service analysis tool grounded in process design proposed by the American scholar Shostock in the early 1980s using a multidisciplinary approach. The service blueprint is a two-dimensional description of the service process, which divides the service process into three parts (patient actions, front-stage action, and back-stage action) to identify the line of interaction and line of visibility. This allows for a clear understanding of the interactions and influences among the different parts of the service process (15–17) while enabling the visual analysis of the root causes affecting the service perception and satisfaction of the elderly population (18).

Unlike other process maps, the service blueprint provides the service designer with a visual representation of customer service perceptions and experiences. Therefore, it is an extremely effective tool that can be used by service designers for service optimization to improve service quality, service efficiency, and customer satisfaction (15, 18). Institutionalized elderly people require long-term, continuous, diverse, and personalized services, and they can easily perceive the quality of each step in the service process. The service blueprint presents the roles of and the services provided by social workers in the institution, and identifies the areas that need improvement, which helps promote a more robust human resource system in the institution. The service designer can use the service blueprint to describe the service process to identify the parts of the service process with potential service failures. By analyzing these service failures, they can then define the possible conflicting factors in the service process and identify corresponding solutions.

Fuzzy FMEA

FMEA is a systematic analysis tool proposed in the early 1950s. It analyzes each process of a product or service process to identify all possible failure modes and seek the causes and influencing factors of these failures. Accordingly, suitable optimization solutions are proposed through detailed analysis to prevent and control the risks of product quality or service processes and achieve the reduction of loss rate. The core tasks of FMEA involve the a priori analysis and control of product defects and service failures, as well as continuous quality improvement, elimination of possible risks and adverse effects, and improvement of the reliability of products and services during the work process (19). FMEA evaluates the severity effect of a failure mode by combining the RPN, which is the product of severity (S), occurrence probability (O), and detectability (D) (20). Among these, S refers to the degree of effect that the occurrence of a service failure mode has on the service process, O refers to the frequency at which the different failure modes occur during the service process, and D refers to the probability that the occurrence of different failure modes remains undiscovered by the relevant personnel within a fixed environment and under fixed conditions. The higher the RPN value, the higher the risk level of a given failure mode (21, 22).

However, in the process of using FMEA, there is a certain discrepancy between subjective human perception and objective facts, and this discrepancy can lead to arbitrariness, ambiguity, and uncertainty in expert judgment, which contribute to the inability of relevant theories in providing accurate data or establishing precise mathematical models for the object of study. To address this disadvantage, the previous research utilized fuzzy in FMEA. Zolfaghari and Mousavi (21) utilize the interval-valued hesitant fuzzy linguistic sets by integrating triangular fuzzy numbers to deal with group decision-making in FMEA suffering from ambiguous information. Meng

et al. (23) cooperate triangular fuzzy numbers to interval-valued hesitant fuzzy linguistic sets, which can obtain both advantages of quantitative assessment in terms of interval value and quantitative assessment in terms of linguistic set. Dagsuyu et al. (24) utilize a fuzzy FMEA approach based on triangular fuzzy numbers to measure the risk priority number (RPN, composed of the severity rating, occurrence probability rating, and detection rating). The RPN is measured by five linguistic variables (inclusive of strongly disagree, disagree, neither agree nor disagree, agree, and strongly agree). These linguistic variables are suitable extraordinarily to convert into triangular fuzzy numbers (19–22).

Therefore, in this study, triangular fuzzy numbers was introduced in the FMEA method to address this deficiency. With the help of the Fuzzy-FMEA method, the uncertainty of potential service failure analysis can be resolved when applying traditional FMEA to the CMEC service process of elderly care institutions (19–22, 24). Based on the causes of failure and possible effects obtained through Fuzzy-FMEA, a series of optimization measures can be adopted to innovate and optimize the entire service process more precisely to optimize CMEC services and alleviate the pressure on elderly care resources.

TRIZ

In 1946, Altshuller proposed the TRIZ, which was gradually shaped by summarizing the principles and innovation modes behind patented inventions. The TRIZ was initially applied in the field of engineering technology. However, with the continuous reform of the service industry, some researchers began applying TRIZ to the innovation and optimization of service processes, such as in the fields of tourism, catering, sharing economy, and e-commerce. Ilevbare et al. later proposed the TRIZ contradiction matrix, the 40 principles of invention, and other related theoretical models, tools, and research methods (25).

TRIZ is a knowledge-centered, holistic problem-solving approach that shifts the focus away from the service designer's experience and individual perceptions. It consists of many toolkits, such as problem formulation, contradiction matrix, and inventive principles, which can be applied by designers to systematically conduct the design process (15, 25). The 40 inventive principles of TRIZ and their implications have provided a new basis for understanding and applying TRIZ (26). The technical contradictions created by TRIZ can be resolved by completing the TRIZ matrix. The service designer screens for principles of resolving particular contradictions are based on the 39 engineering parameters and 40 inventive principles of TRIZ, both of which can be applied in the TRIZ method.

Research framework

From the research background and literature review provided above, previous studies seem to have only employed objective and quantitative methods for analysis in the early design phase of elderly care service optimization, while neglecting systematic mechanisms for improving the service process. In fact, the CMEC service process often encounters conflicts between the special needs of the elderly and the services provided. To resolve these conflicts in the CMEC service process, a systematic approach is needed to identify potential service failures and develop solutions to improve the service process. In this study, we explored a systematic approach to service optimization design by integrating the FMEA and TRIZ models through a service blueprint (Figure 1). The research method consisted of three phases: phase I: service process analysis; phase II: service failure diagnosis; and phase III: generation of service optimization solutions.

Phase I: Service process analysis

The purpose of this phase was to analyze the current service process for potential service failures. The service process was reviewed through field observations and interviews with service personnel. A service blueprint was then created depicting the process and indicating the service failure points of the current service process. Finally, potential service failure points were identified after the managers sought confirmation from frontline healthcare workers.

Phase II: Service failure diagnosis

In this phase, an assessment questionnaire on potential service failures rated using a five-point scale (Appendix B) was used to gather the views of selected managerial participants. A quantitative and structural analysis was then conducted using the Fuzzy-FMEA method to diagnose potential service failures and analyze their causes and effects. To address the ambiguity and uncertainty in the opinions of the managerial participants, triangular fuzzy numbers were introduced to fuzzily the FMEA process after the collection of questionnaire data. This process is described as follows.

Step 1: Fuzzification of questionnaire data

To use triangular fuzzy numbers, the weights of the three factors (S, O, and D) were classified using a five-point Likert scale into five levels of semantic variables: EI (Extremely Important), VI (Very Important), I (Important), LI (A Little Important), and NI (Not Important). The membership functions of the semantic variables were normalized within {0, 1}, where the

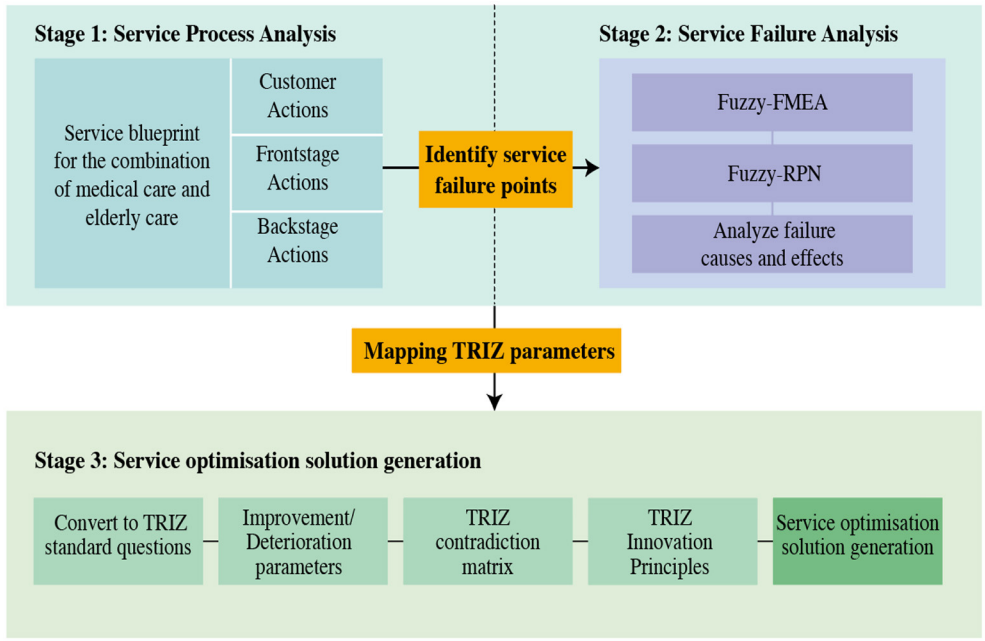

FIGURE 1
Integrated service blueprint-TRIZ model.

semantic variables {"EI," "VI," "I," "LI," "NI"} corresponded to the fuzzy numbers {(0.75,1,1), (0.5,0.75,1), (0.25,0.5,0.75), (0,0.25,0.5), (0,0,0.25)}, it was proposed by Bhuvanesh Kumar and Parameshwaran (27), respectively (Table 1).

Step 2: Calculation of fuzzy number mean

After mapping the questionnaire data to fuzzy numbers, the mean values of the fuzzy numbers were calculated according to the equations given below. Let the fuzzy number $S_{tij} = (q_{tij}, o_{tij}, p_{tij})$ be the triangular fuzzy number of the j^{th} factor of the i^{th} type of service failure faced by the managerial participant t, and n be the total number of managerial participants. The fuzzy number means for each factor in each type of service failure Q_{ij}, O_{ij}, and P_{ij} were given by equations (1), (2), and (3), respectively.

$$Q_{ij} = \frac{1}{n}\sum_{t=1}^{n} q_{tij} \quad (1)$$

$$O_{ij} = \frac{1}{n}\sum_{t=1}^{n} o_{tij} \quad (2)$$

$$P_{ij} = \frac{1}{n}\sum_{t=1}^{n} p_{tij} \quad (3)$$

Step 3: Defuzzification

After calculating the fuzzy number means, The defuzzification method based on Tooranloo and Ayatollah (28) and Chen (29) 's study is applied in this study. Let X be the defuzzified value of the integrated fuzzy number for the three factors occurrence, severity, and detection (Q_i, O_i, P_i). Then, the defuzzified values can be calculated with equation (4). The equation (4) was proposed by Chen (29)'s study using defuzzification method of trapezoidal fuzzy numbers. Based on the characteristic of the fuzzy number addition and multiplication operations, his formula proofed the triangular fuzzy number parametrized by the triple (e.g., Q, O, P) is equivalent to the trapezoidal fuzzy number parametrized by quadruple (e.g., Q, O, O, P). Chen (29)'s method not only considers the additivity and multiplicity in the finite data but also satisfy the unbiasedness of the finite data. Thus, the defuzzification value X of a triangular fuzzy number by (Q, O, P) is equal to

$$X = \frac{Q_i + O_i + O_i + P_i}{4} \quad (4)$$

Step 4: Calculation of Fuzzy-RPN and prioritization

In Fuzzy-FMEA, the Fuzzy-RPN needs to be calculated to rank the risk level of service failures. After defuzzification of the

TABLE 1 Correspondence table between questionnaire data and fuzzy numbers [adopted from Bhuvanesh Kumar and Parameshwaran (27)].

Questionnaire language			Questionnaire score	Semantic variable	Fuzzy number
S	O	D			
Catastrophic service failures	Frequent service failures	Detectable by tests after service failure occurrence of	5	EI	(0.75,1,1)
Critical service failures	Repeated service failures	Detectable once service failure has occurred	4	VI	(0.5,0.75,1)
Moderate service failures	Occasional service failures	Detectable by multiple tests before service failure occurrence	3	I	(0.25,0.5,0.75)
Minor service failures	Very few service failures	Detectable by a few tests before service failure occurrence	2	LI	(0,0.25,0.5)
Almost no service failures	Extremely unlikely service failures	Detectable without service failure occurrence or tests	1	NI	(0,0,0.25)

questionnaire data, the Fuzzy-RPN for each service failure mode was calculated using the scores of three factors (S, O, and D), as given by equation (5).

$$\mathbf{FRPN = S \times O \times D} \quad (5)$$

Subsequently, prioritization of the service failure modes was performed based on the resulting Fuzzy-RPN. This phase provides a design decision-making method for potential failures, aiming to predict and detect service failures in the service process and alert managers to prioritize these failures based on their importance.

Phase 3: Generation of service optimization solutions

In the third phase, the corresponding inventive solutions were derived from the table of TRIZ principles, which first converted the service failures in the CMEC process into standard TRIZ problems by employing the corresponding TRIZ parameters. The TRIZ contradiction matrix was then used to identify the most critical service failure models and the 40 inventive principles required as basic design elements to satisfy the service optimization. This allowed the mapping of service failures to TRIZ improving and worsening parameters. Next, the TRIZ matrix was used to select the corresponding TRIZ inventive principles. Finally, the TRIZ inventive principles obtained were screened based on an expert evaluation process, and the selected TRIZ inventive principles were then used to generate inspiration for service optimization solutions.

Participant selection

Huai'an City, Jiangsu Province, is one of the 59 pilot cities funded by the central government for the reformation of elderly care services, and a key city in Jiangsu Province for the development of CMEC services. Therefore, Huai'an City, Jiangsu Province, was selected for this study (30, 31). By the end of 2018, more than 200 elderly care institutions were built in Huai'an City, with nearly 44,000 beds (30, 32), to cope with an aging population. These institutions provide medical services, elderly care services, and recreational facilities for the elderly. In addition, they are usually capable of providing long-term care to older adults who are unable to receive elderly care at home for various reasons.

Field surveys were first conducted in three elderly care institutions in Huai'an, followed by interviews with the managers of these institutions, to analyze the CMEC service process of elderly care institutions. Finally, the integrated service blueprint-TRIZ model was applied to the optimization of the CMEC service process in Huai'an to demonstrate the applicability of this model.

Field surveys and interviews with front-line healthcare workers were conducted to collect the participants' real opinions and develop a service blueprint for the CMEC process (Figures 2, 3). Owing to the constraints in the medical facilities of general elderly care institutions, they can handle only a limited number of medical conditions. Therefore, patients with medical conditions beyond the capabilities of these medical facilities are transferred to hospitals. Based on the results of the interviews, this limitation was used to define the boundary between elderly patients whom the institutions were able to handle (i.e., those with mild illness) and those whom the

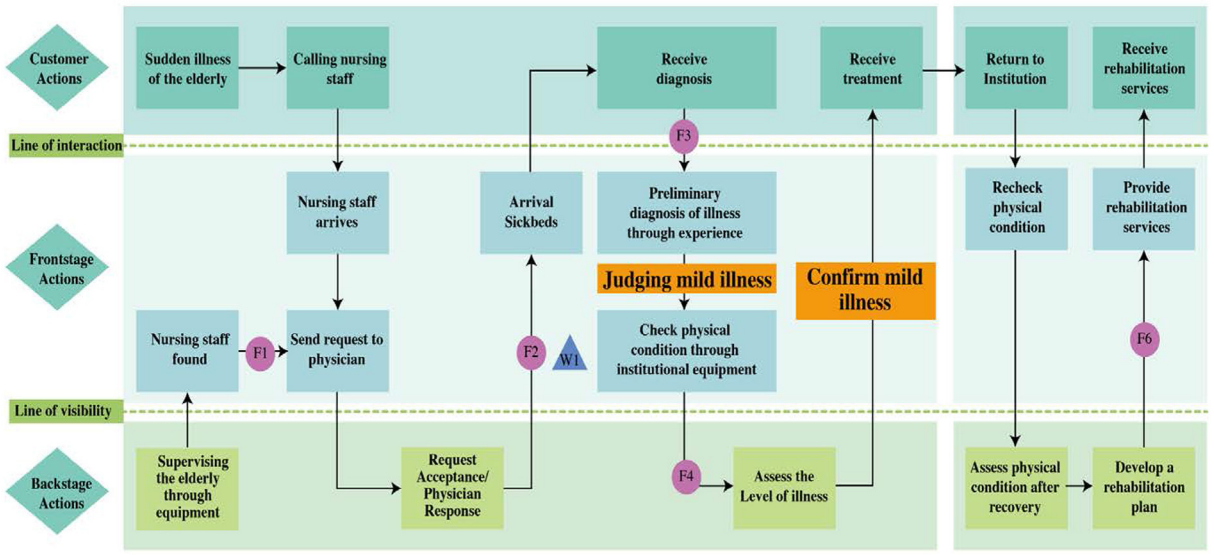

FIGURE 2
Service blueprint of CMEC for elderly people with **mild illness**.

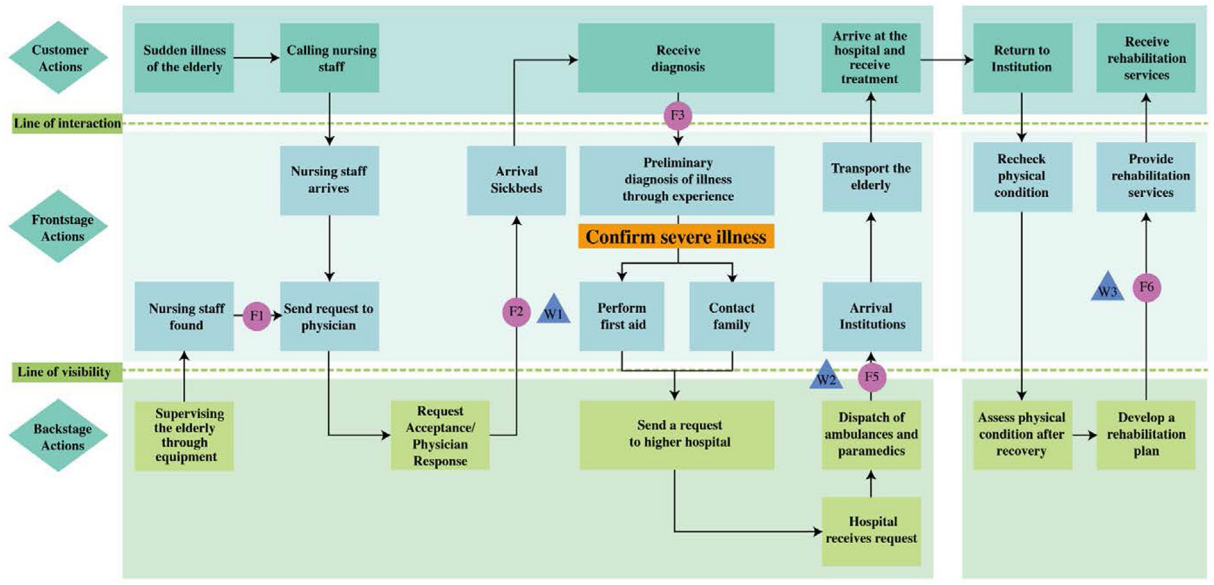

FIGURE 3
Service blueprint of CMEC for elderly people with **severe illness**.

institutions were unable to handle (i.e., those with severe illness) in the CMEC process. First, the actions of elderly patients were used to specify their behaviors and requirements. These actions included contacting nursing staff and receiving services (diagnostic services, therapeutic services, and rehabilitation services). Second, the front-stage actions of nursing staff (placed between the line of interaction and visibility) were used to specify the activities of frontline staff in providing care services to the elderly. These actions included receiving requests from the elderly, arriving at the bed, providing services, and performing rehabilitation activities. Finally, the back-stage actions of nursing staff (presented beneath the line of visibility)

TABLE 2 FMEA of the CMEC model.

No.	Potential service failure points	Service failure situation	Causes of failure	Effects of failure
F1	Detection of sudden illness in the elderly	Human resource misallocation	Inadequate healthcare workers; Prolonged interval between ward rounds	Failure to detect the patient's illness in time, causing their condition to deteriorate
F2	Healthcare worker's response	Slow response by healthcare worker	Inadequate healthcare worker; Prolonged arrival time of healthcare workers	Inability of elderly care facilities to provide responsive services
F3	Healthcare worker's judgement of patient's condition	Error in judgement	Inexperienced healthcare workers	Failure causing the elderly to miss optimal treatment window, leading to death
*F4	Provision of testing equipment	Poor testing equipment	Inadequate maintenance of testing equipment; Inadequate service resources	Failure to meet the needs of the elderly; Failure causing illness in the elderly
*F5	Arranging referrals	Referral delays	Inadequate healthcare workers; Prolonged arrival time of ambulances	Failure to detect the patient's illness in time, leading to deterioration of their condition; Missing the optimal treatment window
F6	Commencing rehabilitation services	Inappropriate rehabilitation services	Inadequate service resources (e.g., equipment, funding and rehabilitation staff); Impatience of nursing staff	Failure leading to the degeneration and atrophy of physical functions in the elderly

*F4 is a service failure unique to minor illnesses, and *F5 is a service failure unique to major illnesses.

were used to specify the care services provided by back-stage staff in response to the elderly person's needs and to assess their health status. The key task in this phase was to identify possible service failures in the service process. After the analysis, the service failure points were presented in the service blueprint (Figures 2, 3).

In conjunction with the service blueprint shown in Table 2, six service failure points were identified: detection of sudden illness in the elderly (F1), healthcare worker's response (F2), healthcare worker's judgement of patient's condition (F3), provision of testing equipment (F4), arranging referrals (F5), and commencing rehabilitation services (F6). These potential service failures were further diagnosed in the next phase.

Empirical analysis

In the second phase, the potential service failures in the CMEC service model were analyzed using the diagnostic tool, Fuzzy-FMEA. Based on the service blueprint developed in the previous phase, individual service failure modes were identified. In the field survey, interviews were first conducted with the managers of the elderly care institutions and front-line healthcare workers, followed by the distribution of interview questionnaires covering the causes and effects of service failures to the experts, who were interviewed based on the relevant questions. The measures in the interview questionnaire included the severity rating (S), occurrence probability rating (O), and detection rating (D), which were used to analyze each service failure mode. A total of 35 interview questionnaires were administered, and these were distributed to managers and specialists conducting front-line care in each facility. The three measures in the interview questionnaires were subjective indicators evaluated by the experts based on their empirical judgments. The interview questions were highly relevant to the research questions of this study, possessing both face and content validity. The results obtained from the FMEA method did not need to follow a normal distribution, thus confirming the reliability of the data.

For each factor, a five-point Likert scale was used to measure each service failure mode. Specifically, an S rating of 1 indicated that the service failure had almost no effect, whereas 5 indicated the most severe service failure; an O rating of 1 indicated that the occurrence of the service failure was almost impossible, whereas 5 indicated that the failure was inevitable; a D rating of 1 indicated that the healthcare worker detected the service failure mode, whereas 5 indicated that the service failure could not be detected. The questionnaire data were processed using a triangular fuzzy function. The fuzzy number means were calculated using equations (1) to (3), as shown in Tables 3–5, while the defuzzified values were calculated using equation (4), as shown in Tables 6–8. The resulting Fuzzy-RPN for each service failure mode was given by equation (5) using the scores obtained from the fuzzy calculation of the participants' questionnaire ratings. Finally, the critical service failure modes

TABLE 3 Fuzzy number means for S ratings in Fuzzy-FMEA.

Category 1		Category 2		Category 3		Category 4		Category 5		Category 6	
Q_1	0.429	Q_2	0.343	Q_3	0.350	Q_4	0.357	Q_5	0.293	Q_6	0.364
O_1	0.679	O_2	0.593	O_3	0.600	O_4	0.607	O_5	0.543	O_6	0.614
P_1	0.900	P_2	0.843	P_3	0.843	P_4	0.829	P_5	0.779	P_6	0.850

TABLE 4 Fuzzy number means for O ratings in Fuzzy-FMEA.

Category 1		Category 2		Category 3		Category 4		Category 5		Category 6	
Q_1	0.414	Q_2	0.400	Q_3	0.314	Q_4	0.357	Q_5	0.314	Q_6	0.364
O_1	0.664	O_2	0.650	O_3	0.564	O_4	0.607	O_5	0.564	O_6	0.614
P_1	0.893	P_2	0.871	P_3	0.800	P_4	0.843	P_5	0.807	P_6	0.843

were prioritized according to the magnitude of the Fuzzy-RPN, where a higher Fuzzy-RPN indicated a greater need for improvement (Table 9). Meanwhile, the comparison between traditional FMEA and Fuzzy FMEA was conducted (Table 10), and the results presented that the RPN value and prioritization in traditional and Fuzzy were similar.

The prioritization of Traditional FMEA and Fuzzy FMEA was confirmed by the 13 CMEC experts using an expert questionnaire (Table 11). The difference between the traditional and Fuzzy FMEA-RPN was explained to 13 CMEC experts and then we asked them to mark '√' on the two RPN options for finding suitable solutions in accord with solving practical problems. The result represented that 10 CMEC experts agreed with Fuzzy-RPN, which verifies that the applicability of Fuzzy-RPN is better than traditional RPN in solving practical problems.

Thus, the key service failure points included human resource misallocation, inappropriate rehabilitation services, and slow response by healthcare workers. These three service failure modes were caused by inadequate healthcare workers, prolonged interval between ward rounds, prolonged arrival time of healthcare workers, inadequate service resources, and impatience of nursing staff. To address these service failure situations, we proposed TRIZ inventive principles based on each failure cause in the next phase after analyzing the TRIZ contradiction matrix.

In the third phase, the TRIZ parameters were first mapped and sorted according to the TRIZ correspondence table for CMEC services (see Appendix A) (15, 33). This facilitated the subsequent analysis of the TRIZ contradiction matrix to generate the TRIZ inventive principles. According to Table 9 and Appendix A, the mapping results are as follows.

The most critical service failure was "human resource misallocation," caused by "inadequate healthcare workers" and "prolonged interval between ward rounds." These two causes of failure corresponded to service quality determinants No. 13 (number of nursing staff) and No. 5 (service adaptability) in Appendix A, respectively, leading to the corresponding TRIZ improving parameters No. 26 (amount of substance) and No. 35 (adaptability or versatility).

The second most critical service failure was "inappropriate rehabilitation services" caused by "inadequate service resources" and "impatience of nursing staff." These two causes of failure corresponded to service quality determinants No. 18 (service capacity) and No. 7 (healthcare workers' attitude) in Appendix A, respectively, leading to the corresponding TRIZ improving parameters No. 26 (amount of substance) and No. 17 (temperature).

The third most critical service failure was "slow response of healthcare workers," caused by "inadequate healthcare workers" and "prolonged arrival time of healthcare workers." These corresponded to service quality determinants No. 13 (healthcare worker numbers) and No. 20 (time of service delivery time) in Appendix A, respectively, leading to the corresponding TRIZ improving parameters No. 26 (amount of substance) and No. 9 (speed).

In summary, we hoped to improve TRIZ parameters Nos. 9, 17, 26, and 35, but also expected that these improvements would lead to the consumption of additional resources and costs, as well as increase the complexity of the service system. This suggested that the TRIZ worsening parameters No. 22 (loss of energy) and No. 36 (system complexity) should also be considered. In other words, the five failures resulted in "inadequate healthcare workers," "prolonged interval between ward rounds," "inadequate service resources," "impatience of nursing staff," and "prolonged arrival time of healthcare workers," which were directly related to greater costs or loss of resources and the increased complexity of system services. Based on the improving parameters Nos. 9, 17, 26, and 35, and worsening parameters Nos. 22 and 36, we derived the TRIZ contradiction matrix (Table 12).

Following the TRIZ contradiction matrix analysis, the experts were asked to filter the inventive principles according

TABLE 5 Fuzzy number means for D ratings in Fuzzy-FMEA.

Category 1		Category 2		Category 3		Category 4		Category 5		Category 6	
Q_1	0.429	Q_2	0.364	Q_3	0.314	Q_4	0.336	Q_5	0.329	Q_6	0.407
O_1	0.679	O_2	0.614	O_3	0.564	O_4	0.586	O_5	0.579	O_6	0.657
P_1	0.893	P_2	0.821	P_3	0.807	P_4	0.807	P_5	0.807	P_6	0.836

TABLE 6 Defuzzification of S ratings in Fuzzy-FMEA.

NO.	Integrated triangular fuzzy number			Defuzzified value
	Q_i	O_i	P_i	
1	0.429	0.679	0.900	0.669
2	0.343	0.593	0.843	0.593
3	0.350	0.600	0.843	0.598
4	0.357	0.607	0.829	0.598
5	0.293	0.543	0.779	0.538
6	0.364	0.614	0.850	0.610

TABLE 7 Defuzzification of O ratings in Fuzzy-FMEA.

NO.	Integrated triangular fuzzy number			Defuzzified value
	Q_i	O_i	P_i	
1	0.414	0.664	0.893	0.657
2	0.400	0.650	0.871	0.640
3	0.314	0.564	0.800	0.560
4	0.357	0.607	0.843	0.602
5	0.314	0.564	0.807	0.562
6	0.364	0.614	0.843	0.607

TABLE 8 Defuzzification of D ratings in Fuzzy-FMEA.

NO.	Integrated triangular fuzzy number			Defuzzified value
	Q_i	O_i	P_i	
1	0.429	0.679	0.893	0.667
2	0.364	0.614	0.821	0.600
3	0.314	0.564	0.807	0.562
4	0.336	0.586	0.807	0.576
5	0.329	0.579	0.807	0.571
6	0.407	0.657	0.836	0.633

to their relevance to the attributes of CMEC services. After screening by the experts, seven inventive principles were selected from Table 12 with a high degree of relevance to the attributes of CMEC services, thereby generating inventive solutions: TRIZ inventive principles Nos. 1, 4, 21, 25, 27, 10, and 28.

The TRIZ inventive principle No. 4 (Asymmetry) suggests that the conditions must be changed to increase the asymmetry of an object or system. Owing to the disparities in their health status, elderly people in care facilities have different levels of care needs, possibly affecting the response of healthcare workers. Accordingly, the inventive solution **S1 "Differential distribution of resident healthcare workers according to the level of care needed by the elderly"** was introduced. In the initial stage, physiological data is collected from the elderly upon admission to CMEC institutions, and used for the tiered placement of the elderly in CMEC services (including premium care, primary care, secondary care, and tertiary care), which can then be used as a basis for the differential distribution of resident healthcare workers. After admission, the initial data is combined with the acquisition of real-time physiological data, and the level of care needed by the elderly is analyzed through big data monitoring (Figure 4). This would enable the dynamic classification of care required by the elderly, with fewer healthcare workers stationed near the rooms of elderly with higher self-care capacity, and more healthcare workers placed near the rooms of those who need a higher level of care, thereby decreasing healthcare worker response and arrival times. By increasing the asymmetry in elderly care services and implementing the differential distribution of resident healthcare workers, this principle seeks to enhance the dynamic balance of manpower and resources between "medical care" and "elderly care" services in CMEC workforce.

The TRIZ inventive principle No. 21 (Rushing Through) refers to taking steps that are hazardous to the object or harmful to the system at a very high speed. Owing to the lack of staff in CMEC institutions, nursing staff often have to perform other tasks such as cleaning the premises in addition to their daily nursing duties, which affects the speed of nursing response to a certain extent. Accordingly, the innovative solution **S2 "Reduce unnecessary workflows for nursing staff and speed up service completion by establishing remote ward rounds"** was introduced. On the one hand, reducing the workflows of nursing staff beyond the scope of nursing services would reduce service delivery time and enable rapid service completion without affecting the rehabilitation services provided. Furthermore, avoiding response failures by nursing staff would also affect the elderly's perception of service. On the other hand, remote ward rounds can be established (Figure 5) by designing an integrated set of equipment, including a cart, multiple screens,

TABLE 9 Analysis of the causes of failures in the CMEC service model for the elderly.

NO.	Service failure situations	Causes of failure	Defuzzified value of S rating	Defuzzified value of O rating	Defuzzified value of D rating	Fuzzy RPN	Prioritization
F1	Human resource misallocation	Inadequate healthcare workers Prolonged interval between ward rounds	0.669	0.657	0.667	0.293	1*
F2	Slow response by healthcare workers	Inadequate healthcare workers Prolonged arrival time of healthcare workers	0.593	0.640	0.600	0.228	3*
F3	Error in judgement of patient's condition	Inexperienced healthcare workers	0.598	0.560	0.562	0.188	5
F4	Poor testing equipment	Inadequate maintenance of testing equipment Inadequate service resources	0.598	0.602	0.576	0.207	4
F5	Referral delays	Inadequate healthcare workers Prolonged arrival time of ambulances	0.538	0.562	0.571	0.173	6
F6	Inappropriate rehabilitation services	Inadequate service resources (e.g., equipment, funding and personnel) Impatience of nursing staff	0.610	0.607	0.633	0.234	2*

The symbol * indicates The top three items.

a camera with PTZ, video software, and built-in lithium battery. Remote ward rounds can overcome the geographical constraints involved when healthcare workers are required to physically travel to the elderly's wards. The equipment will support the movement of healthcare workers between different environments, provide real-time access to medical records and vital signs, and offer multi-scenario applications, thereby reducing the waiting time and improving the quality of CMEC services.

The TRIZ inventive principle No. 25 (Self-Service) suggests that an object or system needs to serve itself in some way. Accordingly, the inventive solution **S3 "Guiding the elderly to voluntarily engage in self-help services"** was introduced. Owing to staff shortages, the promotion of self-help services is essential for CMEC institutions. For elderly people who are fully mobile, healthcare workers can motivate their willingness to engage in self-service through routine instruction and encouragement (Figure 6). For example, in daily life, meals can be served in the cafeteria rather than be delivered to the ward; the delivery of CMEC services can be simplified through a remote system to reduce the difficulty of self-service; or, elderly people who are unwell but fully ambulatory can be encouraged to proactively engage in rehabilitation training and medical check-ups and to pick up medication from the pharmacy independently. Promoting self-service among the elderly would greatly reduce the workload of care services, thus alleviating the problem of shortages in healthcare workers.

The TRIZ inventive principle No. 10 (Preliminary Action) suggests performing the required action on an object or system in advance. In other words, elderly care institutions must provide healthcare workers with training required for CMEC services in advance through internships and other means. Accordingly, the inventive solution **S4 "Provide educational training and internships on CMEC services to pre-service healthcare workers"** was introduced. As CMEC services need to combine the functions of "medical care" and "elderly care," nursing staff are required to acquire more expertise on CMEC, thus placing new demands on pre-service healthcare workers. CMEC institutions could invite pre-service healthcare workers to visit the institution, or launch live training and distance learning sessions at any time through audio and video terminals, which could be viewed by pre-service healthcare workers by scanning the QR code. Pre-service healthcare workers who were unable to attend these sessions could access on-demand learning in the cloud through audio and video terminals, thus improving their experience (Figure 7). In addition, when front-line staff of elderly care institutions would provide care to the elderly, interns could be assigned to participate in this task to acquire more practical experience of CMEC services and the operation of complex medical systems (e.g., telemedicine). This would also

TABLE 10 Comparison of the RPN value and prioritization between traditional and Fuzzy FMEA in the CMEC service model for the elderly.

NO.	Service failure situations	Causes of failure	Traditional RPN	Prioritization	Fuzzy RPN	Prioritization
F1	Human resource misallocation	Inadequate healthcare workers Prolonged interval between ward rounds	44.73	1*	0.293	1*
F2	Slow response by healthcare workers	Inadequate healthcare workers Prolonged arrival time of healthcare workers	39.865	3*	0.228	3*
F3	Error in judgement of patient's condition	Inexperienced healthcare workers	34.32	6	0.188	5
F4	Poor testing equipment	Inadequate maintenance of testing equipment Inadequate service resources	38.14	4	0.207	4
F5	Referral delays	Inadequate healthcare workers Prolonged arrival time of ambulances	34.325	5	0.173	6
F6	Inappropriate rehabilitation services	Inadequate service resources (e.g., equipment, funding and personnel) Impatience of nursing staff	41.641	2*	0.234	2*

≥ average of FRPM (0.2205).
The symbol * indicates The top three items.

TABLE 11 Comparison between traditional and Fuzzy FMEA-RPN with the CMEC experts' agreement.

CMEC experts	Traditional RPN	Fuzzy-RPN
Expert 1		√
Expert 2		√
Expert 3		√
Expert 4		√
Expert 5		√
Expert 6	√	
Expert 7	√	
Expert 8		√
Expert 9		√
Expert 10	√	
Expert 11		√
Expert 12		√
Expert 13		√
Percentage of agreement with the experts	**23.07**	**76.93**

TABLE 12 TRIZ contradiction matrix analysis.

Improving parameters \ Worsening parameters	22 Loss of energy (costs)	36 System complexity
9 Speed	20, 14, 19, 35	10, 28, 4, 34
17 Temperature	21, 17, 35, 38	2, 17, 16
26 Amount of substance	25, 7, 8	3, 13, 10, 27
35 Adaptability or versatility	18, 15, 1	15, 29, 28, 37

help to train staff at all levels to alleviate the shortages in healthcare workers.

The TRIZ inventive principle No. 27 (Cheap Short-Living Objects) implies replacing more resource-intensive parts and steps of an object or system with less resource-intensive parts or steps. Accordingly, the inventive solution **S5 "Use of inexpensive devices and methods for CMEC services"** was introduced. The rehabilitation services in CMEC should be provided using professional training devices. However, inexpensive rather than expensive devices could be used without affecting their established functions, while improving these devices to suit the requirements of CMEC services. For example, a rehabilitation electric bicycle (market price of over RMB 100,000 per unit) can be replaced with a hydraulic stepper (market price of around RMB 5,000 per unit), as both can be used for lower limb training. The hydraulic stepper can also be equipped with sensors for real-time monitoring (Figure 8) to prevent falls and collect exercise data, which will reduce the need for healthcare workers to accompany the elderly during rehabilitation activities. In addition, the institution can provide customized rehabilitation training programs to enhance the lower limb muscle strength and cardiopulmonary function of the elderly by combining their symptoms with the acquired rehabilitation data. This solution reduces capital and labor costs, while meeting the need for lower limb training services, thereby enhancing the institution's elderly care capacity as part of its CMEC services.

The TRIZ inventive principle No. 1 (Segmentation) implies dividing an object or system into several parts to optimize the whole. Accordingly, the inventive solution **S6 "Segmentation**

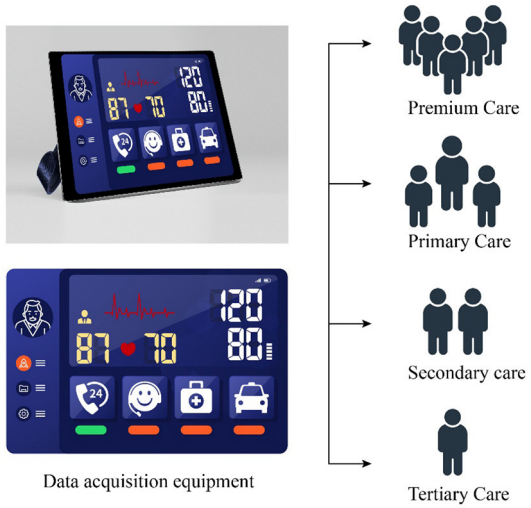

FIGURE 4
Differential classification of CMEC services.

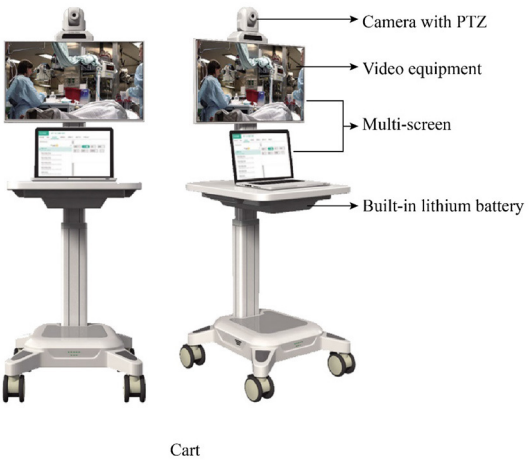

FIGURE 5
Schematic diagram of CMEC remote ward rounds.

of some services in CMEC institutions for outsourcing" was introduced. General elderly care institutions must consider the needs of the elderly while completing convalescence services. Hence, they are unable to fully meet the needs of the elderly, which can lead to problems such as having prolonged intervals between ward rounds.

Therefore, CMEC institutions can outsource some of their services to service providers located in their vicinity, including non-essential services such as catering (the institution is only responsible for delivery), physical examinations (blood tests, urine tests, etc.) and dialysis treatment. For example, outsourcing catering can strengthen the professionalism of

FIGURE 6
Simplified delivery of CMEC services.

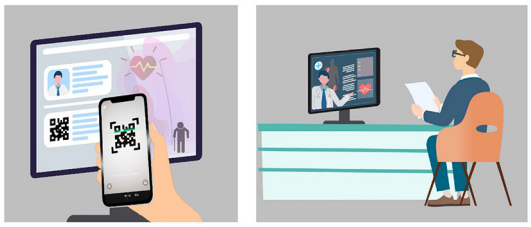

FIGURE 7
Remote training and teaching for CMEC services.

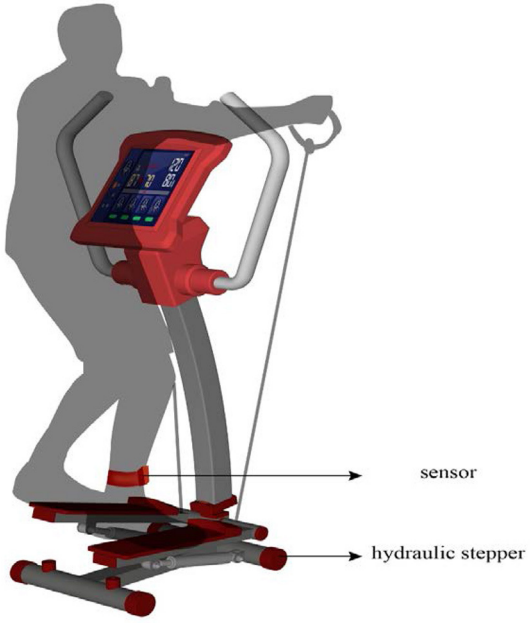

FIGURE 8
Hydraulic stepper for CMEC services.

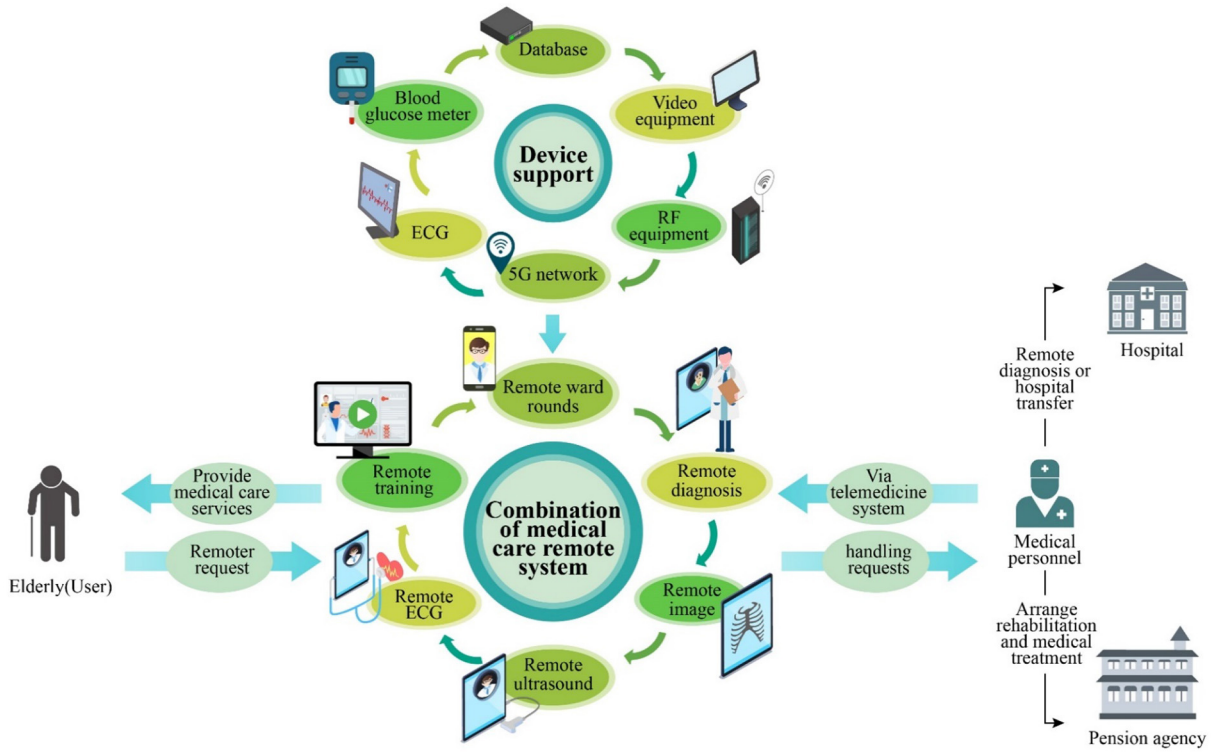

FIGURE 9
CMEC telemedicine system.

the institution's CMEC services, and outsourcing medical examination services and dialysis treatment to hospitals near the institution can reduce its capital investment by at least RMB 20 million. This solution allows the institution to meet the needs of the elderly for CMEC, while minimizing the service time and operating costs of all aspects of CMEC services, reducing the service content provided by healthcare workers and capital investment, and shifting the focus toward handling the medical care and rehabilitation services of the elderly.

The TRIZ inventive principle No. 28 (Replacement of Mechanical System) refers to the replacement of simple and traditional mechanical fields and mechanical systems with other fields and systems. Accordingly, the inventive solution **S7 "Building intelligent wards with telemedicine systems" was introduced.** By integrating existing medical equipment (e.g., blood glucose meter, electrocardiogram, and rehabilitation equipment) in the ward through a wireless network, surveillance cameras, radio frequency identification equipment, smart wearable equipment, and so on, a CMEC telemedicine system (including teleconsultation, teleradiology, tele-ultrasound, remote ward rounds, and tele-electrocardiogram) can be constructed (Figure 9) to provide intelligent services and improve service efficiency. Real-time testing can be performed on the elderly through a series of body monitoring devices, and the timely detection and diagnosis of diseases can be achieved through big data. With networked and intelligent ward rounds, an elderly person who is suffering from a condition but cannot travel to the hospital can receive remote medical care, thus resolving the spatial constraints of referrals and the limitations in medical resources, while reducing the possibility of service failures leading to the aggravation of the elderly person's condition.

Finally, Table 13 summarizes the seven new service optimization solutions for CMEC services inspired by the TRIZ inventive principles.

Policy implications

Additionally, the policy recommendations based on the research finding were developed in this study for the Jiangsu provincial government, such as the perspectives of multiple stakeholders (institutional interests, frontline healthcare workers, families of the elderly, and the government) were considered when reviewing service failures and developing solutions to improve service processes. These experiences and opinions can be viewed as key factors in determining the quality of services, optimizing service processes, and ensuring the

TABLE 13 Translation of TRIZ principles into service optimization solutions.

Inventive principles	Service optimization solutions
No. 4: Asymmetry	S1. Differential distribution of resident healthcare workers according to the level of care needed by the elderly.
No. 21: Rushing Through	S2. Reduce unnecessary workflows for nursing staff and speed up service completion by establishing remote ward rounds.
No. 25: Self-Service	S3. Guiding the elderly to voluntarily engage in self-help services
No. 10: Preliminary Action	S4. Provide educational training and internships on CMEC services for pre-service healthcare workers
No. 27: Cheap Short-Living Objects	S5. Use of inexpensive devices and methods for CMEC services
No. 1: Segmentation	S6. Segmentation of some services in CMEC institutions for outsourcing
No. 28: Replacement of Mechanical Systems	S7. Building intelligent wards with telemedicine systems

effectiveness of improvement models. We recommend that the government should take the lead in overall regional planning, position various services offered by CMEC institutions, integrate service resources through public-private partnerships, and conduct the joint management of resources under a government framework. The government's promotion of collective elderly care may help reduce the average cost of elderly care, thereby improving the accessibility and standards of CMEC services and alleviating the lack of resources for the elderly within the context of an aging population.

Furthermore, the managerial participants involved in the case study of elderly care institutions have expressed that this model can facilitate the optimization and improvement of their service system through a set of scientific and systematic methods. In particular, the service blueprint provides an effective analytical approach to help review the entire service process. Unlike production processes in manufacturing, the service blueprint emphasizes a service-oriented approach to assist managers in redesigning and optimizing their service processes. In addition, Fuzzy-FMEA can help managers develop solutions more precisely while eliminating ambiguity and incorporate expert assessment of the proposed solutions. Therefore, managers should establish a management mechanism to inspire diverse optimization solutions, which would enable institutions to continuously optimize their service processes within the context of CMEC for the elderly.

Finally, the service optimization solutions were generated, and we invited the managers and front-line staff of elderly care institutions to evaluate the value of these solutions. The optimization solution **S2**, generated by the inventive principle "Rushing Through," proposes the speedy completion of services by establishing remote ward rounds, which can reduce the burden of ward rounds for nursing staff and shorten the intervals between ward rounds. This optimization solution allows the institution to decrease the ward round interval from 6 h/ward round to 1 h/ward round or less and reduces the nursing staff's response time by approximately 30%. The optimization solution **S3**, generated by the inventive principle "Self-Service," proposed that the willingness of the elderly to engage in self-service should be motivated through routine instructions and encouragement. This optimization solution is expected to reduce the routine care work of nursing staff by 25%, which would significantly alleviate the work pressure on nursing staff and the shortage of human resources in the institution, thus allowing more resources to be invested in CMEC services. The optimization solution **S7**, generated by the inventive principle of "Replacement of Mechanical Systems," requires a certain amount of capital investment and integrated research and development in the initial stages. However, as a long-term investment, it can transform manual healthcare into 24/7 intelligent monitoring, and promote more comprehensive CMEC services when combined with telemedicine systems. Based on the assessment results of institutions that have adopted such systems, this optimization solution can reduce the demands on healthcare workers by 20–30% and increase client satisfaction by 20%.

Conclusions

The integrated service blueprint-TRIZ model proposed in this study is a systematic method of service optimization design that integrates service blueprint, Fuzzy-FMEA, and TRIZ to realize the connections among the service environment, problem solving, and technological application. Based on this model, we effectively proposed a systematic integration solution for the process optimization of CMEC services, thus providing a micro-level perspective and theoretical guidance for the development of CMEC services in China and effectively alleviating the imbalance of resources between medical care and elderly care services in China's aging society.

Our service design methodology was refined to achieve the feasibility of applying service blueprint and TRIZ based theories in the field of care services. Compared to other service design methodologies (service blueprint, FMEA, QFD, etc.), the integrated service blueprint-TRIZ model is more scientific and advanced with respect to defining the service problems as well as generating and evaluating solutions. Furthermore, it employs fuzzy functions to eliminate the crisp boundaries between the five evaluation levels of the five-point Likert scale. Instead, it divides the evaluation levels of managers into the evaluation of adjacent levels, while using

TABLE 14 The novelty of the present study used in CMEC compared with the existing studies.

Source	Topic	The previous studies
Yang et al. (2); Wei and Zhang (4); Penkunas et al. (14); Zolfaghari and Mousavi (21); Chowdhury and Quaddus (34); Behdioglu et al. (35); Sun et al. (36); Karami et al. (37); Xu et al. (38)	Hospital service quality survey	* The fuzzy method was used largely in evaluating hospital service quality and elderly's requirement. * The triangular fuzzy number was utilized to eliminate an ambiguous expression of the decision-makers' opinions for service quality improvement. * A fuzzy probability distribution was integrated into the decision-making attributes of the expert. * The fuzzy linguistic variables were utilized for measuring service quality from the attitude of decision makers. * The service process and quality evaluation in hospital was conducted, the method includes: SERVQUAL, Kano model, AHP, ANP, TOPSIS, and QFD. * The triangular fuzzy number was applied (e.g., QFD and AHP) to calculate the relationship between customer requirement and service design strategies.
Source	**Topic**	**The novelty of the present study**
Present study	CMEC service optimization and in*nova*tion	* The integrated service blueprint-TRIZ model was proposed in this study for optimizing the combined medical and elderly care services (CMEC). * The fuzzy-FMEA incorporating qualitative and quantitative methods was used in CMEC service failure diagnosis. * The CMEC service blueprint was established and its potential service failures were recognized. * The ambiguous expression of the CMEC managers was eliminated by the fuzzy-FMEA approach. * A systematic innovation method for CMEC service was proposed to facilitate service designers generating suitable innovative principles for the new service optimization solutions. * The new service optimization solutions were realized for optimizing CMEC service efficiency.

the degree of membership of the triangular fuzzy function to reflect the degree to which the evaluation levels belong to the evaluation of adjacent levels, thereby addressing the uncertainty arising from the evaluation of service failure modes by the managerial participants. The advantages of the integrated service blueprint-TRIZ model are summarized as follows.

(1) The integrated service blueprint-TRIZ model combines the service blueprint with Fuzzy-FMEA to resolve the ambiguity in the evaluation of service failure modes by managers, thus enabling service designers to clearly understand potential service failures and analyze the causes and effects of each service failure mode in the service process.
(2) Instead of relying on the intuition and personal experiences of the service designer, the integrated service blueprint-TRIZ model uses the TRIZ contradiction matrix to eliminate conflicts and generate appropriate inventive principles for the service conceptualization process.
(3) The integrated service blueprint-TRIZ model offers expert-centered screening of inventive principles, service solutions based on the selected inventive principles, and ideal optimization solutions.

Specifically, the academic contributions of this study are as follows: (1) investigation of the Fuzzy-FMEA method for the quantification and measurement of service failures; (2) investigation of service system optimization design, especially the systematic research on the optimization design of CMEC services for the elderly; (3) design of service system optimization strategies based on the actual needs of elderly care institutions for CMEC in Huai'an City, Jiangsu Province; and (4) expansion of service innovation research in the field of CMEC services for the elderly based on previous literature.

The integrated service blueprint-TRIZ model with fuzzy-FMEA approach that was proposed and validated to answer the research questions and bridge the research gaps mentioned in the introduction section. As such, (1) qualitative and quantitative methods were incorporated in fuzzy-FMEA and TRIZ for developing new service conceptualization in initiated from a service failures diagnosis; (2) an efficient elicitation of the new service optimization solution could be achieved by TRIZ; and (3) the abundant fuzzy elements, including the triangular fuzzy number, fuzzy linguistic variables, and fuzzy probability range were utilized in the proposed model for eliminating arbitrariness, ambiguity, and uncertainty from expert judgment. Meanwhile,

a comparison of the integrated service blueprint-TRIZ model with the existing studies is described clearly in Table 14. A better understanding of the research novelty could be achieved.

Finally, this study used the TRIZ inventive principles to inspire seven inventive solutions for improving service processes. These inventive solutions can be applied in practice within the field of CMEC services. As this was an exploratory study, its scope is limited to the systematic design of a decision-making model and field of elderly care services. Therefore, further investigations in other related areas should be conducted in the future.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary material, further inquiries can be directed to the corresponding author.

Ethics statement

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. Written informed consent from the participants was not required to participate in this study in accordance with the national legislation and the institutional requirements.

Author contributions

A-JS: writing—original draft and revising the manuscript, research conceptualization, methodology, supervision, and data analysis. W-FW: investigation, data analysis, coordinating tasks, and writing—revising the manuscript. MY: formal analysis and validation, investigation, writing—revising the manuscript, and final approval of the version. XW and HL: research administration for the empirical project, resources, interpretation of data, writing—revising the manuscript, and final approval of the version. All authors read and approved the final manuscript and agreed to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpubh.2022.965443/full#supplementary-material

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The impact of Otago exercise programme on the prevention of falls in older adult: A systematic review

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Objective: To improve the quality of life of older adult in their later years, by increasing the physical activity participation of older adult, the occurrence of falls accident scores in older adult can be prevented. This paper comprehensively summarizes the origin, development, participation forms, and fitness effects of the Otago exercise program (OEP).

Methods: Using PubMed, web of science, CNKI, dimensional spectrum, and other databases, search for research papers from 2005 to April 2021 by using keywords such as Otago project exercise; aged, Fall; Cognitive function, Balance ability, Lower limb strength, Fall efficiency, and so on. PEDro Scale was used to check the quality of the literatures.

Results: A total of 34 papers were included after searching for kinds of literature related to the subject of this paper and after careful review by researchers.

Conclusions: Otago exercise programme is beneficial to improve the cognitive function of older adult, enhance their lower limb muscle strength and dynamic and static balance ability, and then improve the gait stability and posture control ability of older adult, which has significant positive benefits for the prevention of falls in older adult. OEP is helpful to improve the falling efficiency of older adult, help older adult overcome the fear of falling, and form a positive emotion of "exercise improves exercise," to reduce the harm caused by sedentary behavior and the incidence of depression and improve their subjective wellbeing. Although OEP has significant positive effects on improving the health and physical fitness of older adult, preventing falls, and restoring clinical function, the corresponding neural mechanism for preventing falls is not very clear. At the same time, how OEP can be combined with emerging technologies to maximize its benefits needs to be further discussed in the future.

KEYWORDS

Otago exercise programme, prevent falls, balance ability, cognitive function, fall efficiency

Introduction

Falling refers to falling on the ground or below the level without conscious or external force (1). It is easy to cause fracture, stroke, and limited mobility in older adult. Indirectly, it causes physical weakness, cognitive decline, sedentary behavior, social exclusion, and even death (2, 3). Aging leads to the decline of balance ability and posture control ability of older adult, which increases the risk of falls, About 300,000 people worldwide die from falls every year. Among older adult over 65 years old, 30% have fallen and 15% have fallen many times (4). Therefore, the injury caused by falls has become an important public health problem, which has a huge negative impact on the high-quality and healthy life of older adult.

As we all know, human body function and neurosensory perception will weaken with age, accompanied by chronic diseases or sarcopenia and other diseases; At the same time, aging causes problems such as long reaction time, cognitive decline, balance ability, muscle strength, and side effects of drugs, which will increase the risk of falls (5, 6). However, proper participation of older adult in sports events focusing on flexibility, lower limb strength, and balance can improve the balance ability and physical flexibility of older adult and reduce the occurrence of fall injury (7, 8). According to relevant research reports, at present, many exercise prescriptions are effective in preventing falls in the world, such as the Otago exercise program (OEP), fitness exercise for older adult, fall prevention lifestyle, multi-objective stepping exercise, Tai Chi, yoga, Pilates and resistance training (9). Among them, OEP has been proved to effectively improve the cognitive function, balance ability, lower limb muscle strength, functional physical fitness of older adult (10), prevent falls in older adult (11), accelerate the recovery of physical function, and reduce economic costs (12, 13), because its training content emphasizes strength and balance exercises more; In recent studies, it was also found that OEP can not only effectively improve the balance ability, but also enhance the self-confidence of balance control after multiple falls and overcome mental health problems such as social isolation and fear (14, 15). In short, with the aggravation of population aging, more and more elderly people cannot go out to participate in leisure activities due to physical reasons, and can only stay at home for a long time due to physical reasons (such as arthritis, stroke, heart disease, and other chronic diseases), poor health self-assessment, and less social support and higher living floors. Staying at home during the period can reduce the amount of physical and mental activity of older adult, reduce their mobility and balance, and increase the risk of falls. Falls may lead to the decline of the quality of life of older adult and the improvement of the bedridden rate. These serious clinical problems will greatly increase the family and socio-economic costs. The Otago exercise program aims to prevent falls in older adult, the personalized and progressive exercise of muscle strength and balance at home is just a multi-component exercise prescription of personalized and progressive exercise of lower limb muscle strength and balance at home. Therefore, this review will comprehensively comb and summarize the content, development history, and fitness efficacy of OEP, to better understand and promote OEP, help older adult actively deal with falls, and provide a theoretical basis for future research design and practical application.

Date and methods

Date sources

Using PubMed, web of science, China National Knowledge Infrastructure (CNKI), dimensional spectrum, and other databases, search for research papers published in relevant journals at home and abroad from 2005 to April 2021 by using keywords such as Otago project exercise; aged, Fall; Cognitive function, Balance ability, Lower limb strength, Fall efficiency, Subjective wellbeing, self-confidence and so on.

Eligibility criteria

(1) The study group consisted of older adults 60 years and older who were at risk of falls or had a history of falls. (2) The experimental group had a strict exercise prescription design. (3) The exercise prescription of the experimental group must be based on the OEP, and the control group can be prescribed other exercises or not intervened. (4)The prescription design is following the standards of the American College of sports medicine (ACSM). The evaluation indexes mainly include cognition, balance ability, lower extremity muscle strength, and fall efficacy.

Literature exclusion criteria

(1) Literature whose language is not English or Chinese is excluded. (2) Repeated and nonexperimental studies were excluded. (3) An experimental study to exclude Otago exercise prescriptions unrelated to the subject of falls.

Data intake quality assessment

(1) The reading and review of the literature are divided into three stages. In the first stage, The researcher searches the literature in the database, and initially browses and reads the abstract to select the appropriate literature. In the second stage, other researchers sorted out the literature and eliminated duplicate literature. In the third stage, two researchers jointly read the full text to determine whether the articles met the inclusion criteria. If there is any literature that has not reached a consensus, it will be decided after discussion.

(2) Literature quality and empirical level. PEDro scale was used to check each document and evaluate its research quality. The higher the score, the better the research quality of this document. Each document was scored independently by two researchers. If there are different scoring items, a consensus was reached after discussion. Due to the characteristics of the included papers, the therapists are required to provide treatment intervention in the research process. The highest total score maybe 9 for the items that cannot be single-blind for the therapists. Therefore, it is determined that those whose pedroscale score is $\geq$5 are high-quality papers, and those whose score is $\leq$4 are low-quality papers.

The system search results are shown in Figure 1. A total of 1,192 relevant articles were retrieved from four databases. Deleted 656 duplicate literature, and selected 536 kinds of literature According to the title and abstract, 105 full texts were obtained for further analysis, of which 71 were excluded because they did not meet the qualification criteria. Through the full-text analysis, 34 papers meet the qualification criteria. The number of articles finally included in this paper is 34.

Results

Origin and development of Otago exercise program

The OEP originated in New Zealand, Campbell et al. (16) conducted the intervention pilot study of this exercise therapy for elderly women for the first time and achieved good results. OEP has now been listed as a key intervention project for fall prevention in New Zealand and has invested a lot of money in development and promotion (17). The training content of OEP is mainly composed of four parts: warm-up activities, strength training, balance training, and walking training, 5-min warm-up activities: head movement, neck movement, back stretching, trunk movement, and ankle movement; Strength training and balance training take about 30 min, of which five strength training include sitting knee extension, standing hip abduction, standing knee flexion, tiptoe and heel tiptoe; The 12 balance exercises include standing on one foot, walk in the shape of the number eight, walking sideways, walking backward, standing to sit position training, knee bending, toe to heel standing, heel walking, toe to heel walking, toe to heel walking, toe to heel walking, toe to heel walking backward, and climbing stairs; The last part consists of 10-min walking training to consolidate the effect of muscle strength and balance training. The exercise intensity is divided into four levels of ABCD, and the intensity increases gradually; The exercise frequency shall be no <3 times a week. In terms of training monitoring, physiotherapists understand the training status of older adult and adjust the content through telephone interviews and home visits (11, 18, 19).

After the initial success of OEP in New Zealand, it was gradually introduced by Germany, the United States, Canada, and other countries, and OEP was improved and developed according to the actual situation. American scholars have discussed the enforceability and scientificity of OEP and demonstrated it many times in combination with the feedback

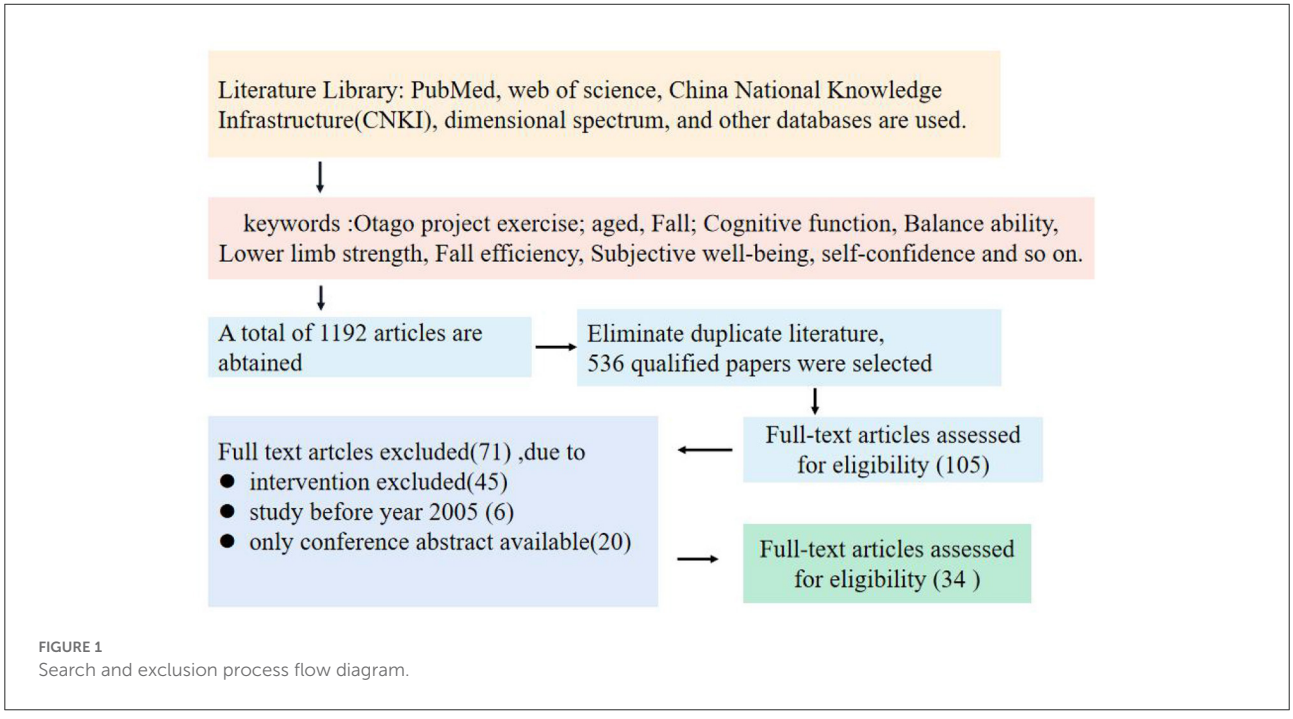

FIGURE 1
Search and exclusion process flow diagram.

of physiotherapists. The research results preliminarily prove the effectiveness of OEP, but there are still some problems, such as imperfect rehabilitation training institutions, lack of professional guidance, and high medical expenses (20). Subsequently, the improved OEP gradually became efficient and feasible. Through the training of professional physiotherapists and combined with virtual technology, its feasibility and scientificity were ensured (11, 21). OEP has been widely used in clinical rehabilitation and postoperative recovery. The intervention objects are stroke (22), knee arthritis (23), cognitive impairment (24), and knee replacement surgery (25). After OEP intervention, the patients' physical function and balance ability have been effectively improved, and their fall risk has also been effectively reduced.

The operation form of OEP training can take the form of personal exercise, emerging technology, and group exercise. To carry out the traditional mode of OEP, professional physiotherapists need to be equipped to design movement guidance and exercise prescriptions, and fully grasp the comprehensive situation of training (26). With the development of multimedia technology and intelligent platform, the form and operation of OEP are becoming more and more intelligent and diversified, such as augmented reality (VR), remote live broadcasting, and wearing trackers (12, 27). older adult living alone can complete exercise tasks online. Physiotherapists use wearable devices to monitor the physical condition and training of exercisers, and give established plans according to the actual situation, At the same time, online OEP training can reduce the sense of loss of older adult due to differences in skill levels and enhance their confidence in adhering to sports (28), To maximize the satisfaction of the personalized needs and sense of security of older adult at home, it is very effective to use such a way of exercise that breaks through the limitations of time and space in the period of epidemic isolation. However, some studies believe that OEP in group mode expands the social participation of older adult and has stronger compliance than exercise alone (7). In short, OEP is beneficial to older adult. No matter what form of exercise OEP is, it is effective in specific circumstances.

Effect of OEP on the prevention of falls in older adult

Effect of OEP on cognitive function of older adult

The most common mental disorders of older adult mainly include dementia, depression, delirium, etc., commonly known as 3D diseases, These three factors often lead to the functional decline of older adult in a short time, which not only leads to the impairment of older adult's self-care ability, but also gives caregivers a great burden and increases the difficulties in care, and the resulting complications increase the medical cost.

Otago exercise program training can improve the brain processing speed, sustained attention, visuospatial skills, working memory, and other related cognitive abilities of older adult (24). In terms of executive function, as a key field of cognitive function, the advanced cognitive process of controlling and integrating other cognitive abilities can test and evaluate the fall risk level of older adult (29). The role of executive function in preventing falls can be achieved through exercise induction (30). After exercise therapy, the improvement of executive function will help to improve the compliance of older adult and better adhere to participate in the exercise. It is worth noting that OEP has positive effects on motor function in improving neurocognitive function in older adult, and there is also an interaction between neurocognitive function and motor function (31). According to the special physiological conditions of patients with mild cognitive impairment, the weak state further increases their fall risk. The group mode OEP is a potentially effective strategy to improve patients with mild cognitive impairment, which can improve their cognitive weakness to a certain extent (32, 33). In addition, after OEP intervention, it was found that cognitive status and activities of daily living at baseline can predict the longitudinal pattern of compliance, and a higher baseline level of executive function may lead to better use of self-regulation strategies, which is beneficial to the prevention of falls in older adult (34). Maintaining and improving executive function plays a long-term role in exercise. The improvement of working memory and attention can also promote older adult to adhere to exercise and reflect good compliance (35). However, these three studies only prove that OEP can improve the physical function of older adult and indirectly reflect the positive effect of cognitive function on older adult. There are some limitations because it is not studied directly from the cognitive level. It may be more valuable to explore the research on reducing the risk of falls directly from the cognitive level of exercise improvement. Response inhibition is an important part of executive function, which mainly includes intentional inhibition of dominant response, automatic response, or strong response. After 6 months of OEP intervention, the lower limb strength and balance ability of older adult were improved, and the most important thing was to improve the path of response inhibition, which proved the effectiveness of preventing falls and reducing the risk of falls in older adult by improving cognitive performance (36). OEP is widely used in rehabilitation training for special patients. Stroke patients will be at risk of cognitive impairment due to factors such as cerebral ischemia and brain damage. Studies have shown that OEP combined with music therapy can improve the memory ability, orientation ability, and language ability of stroke patients, contribute to the repair of neurological function and improve cognitive impairment (37). In addition, short-term Ortega exercise can not only improve the cognitive function of stroke patients, but also greatly improve their ability of daily living, and then promote the improvement of the quality of life

TABLE 1 Research data on OEP improving cognitive function in older adult.

Researcher	Country	Sample size	Intervention time	Intervention mode	Test task	Research results
Liu-Ambrose et al. (24)	Canada	$n = 256$; Age ≥ 70	1 year, 3 times a week/30 min	①OEP ②Routine nursing	MOCA; MMSE	The score of the digit symbol replacement test in the intervention group was higher than that in the control group, indicating that the processing speed of older adult was effectively improved after the intervention
Huang and Ou (31)	China	$n = 87$; Age ≥ 60	3 months, 2–3 times a week/30 min	①OEP ②Routine nursing	NIS	After OEP intervention, neurological function was improved based on improving motor function
Davis et al. (33)	Canada	$n = 172$; Age ≥ 70	1 year, 3 times a week/30 min	①OEP ②No	MOCA; MMSE	The average score of recommended mental state after the intervention was 27.7 (24–30 were normal), and the improvement of cognitive function reflected good compliance
Liu-Ambrose et al. (35)	Canada	$n = 74$; Age ≥ 70	6 months, 3 times a week/30 min	①OEP ②Routine nursing	MMSE	There was a significant difference in response inhibition between the OEP group and control group ($p < 0.05$); The risk of falls was 0.47 in the OEP group and 0.56 in the control group
Liu et al. (36)	China	$n = 142$; Age ≥ 60	6 months, 3 times a week	①OEP ②Routine nursing	MMSE	After OEP intervention, the memory ability and orientation ability of stroke patients were significantly higher than those before intervention and those in the control group
Davis et al. (34)	Canada	$n = 172$; Age ≥ 70	1 year, 3 times a week/30 min	①OEP ②Routine nursing	ODT; MOCA	The improvement of executive function, attention, and working memory promote older adult to adhere to exercise and reflect better compliance
Shao (37)	China	$n = 30$; Age ≥ 70	6 months, 3 times a week/30 min	①OEP ②Routine nursing	MOCA; MMSE	After OEP intervention, the left and right hippocampal connections changed, and the scores of delayed memory, attention, and language were significantly improved ($p < 0.01$)

① experimental group ② control group.
The intervention time is only the intervention time of the experiment.
M0CA, Montreal Cognitive Assessment; MMSE, simple mental state score; NIS, National Institutes of Health Stroke Scale; ODT, Oral digital test.

of elderly stroke patients (38). The research data for this part are shown in Table 1.

Effect of OEP on balance ability of older adult

Effect of OEP on static balance ability of older adult

Static balance ability can keep older adult stable in a special environment, such as sitting and standing posture. It seems that static posture is not easy to fall. But, on the contrary, when older adult are in a sitting or standing position, poor physical control will lead to falls and backward tipping, resulting in physical injury. In a previous static balance study of 68 elderly people, it was observed that after 12 weeks of OEP intervention (39), the Berg Balance Scale (BBS) scoring ability was significantly improved, and the balance scale score increased from 15.32 ± 2.18 to 16.78 ± 2.20, and the static balance ability of older adult was significantly improved ($p < 0.001$). The risk of falls decreased from two times before intervention to 0 times. In addition, the physical fitness level of older adult in older adult nursing home has also been greatly improved (1). Current research reports that online OEP intervention in sedentary elderly can effectively improve their static balance ability, and its economic cost is not high. The most important equipment cost is wearable tracker equipment, which is used to measure basic information, and the content of OEP is presented in the form of a video conference (27). After the balance training and walking exercise program based on family basic OEP, the number of falls and disability risk of older adult in assisted living facilities are reduced (40, 41).

The OEP of virtual mode seems to be more in line with the realistic requirements of the rapid development of science and technology.OEP training based on virtual reality improves static posture control and can achieve the training effect of traditional OEP. This method is beneficial to older adult with special contraindications, such as home-based elderly with mobility difficulties, asthenia, etc (42). After standing training through

the new virtual OEP, the single leg standing test index and the 30-s sitting test score are higher than the pre-test score, which shows that the static balance ability of older adult has been improved and the fall risk has been improved in the objective measurement index (20), However, there are some limitations. This form of OEP has poor benefits for the weak elderly; Recent empirical studies have proved that group OEP in virtual mode can reverse the frailty of elderly patients with mild cognitive impairment and the physiological function of cognitive impairment, and improve their balance ability (43) and physical activity ability (32). However, different intervention objects will lead to some differences in research results.

Effect of OEP on dynamic balance ability of older adult

Dynamic balance ability is an important guarantee for older adult to step out of the small home environment. older adult need better dynamic balance ability to maintain posture stability in their daily activities. Multi-component exercise can improve older adult's posture control ability, maintain certain stability in moving activities such as climbing stairs, and prevent them from falling, causing damage and affecting their quality of life. Relevant studies have reported that short-term group OEP can effectively improve the balance ability of older adult, improve the physical level of older adult, and enable older adult to obtain good compliance and satisfaction (44); After repeated training such as sitting and standing, standing and walking, the dynamic balance ability is significantly improved (39). Shubert te et al. (11) found through the comparative study of the two modes of family OEP and community OEP that both modes improve the balance ability of older adult and have positive benefits for older adult, but there are differences in economic level and development mode. The OEP of group mode can participate more elderly people, and the economic cost is more affordable than private treatment, but the positive effect of the traditional mode on special elderly people is indispensable. Therefore, OEP can be used as a long-term treatment for older adult to prevent falls, meet the diversified needs of older adult and improve their actual balance ability. As a traditional Chinese national sport, Tai Chi has a long history and has the effect of cultivating the body and mind and strengthening the body, and is deeply loved by older adult. Tai Chi and OEP are both effective means to prevent falls in older adult. Some scholars compared the two methods and found that after participating in Tai Chi and OEP intervention, both interventions improved the balance ability of older adult, but the balance ability of the OEP intervention group was better. The test indexes of sitting and standing in 30 s and step frequency were significantly higher than those of the Tai Chi Group, but the test index of standing on one foot of the Tai Chi group was better than that of the OEP group, This may be due to the different exercise modes and muscle use modes of the two. There are more balance training contents in OEP, especially dynamic training, while tai chi moves more slowly with one foot, but both improve the dynamic balance ability of older adult on the whole (8). In the OEP plan, walking backward on tiptoe and walking eight characters have improved the coordination and flexibility of older adult, and further increased the extension length and stability of older adult during movement (45). The combination of the movement observation method and OEP increases the understanding and excitement of movement in relevant brain areas such as the motor cortex, and shows the improvement of balance ability and walking speed in practical performance (46). The research data for this part are shown in Table 2.

Effect of OEP on lower limb muscle strength in older adult

Otago exercise program improves the lower limb strength of older adult through its special training content, to reduce the risk of falls older adult. OEP's muscle training is a kind of repeated low-intensity resistance training, which stimulates knee flexion, anterior tibial muscle, and ankle dorsiflexion, fully activates the muscle, maximizes the performance ability of muscle fibers, and may increase the synthesis of actin and myosin, thus delaying the atrophy of muscle cross-sectional area and the decline of muscle strength (12). In a study on grip strength through OEP, it was found that 6 months of lower limb training and exercise can significantly improve the grip strength of older adult, which is in line with the cross effect of exercise and helps to prevent sarcopenia and decline of muscle strength in older adult (45). Although OEP can increase the lower limb muscle strength and reduce the risk of falls and fractures in older adult, some studies believe that this exercise mode cannot increase bone mineral density, which may be due to the time of intervention and the failure of exercise load to reach its threshold (47). A study used an electronic muscle strength meter to measure the effect of OEP on muscle strength and found a positive effect. The "tiptoe" and "tiptoe heel" exercises in OEP stimulate the stretching of lower limb muscles, which may help to increase the body's demand for protein, promote the increase of muscle protein synthesis and muscle oxygen consumption, increase muscle content and improve lower limb muscle strength. Long-term living alone or sedentary behavior can lead to depression and mental health problems, and depression can reduce interleukin-6 and tumor necrosis factor α The levels of pro-inflammatory factors such as C-reactive protein are increased (48), which will lead to the decline of muscle density and skeletal muscle quality. OEP can reduce pro-inflammatory factors to improve the depression of older adult and slow down the decline of muscle function in older adult (49).

Lower limb strength is the basic guarantee of mobility. The lack of lower limb strength will lead to slow movement and a limited range of activities for older adult, which is one of the reasons why many elderly can only stay at home. After OEP intervention, the mobility of older adult can be improved, which can increase their social participation and sports participation.

TABLE 2 Research data on OEP improving balance ability.

Researcher	Country	Sample size	Intervention time	Intervention mode	Test task	Research results
Jahanpeyma et al. (1)	turkey	$n = 72$, Age ≥ 65	12 weeks/3 times/45 min	①OEP ② None	Berg balance scale; 30-s standing test	After the intervention, the score on Berg Balance Scale was significantly improved ($p < 0.001$), and the number of falls was significantly reduced ($p < 0.005$)
Beato et al. (39)	America	$n = 30$ Age ≥ 60	9 weeks/3 times/30 min	①OEP ② None	Manual muscle strength test; Time stand	After OEP intervention, the average number of falls per person per year decreased from 1.4 to 0.5; The physical performance score increased from 11.8 to 17.6
Knott et al. (40)	America	$n = 59$ Age ≥ 70	Unknown	①OEP ② None	Mobile capability test; Balance ability test	After the intervention, the number of falls was significantly improved, and the balance ability and mobility index was increased
Phu et al. (41)	Australia	$n = 195$ Age ≥ 70	6 weeks/twice/60 min	①OEP ② None	30-second standing test; Square step experiment	The posture stability and gait speed of older adult in the OEP intervention group were higher than those in the control group ($p < 0.05$)
Feng et al. (43)	China	$n = 18$, Age ≥ 65	12 weeks/3 times/60 min	①OEP ② None	30-second standing test; Four-stage balance test	After the intervention, the post-test vulnerability score was significantly lower than the pre-test score ($p < 0.05$), and the physical performance and static balance ability were improved
An et al. (44)	China	$n = 32$, Age ≥ 65	21 weeks/3 times/30 min	①OEP ② None	Balance ability test	After the intervention test, the physical fitness and balance level of older adult increased significantly, and the group OEP has good adaptability
Chen et al. (38)	China	$n = 60$, Age ≥ 65	12 weeks/3 times/45 min	①OEP ② None	Berg balance scale; Four-stage balance test	The static and dynamic balance of older adult were improved ($p < 0.001$), and their physical function was enhanced
Shubert et al. (11)	America	$n = 210$ Age ≥ 65	8 weeks/day/3 times/30 min	①OEP ② None	30-second standing test; Four-stage balance test	After the intervention, they significantly improved their physical objective function, flexibility, balance ability, and self-report ability
Son et al. (8)	Korea	$n = 46$ 65–79	12 weeks/twice/30 min	①OEP ②Taichi	Functional extension test; One leg standing test	Both groups improved the mobility of older adult, which is conducive to the prevention of female elderly falls
Liew et al. (45)	Malaysia	$n = 67$; Age ≥ 65	12 weeks/3 times/35 min	①OEP ②Routine nursing	Lower limb function test Hand dynamometer	OEP compared with the control group, the increase of upper limb grip strength and balance ability further enhanced the posture control ability of older adult
Leem et al. (46)	Korea	$n = 30$; Age ≥ 70	12 weeks/3 times/50 min	①OEP ② Action observation	Standing walking test	OEP improves balance and walking speed in actual performance

① Experimental group.
② Control group.

In the form of group OEP, older adult in the nursing center were taken as the research objects. OEP was conducted three times a week for 6 months, with a total of 78 training sessions, After the intervention, the results showed that the strength of the ankle muscle group and ankle dorsiflexion increased significantly. The muscle strength increased from 7.02 to 12.92 kg before the intervention, which increased the strength of the lower limbs. Compared with the pre-test and post-test data for the sitting and standing test, the number of sitting and standing in the experimental group increased from 5.11 ± 2.57 to 9.33 ± 5.12.

There were no falls and adverse events during the 6 months of the intervention. The exercise prescription did not need special equipment, Therefore, scholars believe that OEP is a simple, safe, and effective lower limb resistance exercise (50). In the contrast to augmented reality-based OEP and yoga, OEP effectively improved the knee flexion and ankle dorsiflexion strength of elderly women (12). Another study also supports this view that OEP improves the lower limb strength and physical fitness level of older adult, but the control group is the walking exercise group, and the OEP itself includes walking exercise. There is no significant difference between the two, but this does not affect its positive effect (1). Similarly, OEP is efficient and safe to improve the lower limb strength of older adult under special physiological conditions. Compared with Taijiquan, the OEP plan includes many resistance training for lower limbs to overcome self-weight, which is better than Taijiquan in improving specific lower limb strength, such as ankle strength, knee extension, and flexion strength (8). The nursing home is also an effective model for older adult to improve their muscle weakness and long-term muscle function (45).

Otago exercise program effectively improved the lower limb muscle strength of patients with a history of falls and stroke. Some scholars have discussed the positive benefits of OEP in older adult with knee arthritis disease. The results show that OEP still has a positive effect on the lower limb muscle strength of older adult with knee arthritis, and there is no adverse effect on knee arthritis (23). Although the research results are not fully sure to effectively reduce the fall recurrence rate of older adult with a special history, it can benefit older adult with gait disorders; older adult often suffer from chronic diseases, including lower limb muscle pain, which will hinder the exertion of lower limb muscle function. After OEP, the pain was relieved. It is speculated that lower limb training may improve muscle performance (26), but some studies have found that although OEP can significantly improve the lower limb muscle strength of older adult with another special medical history, it has little effect on their self-care ability, which may be related to the special medical history. In the study on fall prevention of stroke patients, an OEP plan can significantly improve the lower limb strength of stroke patients and reduce the risk of falls, with little impact on their activities of daily living and quality of life (51). OEP can increase the lower limb strength of different groups. Due to the epidemic control, physical therapists and older adult carry out OEP exercise plans at home. The outcome indicators show that family-based OEP can effectively prevent older adult from falling, improve the physical function and lower limb strength of family members, create a harmonious family atmosphere, and improve the subjective wellbeing of older adult (52). Walking movements in OEP projects, such as walking backward, zigzag walking, walking sideways, walking straight, climbing stairs, etc., continue to induce the activity of hip flexion muscle and isotonic flexion of the ankle, which may help to improve muscle strength and coordination (46). The research data for this part are shown in Table 3.

Effect of OEP on fall efficacy in older adult

Fall efficacy refers to the degree of self-efficacy that cannot be judged when participating in a certain activity. After older adult suffer from multiple falls, their fall efficiency and self-confidence decrease due to fear of falls, which increases the risk of falls and forms a vicious circle, further reducing the physical function of older adult. Physical exercise can improve social isolation, fear, and other related mental health problems (27).

The effect of exercise therapy should not be limited to the improvement of physiological outcome indicators. The psychological effect induced by exercise is also one of the important factors to reduce the risk of falls in older adult. Studies have shown that the inducing effect of OEP can enhance the balance and confidence of older adult and help eliminate the shadow and fear of falling. Domestic research using Internet + technology suggests that OEP can improve older adult's fear of falling, encourage older adult to exercise, and reduce the risk of falling (53). After 12 weeks of OEP intervention, psychological-related self-confidence problems will be effectively improved, and older adult's confidence in posture control will be enhanced (39). In addition, most of the fear of older adult comes from past fall history. Bjerk et al. (3) believe that in the positive benefits of OEP intervention, the psychological self-efficacy factor cannot be ignored, which plays an important role in reducing the risk of falls.OEP enhances the self-efficacy and happiness of older adult. The intervention of OEP indirectly improves the high-quality healthy life of older adult and meets the realistic requirements of older adult in their happy old age, rather than blindly extending the lifeline. This result was also verified in the interview survey. According to their many years of practical experience, 17 physiotherapists concluded that OEP can improve older adult's sense of fall efficacy, expand their social participation and promote older adult to better manage their daily life (54). An intervention study based on technical means believes that both online group exercise and social model OEP can improve the loneliness of older adult to a certain extent and improve the level of subjective wellbeing of older adult (28). However, some scholars believe that high cohesion group OEP is better than an individual exercise in reducing loneliness and improving subjective wellbeing, and online training for older adult living alone does not improve their loneliness (55). Before allowing older adult to participate in OEP, first carry out observation and learning for 20 min, control the actions of older adult, and then carry out OEP training, so that older adult can conduct self-assessment according to the observation and learning content, to increase their efforts and obtain a better sense of achievement (46).

The movement of OEP is not complex. Hale L and other (56) scholars took adults with slight intellectual impairment as the

TABLE 3 Research data on OEP improving lower limb muscle strength.

Researcher	Country	Sample size	Intervention time	Intervention mode	Test task	Research results
Lee et al. (12)	Korea	$n = 30$; Age = 72.6 ± 2.67	12 weeks/3 times/60 min	①AR OEP; ② Yoga	Digital manual muscle tester	The knee flexion and ankle dorsiflexion strength in the OEP group increased, and the muscle strength of lower limbs in the OEP group was better than that in the yoga group
Liew et al. (45)	Malaysia	$n = 67$; Age ≥ 65	12 weeks/3 times/35 min	① Improved OEP; ② Routine nursing	Lower limb function test, hand dynamometer	The lower limb activity was improved and showed a cross effect, which improved its grip strength
Duckham et al. (47)	Britain	$n = 142$; Age ≥ 65	24 weeks/3 OEMs	① OEP family; ② Nursing + others	Bone densitometer; questionnaire investigation	There was no difference in bone mineral density between the two groups, and there was no increase in bone mineral density, but the muscle performance was improved, which was conducive to the prevention of fracture
Cheng et al. (50)	China	$n = 20$; Age ≥ 70	26 weeks/3 times/45 min	①OEP ② Daily activities	30-s standing test Lower limb muscle strength test	After OEP intervention, the muscle strength of the knee extensor, knee flexor, and ankle flexor was significantly improved
Jahanpeyma et al. (1)	turkey	$n = 72$, Age ≥ 65	12 weeks/3 times/45 min	①OEP ② None	Berg balance scale 30-s standing test	After the intervention, the number of sit and stand tests increased and the risk coefficient of falls decreased ($p < 0.05$)
Son et al. (8)	Korea	$n = 46$ Age = 65–79	12 weeks/twice/30 min	①OEP ② Tai Chi	Functional extension test One leg standing test	OEP group has a greater improvement in lower limb strength than the Tai Chi Group, which is conducive to the prevention of female elderly falls
Kocic (10)	Spain	$n = 77$ Age ≥ 65	26 weeks/3 times/35 min	①OEP ② Routine nursing	Functional independence measurement Timed standing walking test	Functional activity, lower limb muscle strength, and functional independence have significant effects, further delaying the progress of the disability
Mat et al. (23)	Singapore	$n = 24$; Age ≥ 60	unclear	①OEP ② Routine treatment	Stability test Lower limb strength test	Compared with the control group, it was found that the lower limb function of older adult after the intervention was enhanced and the effect of posture control was better
Park and Chang (51)	Korea	$n = 8$; Age ≥ 60	8 weeks/3 times/50 min	①OEP ② None	Energy efficiency meter Quality of life assessment scale	Due to the short sample size and intervention time, the impact on stroke patients is limited, but it is effective in preventing falls
Hager et al. (52)	Switzerland	$n = 405$; Age ≥ 65	unclear	①OEP ② None	Sitting test Four stages balance test	The risk of falls is reduced, to improve the quality of life of older adult
Leem et al. (46)	Korea	$n = 30$; Age ≥ 70	12 weeks/3 times/50 min	①OEP ② Action observation	Electronic muscle dynamometer	Compared with the control group, the activity of hip flexion muscle and isotonic flexion of the ankle in the OEP group increased, and the strength of lower limbs increased
Cederbom et al. (26)	Sweden	$n = 119$; Age ≥ 75	1 year, 30 min each time	①OEP ② None	Pain scale test Fall fear scale test	The test and follow-up study after the intervention showed that OEP exercise reduced lower limb pain and enhanced lower limb muscle strength

① Experimental group.
② Control group.

research object and found that it is not too difficult for patients to understand the content of OEP and can complete their training movements. Therefore, it is suggested that older adult with cognitive decline do not have too much psychological pressure and burden when completing. In addition to confirming the positive benefits of OEP for older adult, McMahon et al. (57) scholars also discussed the impact of interpersonal components in participating in training, including social environment, social support, cognitive self, self-encouraging behavior change, etc. these components will make older adult dare to exchange experience and share knowledge when participating in exercise, which will promote older adult's self-confidence in exercise and fall efficacy. Isolated elderly people in the context of the epidemic are prone to negative emotions such as depression and loneliness. OEP is used to reduce the negative effects caused by lack of exercise and significantly improve the depression and physical function of older adult (34). In addition, in the intervention study of elderly patients after knee arthroplasty, Liu Heng and other (25) scholars found that OEP significantly improved patients' fall efficiency and increased patients' self-confidence, and the exercise program can still exercise autonomously at home after patients are discharged from hospital to increase exercise benefits. However, there are data on OEP focusing on cognitive function, and it is unclear whether OEP plays several positive benefits in other cognitive fields. From the perspective of the impact of balance ability, after the exercise treatment of OEP, the dynamic and static balance ability of older adult has been significantly improved, which improves the body posture control ability of older adult, and then reduces the fall risk of older adult who are sedentary at home or engaged in daily outdoor activities. The research data for this part are shown in Table 4.

Discussion

To sum up, the positive effects of multi-component OEP on cognitive function, balance ability, lower limb muscle strength, and fall efficiency of older adult are consistent with the views of most literature, and it is considered that OEP is effective in preventing falls for older adult (10, 11, 14). From the perspective of the impact of cognitive function, it shows multifaceted positive effects on the cognitive level of older adult. OEP improves the processing speed, response inhibition, and other cognitive fields of older adult, and good executive function can predict and improve the exercise compliance of older adult, make them adhere to exercise and obtain good exercise benefits. However, most studies were single OEP exercise therapy and did not involve the combination of multiple balance training methods. Research shows that taking inspiratory muscle training as the auxiliary training method of OEP, the combination of the two therapies can better improve the balance function of older adult and the function of the inspiratory muscle of older adult (58). Supplementing OEP therapy with multi-sensory balance practice can also maximize the utility of balance ability (59). Therefore, OEP combined with other therapies may be more effective in balancing ability. In terms of the impact on lower limb muscle strength, OEP mainly reduces the risk of falls in older adult by improving muscle performance and enhancing muscle strength. The muscle strength of the lower limbs of older adult patients is significantly improved, especially the muscle strength of lower limbs is improved, which is affected by the aging of older adult patients. However, the physiological mechanism of OEP improving lower limb muscle strength is not clear, and whether it will increase bone mineral density and muscle cross-sectional area is unknown, but there is no doubt that it can delay muscle atrophy. From the perspective of the impact of older adult's fall efficiency, it is mainly to improve older adult's fall efficiency, increase their self-confidence, overcome the fear of previous falls, and enable them to complete some self-management things independently, so that they are full of confidence in their later life (54, 60), to achieve the purpose of reducing the risk of falls. The long-term sedentary elderly at home can alleviate the mood of depression and loneliness through OEP, expand social participation, enhance the feelings of their families and obtain the support of their families when exercising at home with their families, to improve the subjective wellbeing of older adult, which is very important for older adult who cannot go out of home due to physical factors.

To better participate in OEP exercise, practical problems in its operation also need to be further discussed, such as contraindications and exercise dose in special patients. Short-term training has little improvement on older adult with a history of falls, but only improves their physical performance. Therefore, older adult with a history of falls should actively participate in the exercise, reduce the risk of falls in time, and adhere to it for a long time to ensure the sustainability of the exercise effect. In the research with physiotherapists as interviewees, physiotherapists believe that OEP is an effective means to effectively prevent falls and improve physical function in older adult (61). The main reason is that OEP has strong applicability, simple project action, and diverse participation methods, older adult have little pressure on learning and training content and have good compliance, few adverse events, and high safety, which is very key. Therefore, the application of OEP in daily life exercise is also very feasible, not just limited to the field of clinical rehabilitation. Regardless of any sports event, the degree of exercise persistence is directly related to the exercise effect. After OEP training, telephone interviews, records, and other methods are adopted to encourage older adult to adhere to exercise, but the effect is very little, which is not enough to encourage them to adhere to exercise (62, 63). More means are needed to ensure the effective intensity and progress of the exercise. In the future, it can be combined with online special psychological counseling or

TABLE 4 Research data on the efficacy of OEP on falls in older adult.

Researcher	Country	Sample size	Intervention time	Intervention mode	Test task	Research results
Gu et al. (53)	China	$n = 60$, Age ≥ 65	24 weeks/3 times/30 min	①OEP ②Knowledge learning	Berg Balance Scale Energy efficiency meter test	The fall efficacy index was significantly improved, and OEP could improve the self-confidence of older adult
Chen et al. (38)	China	$n = 60$, Age ≥ 65	12 weeks/3 times/45 min	①OEP ② None	Specific activity balance confidence scale	The results showed that the self-confidence of older adult increased significantly, which was helpful to overcome the fear of falling
Baez et al. (28)	Russia	$n = 40$, Age ≥ 65	8 weeks, times/30–40 min	①OEP ② None	Multidimensional personality questionnaire Physical activity enjoyment scale	The results show that older adult like the sport, have high compliance, and improve their level of wellbeing
Nikitina et al. (55)	Russia	$n = 44$; Age ≥ 60	8 weeks/3 times/30 min	①OEP ② None	Physical activity enjoyment scale	After the intervention, the pre-test and post-test data found that the level of subjective wellbeing increased, but had little impact on loneliness
Leem et al. (46)	Korea	$n = 30$; Age ≥ 70	12 weeks/3 times/50 min	①OEP ② Action observation	Fear efficacy scale test	Compared with the control group, the walking speed, step frequency, step length and stride length of the OEP group increased significantly, indicating that the sense of self-efficacy was enhanced
McMahon et al. (57)	America	$n = 308$ Age ≥ 70	12 months, times/60 min	①OEP ② None	Social support questionnaire measurement Simple pain scale	Participating in exercise can increase the social participation of older adult, expand social support and improve self-efficacy
Chen et al. (32)	China	$n = 62$ Age ≥ 70	12 weeks/3 times/30 min	①OEP ② None	Geriatric depression scale Mental health survey	OEP improves the physical and psychological function of older adult with cognitive impairment
Heng et al. (25)	China	$n = 32$ Age ≥ 60	4 months, 7 times a week/30 min	①OEP ② Regular exercise	Single item problem method Energy efficiency meter	After the intervention, the fall efficacy and fear of elderly patients after knee arthroplasty decreased

① Experimental group.
② Control group.

cognitive intervention to achieve this purpose. The traditional way of one-to-one physical therapy for older adult seems to have been unable to meet the development of a rapidly aging society, and the economic burden is also an obstacle (11). Especially in rural areas with backward basic medical conditions, it is more difficult to implement the intervention plan. The combination of mobility organization and medical and health care, and the implementation of the OEP plan based on community conditions, have improved the physical function of older adult in rural areas and reduced the risk of falls (63–65). Previous literature has confirmed the effectiveness and reliability of OEP in the form of DVDs in rural areas, and older adult gain a sense of entertainment and happiness in social interaction. In addition, to allow special people to participate in the exercise, we need to improve the OEP content according to the actual situation. Therefore, we should design different training contents according to local conditions as far as possible to meet the needs of different patients, develop remote training and online guidance based on emerging technologies, and combine the traditional one-to-one OEP treatment for special elderly needs. Population aging is an inevitable trend of social development, and the problems caused by falls of older adult seem to be not only physical injuries but also have a great impact on the family and society. Therefore, how to effectively prevent falls of older adult is of great significance, especially in the post-epidemic era, after people's special experience of

isolation and closure, they have a deeper understanding of the concept of a healthy life, In the future, we will pay more attention to the integration of sports into life. Based on the need for healthy aging, this paper summarizes the positive effects of OEP on preventing falls in older adult and effectively helping older adult live a healthy life in their later years. Therefore, this review has practical value and significance for the development of elderly health.

Conclusion

Otago exercise has positive benefits in preventing falls in older adult, which can improve the cognitive function of older adult, enhance the muscle strength of lower limbs and the ability of dynamic and static balance, and then improve the gait stability and posture control ability of older adult; OEP is beneficial to improve the falling efficiency of older adult, help older adult overcome the fear of falling, and form a positive emotion of "exercise improve exercise," to reduce the harm caused by sedentary behavior and the incidence of depression, and improve the subjective wellbeing of older adult. according to the review of this article, OEP exercise of 30–50 min three times a week is recommended as the exercise prescription for older adult to prevent falls. It is recommended that this exercise scheme be carried out as the daily regular activities of older adult at home or in the health care center. It is worth noting that special elderly people need to design exclusive exercise prescriptions to prevent the occurrence of adverse events.

Limitations and further research directions

Most of the literature included in this paper is a single OEP exercise prescription, which cannot draw the positive benefit of OEP combined with other exercise methods to prevent falls in older adult; In addition, OPE lacks in-depth exploration of the deep mechanism of preventing falls in older adult. This is one of the limitations of this paper. The possible mechanisms of preventing falls in older adult are the improvement of muscle performance and cognitive function, but other mechanisms are not clear; To normalize this OEP movement in families, communities, and nursing homes in the post-epidemic era, and promote and improve it in combination with the actual situation of our country, it needs to be further discussed, and research in this area can be strengthened in the future.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding authors.

Author contributions

YY collected and consulted literature and designed and wrote a review. KW, HL, JQ, YW, PC, TZ, and JL provide thesis writing guidance. JL is responsible for the evaluation and revision. All authors have read and agreed to the published version of the manuscript.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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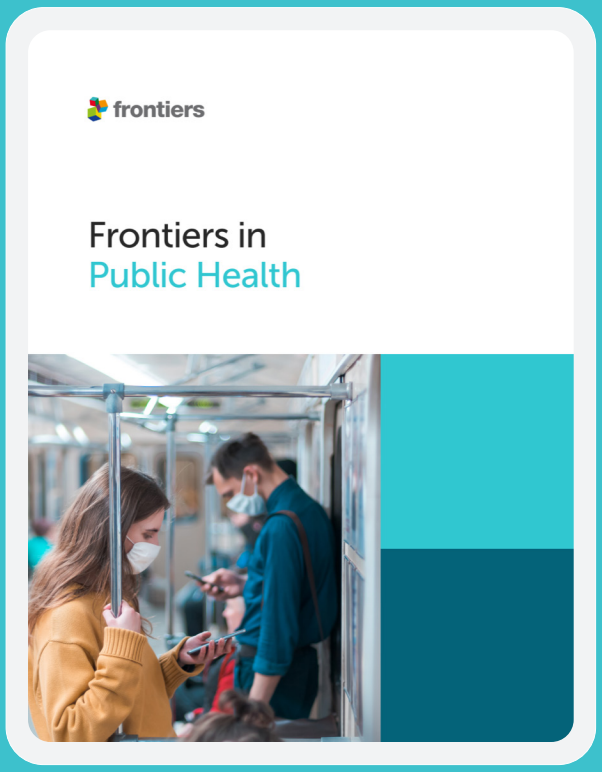

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