frontiers | Research Topics

Population aging and older health in an era of digitalization: Empirical findings and implications

Edited by
Xiangnan Chai, Wei Guo and Zhenmei Zhang

Coordinated by
Zhihao Ma

Published in
Frontiers in Public Health

ISSN 1664-8714
ISBN 978-2-8325-4946-9
DOI 10.3389/978-2-8325-4946-9

About Frontiers

Frontiers is more than just an open access publisher of scholarly articles: it is a pioneering approach to the world of academia, radically improving the way scholarly research is managed. The grand vision of Frontiers is a world where all people have an equal opportunity to seek, share and generate knowledge. Frontiers provides immediate and permanent online open access to all its publications, but this alone is not enough to realize our grand goals.

Frontiers journal series

The Frontiers journal series is a multi-tier and interdisciplinary set of open-access, online journals, promising a paradigm shift from the current review, selection and dissemination processes in academic publishing. All Frontiers journals are driven by researchers for researchers; therefore, they constitute a service to the scholarly community. At the same time, the *Frontiers journal series* operates on a revolutionary invention, the tiered publishing system, initially addressing specific communities of scholars, and gradually climbing up to broader public understanding, thus serving the interests of the lay society, too.

Dedication to quality

Each Frontiers article is a landmark of the highest quality, thanks to genuinely collaborative interactions between authors and review editors, who include some of the world's best academicians. Research must be certified by peers before entering a stream of knowledge that may eventually reach the public - and shape society; therefore, Frontiers only applies the most rigorous and unbiased reviews. Frontiers revolutionizes research publishing by freely delivering the most outstanding research, evaluated with no bias from both the academic and social point of view. By applying the most advanced information technologies, Frontiers is catapulting scholarly publishing into a new generation.

What are Frontiers Research Topics?

Frontiers Research Topics are very popular trademarks of the *Frontiers journals series*: they are collections of at least ten articles, all centered on a particular subject. With their unique mix of varied contributions from Original Research to Review Articles, Frontiers Research Topics unify the most influential researchers, the latest key findings and historical advances in a hot research area.

Find out more on how to host your own Frontiers Research Topic or contribute to one as an author by contacting the Frontiers editorial office: frontiersin.org/about/contact

Population aging and older health in an era of digitalization: Empirical findings and implications

Topic editors
Xiangnan Chai — Nanjing University, China
Wei Guo — Nanjing University, China
Zhenmei Zhang — Michigan State University, United States

Topic coordinator
Zhihao Ma — Nanjing University, China

Citation
Chai, X., Guo, W., Zhang, Z., Ma, Z., eds. (2024). *Population aging and older health in an era of digitalization: Empirical findings and implications*. Lausanne: Frontiers Media SA. doi: 10.3389/978-2-8325-4946-9

Table of contents

frontiers | Frontiers in Public Health

TYPE Editorial
PUBLISHED 16 May 2024
DOI 10.3389/fpubh.2024.1414013

OPEN ACCESS

EDITED AND REVIEWED BY
Marcia G. Ory,
Texas A&M University, United States

*CORRESPONDENCE
Xiangnan Chai
✉ westerncxn@gmail.com

RECEIVED 08 April 2024
ACCEPTED 15 April 2024
PUBLISHED 16 May 2024

CITATION
Guo W, Chai X, Zhang Z and Ma Z (2024) Editorial: Population aging and older health in an era of digitalization: empirical findings and implications. *Front. Public Health* 12:1414013. doi: 10.3389/fpubh.2024.1414013

Editorial: Population aging and older health in an era of digitalization: empirical findings and implications

Wei Guo[1], Xiangnan Chai[2]*, Zhenmei Zhang[3] and Zhihao Ma[4]

[1]Department of Social Work and Social Policy, School of Social and Behavioral Sciences, Nanjing University, Nanjing, China, [2]Department of Sociology, School of Social and Behavioral Sciences, Nanjing University, Nanjing, China, [3]Department of Sociology, College of Social Science, Michigan State University, East Lansing, MI, United States, [4]Computational Communication Collaboratory, School of Jouralism and Communication, Nanjing, China

KEYWORDS

population aging, older adults' health, digitalization, empirical findings, health implications, international perspective, editorial summary

Editorial on the Research Topic
Population aging and older health in an era of digitalization: empirical findings and implications

In this Research Topic, our objective is to solicit research that centers on the health of older adults in the context of the digital era. The phenomenon of population aging has emerged as a significant concern across various regions, including middle-income countries like China (1), as well as in most high-income countries such as Korea (2), Japan (3), the U.S. (4), Canada (5), and many European nations (3). Furthermore, the rapid global advancement of digital technology has profoundly impacted health management and enhancement, influencing healthcare delivery models (6) and timely health communications in users' daily lives (7). Within this context, the examination of how digital technologies shape older adults' health has emerged as a central Research Topic in gerontological and sociological studies.

We received a considerable volume of submissions, and following meticulous editorial and peer review procedures, we ultimately disseminated nine articles of high quality. Among these contributions, eight specifically address the health of older adults in China, while one centers on older adults' health in Korea. All the articles closely align with the overarching theme of older adults' health in the digital era. Notably, each study adopts a quantitative approach. While some investigations rely on nationally representative data, others draw from community-based survey data with relatively modest sample sizes.

The research objectives and outcomes of the nine articles can be summarized as follows.

The study conducted by Wang et al. delved into the advantageous effects of internet usage on support for older adults. Their research findings suggest that increased frequency of internet use is associated with higher probabilities of older Chinese adults engaging in activities such as purchasing commercial pension insurance, accepting formal care, and fostering independence in later life. These positive outcomes are attributed to the dissemination of information and the maintenance of social connections facilitated by internet access.

Xiao et al. explored the relationship between social security enhancements and the health outcomes of older adults actively participating in digital financial inclusion systems. Their results demonstrate that strengthening social security has a positive impact on the wellbeing of older adults. Notably, this influence is more pronounced among older Chinese men than women. Additionally, rural residents derive significant benefits from improved social security provisions, leading to the most favorable health outcomes.

Nan et al. conducted a study to examine the relationship between internet usage and depression among older Chinese adults. Their findings revealed that specific types of internet use are associated with varying levels of depression. For instance, engaging in activities such as chatting via WeChat, browsing online videos, and shopping online is positively correlated with lower levels of depression. These internet activities also contribute to improved interpersonal relationships, which may subsequently reduce depression in older Chinese adults. Conversely, other online activities, such as playing games or online learning, do not show a significant association with depression levels in this population.

Ren et al.s' research focuses on formalizing the domestic service industry to enhance the provision of care services for older adults. Through model construction and simulation analysis, they identified effective strategies. These include increasing the market share of domestic enterprises with employee management systems, implementing subsidy programs for clients, and establishing evaluation and supervision mechanisms. These measures contribute to the overall support and quality of care services.

In their study, Li et al. investigated the factors influencing individuals' intention to use health management systems, which subsequently impact their actual usage. The key factors identified for older adults' behavioral intention to accept a health management system include their expectations of effort, social influences, perceived value, performance expectations, perceived interactivity, and perceived risk.

Wei and Guo conducted a study examining the impact of smart device usage on the self-reported physical and psychological health of older Chinese adults. Their findings indicate that the use of smart devices has a positive effect, particularly among older adults residing in urban areas or those of advanced age. Furthermore, the personal attitudes of older Chinese residents toward smart devices partially mediate the relationship between smart device usage and health outcomes.

Park et al. investigated the relationship between the accessibility of information and communication technology (ICT) and the psychological wellbeing of older Koreans. The COVID-19 pandemic intensified reliance on ICT, shifting engagement from self-motivated to socially passive modes. Despite an initial positive association between ICT use and mental health among older adults in Korea, this link weakened during the pandemic. Notably, heterogeneity exists based on age, sex, and rural residence, with older females in their 70's experiencing the most pronounced effects.

Fan et al. explored the potential of digital health technologies to enhance frailty detection and diagnosis efficiency among older adults. Their investigation revealed that a composite model, which integrated comprehensive geriatric assessment (CGA) and gait parameters, effectively predicted frailty. Remarkably, this composite model outperformed individual features. After feature selection, machine learning models demonstrated significant improvement, with performance gains ranging from 4.3 to 11.4%. Key predictors included large-step walking speed, average step size, age, total step walking distance, and Mini Mental State Examination score.

Liu et al. conducted a study to investigate the influence of digital health literacy on the health-related quality of life (HRQoL) of community-dwelling older Chinese adults. Their findings reveal a positive association between digital health literacy and HRQoL. Importantly, health-promoting lifestyle serves as a mediator in this relationship, emphasizing the need for relevant management institutions, communities, and families to prioritize the cultivation of digital health literacy among older adults.

In summary, the collective evidence from the nine articles featured in our Research Topic unequivocally demonstrates that the advancement of digital and information technology significantly and predominantly benefits the physical, psychological, and social wellbeing of older adults. These findings underscore the necessity of enhancing older adults' access to digital technologies and emphasize the importance of enhancing their digital literacy, particularly in the context of healthcare-related technologies.

Author contributions

WG: Investigation, Resources, Supervision, Writing – original draft, Writing – review & editing. XC: Resources, Supervision, Writing – original draft, Writing – review & editing. ZZ: Investigation, Resources, Supervision, Writing – review & editing. ZM: Resources, Writing – review & editing.

Funding

The author(s) declare that financial support was received for the research, authorship, and/or publication of this article. This editorial summary was funded by the National Social Science Fund of China (21CSH062), National Office for Philosophy and Social Sciences. XC, the corresponding author, is the project holder.

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

References

1. Bai C, Lei X. New trends in population aging and challenges for China's sustainable development. *China Econ J.* (2020) 13:3–23. doi: 10.1080/17538963.2019.1700608

2. Kim KW, Kim OS. Super aging in South Korea unstoppable but mitigatable: a sub-national scale population projection for best policy planning. *Spat Demogr.* (2020) 8:155–73. doi: 10.1007/s40980-020-00061-8

3. He W, Goodkind D, Kowal PR. *An Aging World: 2015*. (2016). Available online at: https://www.census.gov/content/dam/Census/library/publications/2016/demo/p95-16-1.pdf (accessed March 2016).

4. Ortman JM, Velkoff VA, Hogan H. *An Aging Nation: the Older Population in the United States*. (2014). Available online at: https://www.time.com/wp-content/uploads/2015/01/p25-1140.pdf (accessed May 2014).

5. Statistics Canada. *Older Adults and Population Aging Statistics*. (2023). Available online at: https://www.statcan.gc.ca/en/subjects-start/older_adults_and_population_aging (accessed July 2023).

6. Mitchell M, Kan L. Digital technology and the future of health systems. *Health Syst Reform.* (2019) 5:113–20. doi: 10.1080/23288604.2019.1583040

7. Hajli MN. Developing online health communities through digital media. *Int J Inf Manage.* (2014) 34:311–4. doi: 10.1016/j.ijinfomgt.2014.01.006

frontiers | Frontiers in Public Health

TYPE Data Report
PUBLISHED 09 January 2023
DOI 10.3389/fpubh.2022.1079436

OPEN ACCESS

EDITED BY
Wei Guo,
Nanjing University, China

REVIEWED BY
Xiao Feng Xie,
Sichuan University, China
Naveed Noor,
Aga Khan University, Pakistan

*CORRESPONDENCE
Lei Xiao
leisureostrich@126.com

SPECIALTY SECTION
This article was submitted to Aging and Public Health, a section of the journal Frontiers in Public Health

RECEIVED 25 October 2022
ACCEPTED 19 December 2022
PUBLISHED 09 January 2023

CITATION
Xiao L, Wu Y and Cao X (2023) The health of the elderly and social security in the context of digital financial inclusion in China.
Front. Public Health 10:1079436.
doi: 10.3389/fpubh.2022.1079436

The health of the elderly and social security in the context of digital financial inclusion in China

Lei Xiao[1]*, Yanyan Wu[1] and Xin Cao[2]

[1]School of Economics and Management, Kunming University, Kunming, Yunnan, China, [2]Pan-Asia Business School, Yunnan Normal University, Kunming, Yunnan, China

KEYWORDS

the health of the elderly, DFI, social security, PSM–DID, policy effects

1. Introduction

China's economy outperforms those of other nations. However, China's population aging issue is getting progressively worse. Due to its rapidly aging population, China's society is under extreme pressure.

According to China's 14th 5-Year Plan, it should create a multitiered, equitable, and sustainable social security system that protects the entire population in city, urban, and rural areas. The growth of the Internet has significantly altered the Chinese financial sector. Consequently, China is gradually making the transition from traditional financial inclusion to digital financial inclusion (DFI). DFI can greatly raise the participation rate in social security. The question remains, then, what the connection is between the health of the elderly and DFI. This article will conduct a discussion on this subject.

2. Literature review

Previous studies generally concentrate on two aspects of how social security affects the health of the elderly.

First, both public pensions and medical insurance may increase the utilization of healthcare services and medical examinations, thus, improving people's health (1–3). Meanwhile, many studies have found that public pensions are positive for the health of the elderly (4–6).

With the growth of DFI in China, its influence cannot be ignored, although few studies have examined how social security affects the health of the elderly in the context of DFI. Therefore, it is important to investigate whether social security has beneficial effects on the health of the elderly in the context of DFI.

Second, concerning the heterogeneity of its impact on the health of the elderly, early research discovered that socioeconomic status inequalities were associated with differences in consumption of health services or health status (7–9). Nevertheless, there is limited evidence on the impact of social security on health among middle-aged and elderly people in rural China. Therefore, social security should be reformed to enhance its positive impact on health (10). Due to China's unique health insurance system, there

are significant gender differences in health coverage, especially among the elderly (11). Although women tend to live longer than men, many studies have shown that they are in poorer health (12–14).

Most scholars have studied how the social security system affects the health of the elderly. Polsky et al. discovered that the occurrence of self-rated good health improves after the elderly join a health insurance plan (15). Card et al. found no significant effect of enrollment in an old-age health insurance plan on mortality (16). Higher levels of trust have a positive effect on individuals' health status (17). By improving their income status, the social security system has a positive impact on the health status of the elderly (18, 19).

Previous studies have offered a comprehensive overview and can be described as follows: (1) Most studies focus on how social security affects the health of the elderly, but they rarely examine how DFI affects the health of the elderly. This study uses instrumental activities of daily living (IADL) and activities of daily living (ADL) to measure the factors that affect the health of the elderly with the use of the Chinese Longitudinal Healthy Longevity Survey (CLHLS) database. (2) Concerning regional heterogeneity, this article categorizes the samples into different groups according to the place of residence of the respondents. (3) The PSM–DID model is used to analyze the various effects of social security on the health of the elderly during various eras of DFI.

3. Data sources and research methodology

3.1. Data sources

First, DFI in China is provided by Peking University Digital Finance Research Center and Ant Financial company. Second, the health level of the elderly is from the four follow-up surveys in CLHLS in 2011 and 2018 conducted by PKU Center for Healthy Aging and Development.

Considering the poor amount of data of those aged above 105 years, data from the elderly aged 65–105 years were selected. After the elimination of missing values and unsuitable answers, 14,887 samples were finally chosen.

3.2. Research methodology

Propensity score matching–difference-in-differences, proposed by Heckman et al. (20), is often used to evaluate the impact of policies in recent years as it can reject endogeneity problems caused by unobservable variables through propensity score matching. Thus, this article selected PSM–DID to solve the endogeneity problems caused by sample self-selection and omitted variables while controlling the different impacts of the observable variables on the treatment and control groups to measure the average treatment effect of the elderly who participate in social security.

3.3. Model setting

The elderly who participated in social security in 2018 were included in the treatment group. In contrast, those who participated in social security in 2011 but did not do so in 2018 were included in the control group. To guarantee the validity of the empirical findings, missing and erroneous data were removed from the dataset. The fundamental structure of the model is as follows:

$$Health_{i,t} = \alpha_0 + \alpha_1 * did_{i,t} + \alpha_2 * Control_{i,t} + \varepsilon_{i,t} \quad (1)$$

where i represents the data for the treatment group and the control group, t represents different time points and the independent variable did_{it} is a difference-in-differences variable such that $did_{it} = treat_{it} * time_{it}$. Referring to the principle of setting the difference-in-differences variable, this article selected the elderly who participated in social security in 2018 as the treatment group. If they participated in social security, $treat_{it} = 1$; otherwise, $treat_{it} = 0$. In addition, this article took the development of DFI in 2018 as the benchmark and assigned $time_{it}$ as 1 in 2018 and 0 in 2011.

The dependent variable is the health of the elderly, which is measured from the two dimensions of IADL and ADL. IADL is formed by the questions included in the questionnaire. We considered those who answered "Yes" to eight questions as having perfect IADL scores (IADL = 1); otherwise, the IADL score is imperfect (IADL = 0). ADL is formed similarly. We regarded those who answered "Yes" to six questions as having perfect ADL scores (ADL = 1); otherwise, the ADL score is imperfect (ADL = 0). Finally, IADL and ADL were summed to form a single health variable: if both IADL and ADL are assigned as 1, the health variable is assigned as 1; otherwise, the health variable is assigned as 0.

Considering the impact of participating in social security and self-reported health, age, income status, marriage status, access to medical care, and the number of children are regarded as individual and family characteristic variables.

4. Regression results

4.1. Matching quality test on samples

We used PSM–DID to evaluate the impact of social security on the health of the elderly in the context of DFI.

After calculating the propensity score using the logit model, we checked the sample matching accuracy. We examined two fundamental propensity score hypotheses. The balance

hypothesis is one of the two fundamental hypotheses. After matching, practically all control variable biases in the treatment and control groups were decreased by more than 50%, which shows that there is no discernible difference in the observable variables between the treatment and control groups.

4.2. Full sample

Supplementary Table 1 shows that social security can significantly improve the health of the elderly at the 1% level in the context of DFI in Model 1 before adding control variables. When other control variables are added (Model 2), social security can still significantly improve the health of the elderly at the 1% level. Moreover, in Model 2, the R-squared increases from 23.3 to 24.6%. After combining Model 1 and Model 2, the $did_{i,t}$ is significantly positive for the health of the elderly, that is, with the development of DFI, the elderly who participate in social security are healthier than those who do not.

4.3. Sex group subsamples

In this section, we categorize the samples into male and female groups and analyze the impact of social security on the health of elderly men and women. The results are shown in Supplementary Table 2.

Supplementary Table 2 reports that social security has different impacts on elderly men and women in terms of the development of DFI. Compared with Model 3 and Model 4, social security is more positive for elderly men (Model 3) than for elderly women (Model 4). Since men are more likely to suffer than women from occupation-related fatty liver disease, strokes, and chronic lung disease, elderly men participate in social security more actively than women. Moreover, the social division of labor caused by traditional gender norms requires men to have better economic status to maintain good health than women, while women's non-market labor is uncompensated and takes a toll on their health.

4.4. Residence subsamples

In this section, we analyze the place of residence subsamples, that is, city, urban, and rural. The regression result of the DID model is shown in Supplementary Table 2.

Supplementary Table 2 shows that for these residence subsamples, after adding the control variables, social security has significantly different impacts on the health of the elderly. By comparing all models, it can be seen that social security has a significantly positive impact on the health of the elderly in all places of residence. However, according to the different impacts of social security on the city, urban, or rural elderly (i.e., Model 5, Model 6, and Model 7), in the context of DFI, it has the most positive impact on the rural elderly. DFI will thus help rural areas improve their public services. Improving basic public services such as education, social security, and medical care will greatly narrow the health gap between urban and rural areas and increase farmers' economic wellbeing. DFI is, therefore, an important form of rural public service infrastructure that can provide rural residents with comprehensive financial services.

Since DFI is obtained by weighing three subindices of health coverage, depth of use, and digitization, we incorporate each subindex of DFI in the model to analyze their impact on the health of the elderly to further explore how to integrate DFI into the pension insurance system in rural areas. The breadth of coverage reflects the degree of coverage of digital financial services. The wider the coverage, the more it helps the elderly to obtain financial services. Depth of use reflects the actual application of DFI with deeper use, indicating that seniors have access to high-quality financial services that meet their different financial needs.

Based on the aforementioned discussion, the local government is advised to expand coverage and deepen the use of digital finance to improve DFI in rural areas. If DFI is improved in rural areas, social security will have a more positive impact on the health of the elderly.

5. Discussion and conclusions

As mentioned previously, our results demonstrate that enhancing the social security system in the context of DFI is positive for the health of the elderly who participate in it. Social security is much more beneficial for elderly men than women and has the most positive impact on the health of those who live in rural areas.

In the context of the Healthy China strategy, improving the health of the rural elderly has attracted much attention from the government and academia. There are significant differences in how to enhance the health of various elderly groups. The government should combine DFI with social security to improve the health of the elderly. Furthermore, since different areas have varying economic development levels and insurance programs, the government should provide financial assistance to the elderly who are in need of social security.

Moreover, the government is required to improve basic services and medical care to support DFI because it is an important form of rural public service infrastructure that offers rural residents access to a full range of financial services, including payments, credit, insurance, and financial management.

Considering that few studies have studied the impact of DFI on the participation rate of the elderly in social security health of the elderly, the aforementioned findings are conducive to advancing the relevant studies in this area and provide a basis for the formulation and implementation of social security policies in the future.

Most studies focus on how social security affects the health of the elderly, while this article focuses on how DFI affects it and analyzes the gender and regional heterogeneity of the influence of DFI on the health of the elderly in different periods in depth.

The limitations of this study are as follows. First, due to the problem of data acquisition, only two periods of data can be sourced. Second, since the educational level of the respondents cannot be accurately obtained, their educational heterogeneity cannot be studied.

Data availability statement

Publicly available datasets were analyzed in this study. This data can be found here: https://opendata.pku.edu.cn/dataset.xhtml?persistentId=doi:10.18170/DVN/WBO7LK&version=2.0.

Author contributions

LX has designed the research and conducted the original analyses. YYW has re-conducted the analyses required by the reviews and made significant contributions to the revision of the paper. XC has participated in the revision of the paper and made significant contributions to the literature review. All authors contributed to the article and approved the submitted version.

Funding

The study was supported by the National Natural Science Foundation of China under Grant No. U2002201 and Scientific Research Fund of Yunnan Provincial Education Department under Grant No. 2022Y770.

Acknowledgments

The authors express their sincere gratitude to the Chinese Longitudinal Healthy Longevity Survey (CLHLS) database.

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.2022.1079436/full#supplementary-material

References

1. Pan J, Lei X, Liu GG. Health insurance and health status: exploring the causal effect from a policy intervention. *Health Econ.* (2016) 25:1389–402. doi: 10.1002/hec.3225

2. Cuong VN. The impact of voluntary health insurance on health care utilization and out of pocket payment: new evidence for Vietnam. *Health Econ.* (2012) 21:946–66. doi: 10.1002/hec.1768

3. Wagstaff A, Lindelow M, Gao J, Xu L, Qian JC. Extending health insurance to the rural population: an evaluation of China cooperative medical scheme. *Health Econ.* (2009) 28:1–19. doi: 10.1016/j.jhealeco.2008.10.007

4. Schatz E, Gómez-Olivé X, Ralston M, Menken J, Tollman S. The impact of pensions on health and wellbeing in rural South Africa: Does gender matter? *Soc Sci Med.* (2012) 75:1864–73. doi: 10.1016/j.socscimed.2012.07.004

5. Cheng LG, Liu H, Zhang Y, Zhao Z. The health implications of social pensions: evidence from China's new rural pension scheme. *J Comp Econ.* (2018) 46:53–77. doi: 10.1016/j.jce.2016.12.002

6. Galiani S, Gertler P, Bando R. Non-contributory pensions. *Labour Econ.* (2016) 38:47–58. doi: 10.1016/j.labeco.2015.11.003

7. Sutton M. Vertical and horizontal aspects of socio-economic inequity in general practitioner contacts in Scotland. *Health Econ.* (2002) 11:537–49. doi: 10.1002/hec.752

8. Wagstaff A, Doorslaer EV. Overall Versus Socioeconomic Health Inequality: a Measurement Framework and Two Empirical Illustrations. *Health Econ.* (2004) 13:297–301. doi: 10.1002/hec.822

9. Miao J, Wu XG. Urbanization, socioeconomic status and health disparity in China. *Health Place.* (2016) 42:87–95. doi: 10.1016/j.healthplace.2016.09.008

10. Ma X, Oshio T. The impact of social insurance on health among middle-aged and older adults in rural China: a longitudinal study using a three-wave nationwide survey. *BMC Public Health.* (2020) 20:1842. doi: 10.1186/s12889-020-09945-2

11. Shu L. The effect of the New Rural Social Pension Insurance program on the retirement and labor supply decision in China. *J Econ Ageing.* (2018) 12:135–50. doi: 10.1016/j.jeoa.2018.03.007

12. Nathanson CA. Illness and the feminine role: a theoretical review. *Soc Sci Med.* (1975) 9:57–62. doi: 10.1016/0037-7856(75)90094-3

13. Paxson CC. Sex differences in morbidity and mortality. *Demography.* (2005) 42:189–214. doi: 10.1353/dem.2005.0011

14. Zhang H, Bagod'Uva T, Van DE. The gender health gap in China: a decomposition analysis. *Econ Human Biol.* (2015) 18:13–26. doi: 10.1016/j.ehb.2015.03.001

15. Polsky D, Doshi JA, Escarce J, Manning W, Paddock SM, Cen L, et al. The health effects of medicare for the near-elderly uninsured. *Health Serv Res.* (2006) 44:926–45. doi: 10.1111/j.1475-6773.2009.00964.x

16. Card D, Dobkin C, Maestas N. The impact of nearly universal insurance coverage on health care utilization: evidence from medicare. *Amer Econ Rev.* (2008) 98:2242–58. doi: 10.1257/aer.98.5.2242

17. d'Hombres B, Rocco L, Suhrcke M, McKee M. Does social capital determine health? Evidence from eight transition countries. *Health Econ.* (2010) 19:56–74. doi: 10.1002/hec.1445

18. Panis CWA. Annuities and retirement well-being. In: Mitchell, O. S., Mitchell, O. S., & Utkus, S. P. eds. *Pension Design and Structure: New Lessons from Behavioral Finance,* New York: Oxford University Press. (2004). doi: 10.1093/0199273391.003.0014

19. Hochman O, Skopek N. The impact of wealth on subjective well-being: a comparison of three welfare-state regimes. *Res Soc Stratification and Mobility.* (2013) 34:127–41. doi: 10.1016/j.rssm.2013.07.003

20. Heckman JJ, Ichimura H, Todd P. Matching as an econometric evaluation estimator. *Rev Econ Studies.* (1998) 65:261–94. doi: 10.1111/1467-937X.00044

frontiers | Frontiers in Public Health

TYPE Original Research
PUBLISHED 13 January 2023
DOI 10.3389/fpubh.2022.1059346

OPEN ACCESS

EDITED BY
Mika Venojärvi,
University of Eastern Finland, Finland

REVIEWED BY
Shazia Rehman,
Pak-Austria Fachhochschule Institute of Applied Sciences and Technology, Pakistan
Lili Zheng,
Central University of Finance and Economics, China

*CORRESPONDENCE
Lifei Gao
✉ lifeigao@btbu.edu.cn

SPECIALTY SECTION
This article was submitted to Aging and Public Health, a section of the journal Frontiers in Public Health

RECEIVED 01 October 2022
ACCEPTED 22 December 2022
PUBLISHED 13 January 2023

CITATION
Wang J, Gao L, Wang G and Hu B (2023) The impact of internet use on old-age support patterns of middle-aged and older adults. *Front. Public Health* 10:1059346. doi: 10.3389/fpubh.2022.1059346

The impact of internet use on old-age support patterns of middle-aged and older adults

Jingyi Wang[1], Lifei Gao[2]*, Guojun Wang[1] and Baibao Hu[3]

[1]School of Insurance and Economics, University of International Business and Economics, Beijing, China, [2]School of Economics, Beijing Technology and Business University, Beijing, China, [3]Sunshine Life Insurance Corporation Limited, Beijing, China

Background: The trend towards low fertility and low mortality is prominant worldwide. The accelerating ageing and the pressure on public pensions are making the "dependent pattern of old-age support", which relies on family and government, unsustainable. It is urgent for people to change their mindset about ageing and to develop a sense of "relying on themselves for oldage support".

Methods: This study incorporates the commercial pension insurance, formal care and the attitude towards independent old-age support pattern into the framework of "independent pattern of old-age support", using the probit regression model and instrumental variables approach to examine the impact of internet use on old-age support patterns of middleaged and older people based on the CGSS 2012–2018 five-period data.

Results: The more frequent internet use increased the likelihood of purchasing commercial pension insurance, accepting formal care, and endorsing independence in later life. The internet can promote the acceptance of independent pattern of old-age support by delivering information and facilitating social interaction.

Discussion: Consistent with previous research, this study finds that internet use can promote the purchase of commercial pension insurance. There are no relevant studies on the impact of internet use on formal care and attitude towards independent old-age support pattern. Our finding provides important empirical and theoretical references for ageing countries to further transform old-age support patterns.

KEYWORDS

internet use, commercial pension insurance, formal care, independent pattern of old-age support, information access, social interaction

Introduction

Humanity is entering an era of longevity characterised by low mortality and low fertility. As ageing and childlessness are increasing, there is a growing concern about the old-age support pattern. Reliance on the family has long been the dominant pattern of ageing. In East Asian cultural circles, the parent-child relationship is at the heart of the family relationship, with children taking the main responsibility for providing old-age support for their parents (1). Spousal relationships are valued more in Europe and America. Older people in these areas generally prefer living with their spouse for mutual care (2), followed by their adult children (3). However, with modernisation and the replacement of the traditional extended family by the nuclear family, older people can no longer rely solely on their families (4). Since World War II, the world has established social security system for the older adults to provide them financial security with the help of the state. However, as the global economy stagnated in the 1970s and the population became increasingly ageing, the sustainability of social security systems was threatened in many countries. The World Economic Forum report 2017 projected that without adjustments to existing pension systems, six countries—Japan, the United States, the United Kingdom, the Netherlands, Canada, and Australia—would have a $224 trillion shortfall in pension savings by 2050 (5). Hence, reliance on the government for old-age support also becomes unviable. Thus, the "dependent pattern of old-age support", which relies on family and

government, is inadequate to cope with the current situation, and it is urgent to transform the old-age support pattern.

The "independent and dependent pattern of old-age supports" are mutually contradictory. Independent pattern of old-age support emphasises the independence of the individual in accessing support in old age. One's personal savings and investments ensure financial support for old age, making the person financially independent. Commercial pension insurance represents a financially independent pattern of old-age support. The pension funds that individuals obtain through commercial pension insurance are essentially their own investments. Unlike the pension, instrumental support such as daily care cannot be provided independently; however, different styles of care can reflect a person's mental independence. The older people's acceptance of care from a non-family member shows their mental independence from family members. Therefore, receiving formal care services in a nursing home or in the community from professional caregivers indicates a mentally independent pattern of old-age support.

Multiple measures were adopted worldwide in recent years to promote a change from dependent to independent pattern of old-age support. The establishment of the Individual Retirement Account in the United States, the Central Provident Fund system in Singapore, and the privatisation of pensions in Chile are initiatives to develop commercial pension insurance. Countries such as Germany, Japan, South Korea, and China have implemented long-term care insurance systems, providing policy guarantees for older people to receive formal care services. However, due to historical factors and cultural traditions, the independent pattern of old-age support is not popular. Among the Organisation for Economic Co-operation and Development countries where private pensions are voluntary, the Czech Republic, Germany, New Zealand, and the United States have the highest rates of private pension coverage, but only at around 50%. In other countries, private pension coverage remains at around 20%, which is a limited complement to public pensions (6). The South Korean conviction in filial responsibility has led to a negative view of institutional care, with 86% of South Koreans believing that frail older people should be cared for by adult children (7). The transition to independent pattern of old-age support requires national policies to create a supportive external environment. People's acceptance is key to an optimised old-age support pattern. It is therefore a common concern worldwide to promote better acceptance of independent pattern of old-age support and to address the current inadequacy of support in old age due to ageing and infantilisation.

The use of the internet in the information age has accelerated the transition of old-age support pattern. In China, as of December 2020, the number of internet users reached 989 million and the internet penetration rate reached 70.4% (8). With the increase in its penetration, the internet has gradually become the main way for people to access information. As the current mainstream communication medium, the internet is characterised by its abundance, rapidity, and interactivity in disseminating information (9). This has caused a profound impact on traditional lifestyles as well as mindsets and has subliminally changed people's choices of old-age support pattern. Existing research suggests that the use of the internet can promote the purchase of commercial pension insurance and increase the independence of individuals in preparing their pension funds (10, 11). However, the impact of internet use on independent pattern of old-age support from other perspectives remain unexplored. It is important to analyse the impact of internet use on the independent pattern of old-age support, which enable us to explore measures to help people live more independently in later life.

In China, family members are still the main source of financial, instrumental, and emotional support for older people (12, 13). However, rapid ageing and declining fertility rates are preventing older people from receiving adequate support from their families. Public pensions, long-term care, and other social services remain inadequate to meet their needs (14). The Chinese government has taken several measures to this end, such as implementing tax-deferred commercial pension insurance and launching a nationwide pilot long-term care insurance system, creating little effect. Lacking knowledge and experience, many Chinese people are still unaware of or unfamiliar with the private pension plan (15). In terms of acceptance of formal care, a survey based on rural older people showed that only 10.8 and 8.5% of older population were willing to go to institutions and community-based care (16). This study takes China, a representative country, as the subject of this research and incorporates commercial pension insurance, formal care, and the attitude towards independent old-age support pattern into the framework of "independent pattern of old-age support". By examining whether and how the use of the internet has influenced the acceptance of independent pattern of old-age support, this study aims to identify effective ways to promote the transformation of the old-age support pattern in China and to provide references for ageing countries worldwide that are facing similar problems.

The remainder of this study is organised as follows. The theory and literature review section gives the theoretical origins of the concept of "independent pattern of old-age support" and reviews the literature on internet use and ageing. The data, variables, and descriptive statistics section describes the data sources and variable selection and performs preliminary descriptive statistical analysis. The methods section describes the measures used in this study. The results section presents the baseline regression results, tests the robustness of the results using a variety of methods, and explores the channels. Finally, the research findings and its relevant discussions, research contributions, further research directions, and policy recommendations are summarised.

Theory and literature review

Independent pattern of old-age support in active ageing

The independence of older people is often mentioned while discussing active ageing. Active ageing is a scientific concept developed in response to the challenges posed by population ageing, emphasising the various positive conditions of old age throughout the ageing process, such as physical health, positive emotional states, social participation, and security (17). "Independence" takes many forms in active ageing. Valuing self-reliance, independence, and personal responsibility is a key theme in New Zealand's implementation of the Active Ageing Strategy. Independence here is a financial concept suggesting that people should be responsible for their personal growth and development and be responsible in financing their own retirement and living a healthy life (18). Additionally, active ageing is concerned with physical functional

independence and mental independence. One of the goals of Ageing in Place, an important strand of active ageing, is to explore technology's utilisation to ensure that older people can achieve independent living when they become disabled, rather than relying on others for care (19). Another important branch of active ageing, successful ageing, emphasises emotional and spiritual adjustment and autonomy, arguing that autonomy and independence can reduce stress and provide purpose and meaning while facing illness (20, 21).

As representatives of financial and mental independence, the purchase of commercial pension insurance and the choice of formal care both reflect active ageing. Apart from enabling older people to access social services such as healthcare, the purchase of commercial pension insurance also enhances their awareness and ability to plan and manage their finances, increasing their financial security, which is crucial to achieving active ageing (22). Receiving formal care in a nursing home or in the community allows older people to receive support and services when there is insufficient support from their children. Choosing formal care also means that older people are less dependent on their children, have a greater ability to maintain social relationships, and could receive emotional support from multiple sources beyond their children (22).

How the internet influences people's views and behaviour

Early media impact studies focused on the impact of the information disseminated by the media on users, such as cultivation theory, which suggests that the content presented by the communication media in modern society can influence people's perception and understanding of the real world to some extent (23). It originated in the study of the television effect and was later extended to a range of other forms of media (24, 25). The internet is currently an extensively used medium. Contrary to traditional media, the internet offers an increasingly interactive media environment that allows users to choose their own media content. This increasingly prominent personalisation would change the way the media influence users (9). However, the internet has not changed the basic principles of cultivation theory (26). The impact of the abundant information available on the internet on users' attitudes and beliefs may increase (27). Personalisation may also increase the cognitive and emotional engagement of media users, which in turn enhances the effect of the internet on people (28). Some studies have shown that the constant political polarisation of views received from extremists on the internet can decrease the political trust among citizens (29). A study on Indian teenagers shows that those who use internet as their main source of information have a highly negative attitude towards Muslims and Islam, which is closely linked to the negative reports of the same in the Western media on internet (30).

Additionally, the highly interactive nature of the internet allows it to affect people's views and behaviour by influencing interpersonal and group interactions. Social information processing theory suggests that two parties communicating online could increase their intimacy through creative use of verbal cues and interaction strategies (31). The internet-enhanced self-representation hypothesis suggests that the internet is perceived as a safe place and therefore people tend to reveal more information to their friends online (32). It allows for closer contact and more frequent interaction between online communicators and enhances offline interaction to a certain extent. Internet offers the opportunity to develop new offline relationships. Some relationships may start online, but usually continue offline or in a mixed media form (33). There is also evidence suggesting that frequent internet users participate in informal social activities and in various voluntary organisations more frequently than others (34). In addition, frequent internet use is positively correlated with community engagement. Members with access to the internet are more engaged and active in the community (35). Herd behaviour can arise naturally when the strength of exogenous social interactions is high (36). Thus, we find that people who interact with each other regularly tend to think and behave similarly (37). Internet has enabled easier communication among people, which can increase the frequency and intensity of herd behaviour and thus have an impact on social attitudes and behaviour.

Internet use, active ageing, and independent pattern of old-age support

Internet use can promote active ageing. As an information medium, older people can obtain health-related knowledge from the internet, thus helping them to maintain the functional literacy skills required to manage health (38, 39). As an important facilitator of interpersonal and group interactions, older people can interact online to build mutually supportive relationships and strengthen ties with family and friends through the internet, thereby reducing people's depressed isolation and increasing perceived social support and connectedness (40, 41). Internet access seems to improve connexions with the outside world, increase the ability and willingness to leave home, and increase the desire to meet others. The internet also offers older people the possibility of participating in diverse activities and increases the frequency of their participation in leisure activities (42, 43).

While the internet promotes active ageing, it is also supposed to increase the acceptance of independent pattern of old-age support, which is an important manifestation of active ageing. Access to insurance information is an important influencing factor in the purchase of commercial pension insurance. Professional, accurate, and comprehensive insurance information on the internet can raise people's awareness and promote the purchase of commercial pension insurance (10, 11). Additionally, people can obtain relevant explicit or implicit information through social interactions (11), and the internet has a facilitating effect on social interactions, thus further promoting the purchase of commercial pension insurance. However, different information on the internet has different effects on the purchase of commercial pension insurance. Positive messages on news portals can encourage people to buy commercial (pension) insurance; however, BBS messages about insurance are usually negative and therefore have a deterrent effect on commercial (pension) insurance participation (44). No evidence currently suggests that internet use promotes the choice of formal care, but studies have shown that the more the older people know about nursing homes, the more likely they are to choose institutional care (45). The information-mediating properties of the internet and its facilitation of social interaction can provide people with relevant information and promote their understanding of formal care. Access to adequate social support from family and friends and participation in various

activities means that relatively more social resources are available to older people, which can increase their sense of security and independence, thus reducing their dependence on their children in old age and increasing their propensity to choose institutional care (46). Support from family and friends as well as opportunities to get involved in social activities can be obtained from the internet. From these perspectives, internet use can increase the acceptance of formal care. However, there are also arguments that individuals with limited family solidarity may have relatively low expectations of their family as a potential source of care and may be more receptive to using nursing homes (47). The internet's facilitation of family's and friend's contact may therefore also dampen the demand for formal care and have a debilitating effect on its acceptance. Hence, the impact of the internet on independent pattern of old-age support is uncertain, and its ultimate effect must be further explored.

Methods

Data and samples

The data are obtained from the Chinese General Social Survey (CGSS) database. China Survey and Data Centre of Renmin University of China surveyed the data. Based on the principle of Probability Proportionate to Size Sampling, 100 county-level units and 5 metropolitan areas, 480 village/residential committees and 12,000 individuals are sampled nationwide in each survey year to collect tracking information on social change trends in urban and rural areas, with data covering 28 provincial administrative units. The CGSS collects information at multiple levels—social, community, family, and individual—with a section specifically asking respondents about their use of the internet and providing a range of information about old-age support patterns in relation to this study. We select people aged 45 and over as the sample based on World Health Organization's definition of the middle-aged and older adults (48). Using five periods of CGSS data from 2012, 2013, 2015, 2017, and 2018, a database containing 31,049 samples is created after removing missing and outlier samples, of which 2012, 2013, 2015, 2017, and 2018 contain 5,700, 5,152, 5,817, 7,472, and 6,908 samples, respectively. It should be noted that the question on formal care only appeared in the 2017 questionnaire and was asked of a random sample of respondents from the total sample. Therefore, we only obtained 2,436 one-year data on this issue.

Variables

Dependent variables

The dependent variable in this study is the individual's acceptance of independent pattern of old-age support. In the CGSS questionnaire, the question "Do you have commercial pension insurance" reflects the respondents' acceptance of financially independent pattern of old-age support. The variable takes a value of 1 if the respondent possesses commercial pension insurance, otherwise takes a value of 0. The question "Who do you think should primarily take care of the elderly in our country?" asks respondents' acceptance of formal care, which is a mentally independent pattern of old-age support. This variable takes the value of 1 if the respondent selected "government, private business/for-profit, non-profit/charity or religious organization" and 0 if the respondent selected "family, relatives or friends". In addition to

TABLE 1 Descriptive statistics results.

Variables	Mean			
	Total (1)	Internet users (2)	Non-Internet users (3)	Mean difference (4)
Commercial pension insurance	0.054	0.111	0.028	−0.084***
Formal care	0.353	0.428	0.305	−0.123***
Attitude towards independent old-age support pattern	0.407	0.470	0.378	−0.092***
Age	60.476	55.836	62.639	6.803***
Gender	0.498	0.520	0.488	−0.032***
Household registration	0.603	0.379	0.707	0.328***
Education	2.440	3.005	2.177	−0.828***
Income	9.323	10.052	8.984	−1.068***
House	1.106	1.161	1.080	−0.081***
SRH	3.301	3.597	3.163	−0.434***
Marital	0.819	0.876	0.792	−0.084***
Child number	2.095	1.486	2.379	0.893***
Basic pension insurance	0.781	0.844	0.752	−0.092***
Basic medical insurance	0.931	0.945	0.925	−0.020***

T-statistic value in parentheses. $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$.

commercial pension insurance and formal care, the CGSS asks about respondents' attitude towards independent old-age support pattern: "Who do you think should be primarily responsible for the old age of elderly people with children?" The option "by the children or the government" represents the dependent pattern of old-age support, while the option "by themselves" represents the independent pattern of old-age support. This variable takes the value one, if the respondent believes that they should be responsible, or 0 if the respondent believes that their children or the government should be responsible. Ultimately, we construct three binary variables "commercial pension insurance", "formal care", and "attitude towards independent old-age support pattern" to indicate whether an individual accepts independent pattern of old-age support.

Independent variables

The independent variable in this study is internet use. Referring to previous studies (49, 50), we use "past year's use of the internet" to reflect the frequency of individual internet use. This variable classifies the frequency of internet use into five levels: "never", "rarely", "sometimes", "often", and "very often", each with a value from 1 to 5, wherein higher level indicates more frequent use of the internet.

Control variables

Based on previous studies (11, 46, 51) on the factors influencing the old-age support patterns, we select gender (male = 1; female = 0), age, household registration (agricultural = 1; non-agricultural = 0), education, logarithm of per capita household income (income), number of properties (house), and self-rated health (SRH) as control variables at the level of individual characteristics. Where SRH is an integer variable with a value between 1 and 5, wherein higher value indicates better health status. Marital status (married = 1; unmarried, divorced or widowed = 0) and number of children are chosen as control variables at the household characteristics level. The coverage of basic medical insurance (yes = 1; no = 0) and basic pension insurance (yes = 1; no = 0) are added as control variables at the level of social characteristics.

Descriptive statistics

The independent variable in this study is a continuous variable with values ranging from 1 to 5. The higher the value, the more frequent the internet use is, and the never-used value is one. This section divides the sample into those who use the internet and those who do not, based on whether the frequency of internet use is greater than one. By conducting descriptive statistics on different groups, we initially explore the influence of the frequency of internet use on independent pattern of old-age support. The results of the descriptive statistics are shown in Table 1.

Table 1 shows the differences in sample means between the variables for the full sample, internet users, and non-users. According to columns (1–3), in terms of commercial pension insurance, the proportion of people in the whole sample who have purchased commercial pension insurance is higher than non-internet users and lower than internet users. In terms of formal care, the proportion of people accepting formal care in the overall sample is higher than non-users and lower than internet users. In terms of attitude towards independent old-age support pattern, the proportion of people in the overall sample who believe that they should be responsible for their own ageing is higher than non-users and lower than internet users. As shown in column (4), the proportion of the internet users who accepts independent pattern of old-age support is significantly higher than that of non-users. From the descriptive statistics, we can tentatively infer that the more frequently the internet is used, the more likely people are to embrace the independent pattern of old-age support. However, the acceptance of independent pattern of old-age support is influenced by many factors and whether there is a significant relationship between the frequency of internet use and the acceptance of independent pattern of old-age support must be confirmed by further empirical analysis.

Probit regression model construction

As the three dependent variables in this study are binary variables, a probit regression model is chosen to analyse the impact of the internet use on the independent pattern of old-age support. The specific expressions are as follows.

$$\Pr(Commercial\ pension\ insurance_i = 1|X_i) = \varnothing(\alpha_0 + \alpha_1 int_i + \sum \alpha_j Control_{ij} + \varepsilon_i) \quad (1)$$

$$\Pr(Formal\ care_i = 1|X_i) = \varnothing(\beta_0 + \beta_1 int_i + \sum \beta_j Control_{ij} + \varepsilon_i) \quad (2)$$

$$\Pr(attitude_i = 1|X_i) = \varnothing(\gamma_0 + \gamma_1 int_i + \sum \gamma_j Control_{ij} + \varepsilon_i) \quad (3)$$

Among them, $Commercial\ pension\ insurance_i$, $Formal\ care_i$, and $attitude_i$ are three dependent variables, which represent whether individuals have purchased commercial pension insurance, whether they accept formal care, and whether they believe that people should be responsible for their own ageing. X_i represents all variables that can affect the independent pattern of old-age support. int_i is the independent variable in this manuscript, representing the frequency of internet use of individual i. $Control_{ij}$ is a set of control variables including the respondent's gender, age, household registration, education level, household income per capita, health status, marital status, number of children, social security possession, and year of interview. $\alpha_1\beta_1\gamma_1$ are the results of interest, reflecting the extent and direction of the impact of internet use on independent pattern of old-age support. ε_i is the random error term.

Results

Baseline regression results

Table 2 demonstrates the specific impact of internet use on the independent pattern of old-age support. Columns (1, 2) show the impact of internet use on commercial pension insurance, columns

TABLE 2 Impact of internet use on independent pattern of old-age support.

Variables	Commercial pension insurance		Formal care		Attitude towards independent old-age support pattern	
	(1)	(2)	(3)	(4)	(5)	(6)
Internet use	0.228***	0.116***	0.115***	0.090***	0.080***	0.032***
	(31.103)	(12.009)	(6.735)	(4.130)	(15.407)	(4.945)
Age		−0.008***		0.018***		0.012***
		(−5.216)		(5.239)		(13.158)
Gender		−0.022		−0.008		−0.091***
		(−0.843)		(−0.140)		(−6.002)
Household registration		−0.267***		−0.329***		−0.257***
		(−8.110)		(−4.747)		(−13.989)
Education		0.144***		0.046		0.104***
		(7.006)		(1.125)		(9.700)
Income		0.071***		0.012		0.010**
		(5.303)		(0.940)		(2.254)
House		0.167***		−0.170***		−0.019
		(9.362)		(−3.410)		(−1.418)
SRH		0.083***		−0.014		−0.009
		(6.477)		(−0.545)		(−1.264)
Marital		0.025		−0.012		0.084***
		(0.662)		(−0.164)		(4.186)
Child number		−0.005		−0.100***		−0.050***
		(−0.385)		(−2.614)		(−6.752)
Basic pension insurance		−0.064*		−0.063		0.073***
		(−1.887)		(−0.869)		(3.851)
Basic medical insurance		−0.216***		−0.069		0.008
		(−4.392)		(−0.631)		(0.276)
Year		0.005				−0.009***
		(0.874)				(−2.687)
Constant	−2.112***	−13.209	−0.622***	−1.161***	−0.383***	17.272**
	(−97.540)	(−1.087)	(−13.770)	(−3.840)	(−31.842)	(2.525)
Obs	31,049	31,049	2,436	2,436	31,049	31,049
R square	0.069	0.114	0.014	0.057	0.006	0.030

T-statistic value in parentheses. $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$.

(3, 4) show the impact of internet use on formal care, and columns (5, 6) show the impact of internet use on attitude towards independent old-age support pattern. The frequency of internet use has a positive and significant effect on the acceptance independent pattern of old-age support. After calculating the marginal effects corresponding to each coefficient, the results show that for every 1 percentage point increase in the frequency of internet use, without controlling for the relevant variables, the probability of purchasing commercial pension insurance, the probability of accepting formal care, and the probability of believing that people should be responsible for their own ageing will increase by 2.3, 4.2, and 3.1 percentage points, respectively. After controlling for relevant variables, for every 1 percentage point increase in the frequency of internet use, the probability of purchasing commercial pension insurance, the probability of accepting formal care, and the probability of believing that people should be responsible for their own ageing will increase by 1.1, 3.2, and 1.2 percentage points, respectively. The results show that more frequent internet use by people may increase their acceptability of the independent pattern of old-age support.

Further analysis

Endogeneity tests

The relationship between individual internet use and the acceptance of independent pattern of old-age support may be

endogenous due to omitted variables and two-way causation. First, difficult-to-measure variables such as respondents' personalities, habits, or ability to accept new things may influence both individual internet use and acceptance of independent pattern of old-age support, thus creating the problem of omitted variables. Second, individuals who embrace independent pattern of old-age support may already have less social support from friends and family offline and therefore must rely on the internet to alleviate their isolation and use it more frequently, leading to a two-way causal problem. This study uses instrumental variables approach to test the endogeneity question.

Referring to the study by Wang, Nie, and Liu (50), we construct a provincial internet penetration variable using the share of internet access ports in the total population in the year surveyed as an instrumental variable for individual internet usage. Internet penetration can influence individual internet use, satisfying the relevance of the instrumental variable. However, internet penetration, as a macro-level figure, does not directly impact the acceptance of independent pattern of old-age support by micro-individuals in the current period. Additionally, referring to Yue, Wang, and Zhang (52), this study calculates the mean value of annual internet usage frequency for people under 45 years old in each province in the database as an additional instrumental variable for individual internet usage. We use a sample of middle-aged and older people aged 45 years and above. According to the peer effect theory, the frequency of internet use by young people can influence the frequency of internet use by middle-aged and older people. However, it has a relatively small impact on the acceptance of independent pattern of old-age support for middle-aged and older people. In addition, as a macro-level variable, this further attenuates the impact on individual's attitude towards old age, satisfying the conditions for selection of the instrumental variable. Table 3 shows the results of the first- and second-stage regressions when internet penetration and the mean value of internet use, are used as instrumental variables. The coefficients of the instrumental variables in the first stage regressions are significantly positive when internet penetration and internet usage mean are used as instrumental variables, and the F-statistic values are all >10, indicating that the instrumental variables have been selected effectively. The results of the second stage of the regression show that after the endogeneity problem is mitigated using instrumental variables, there is still a significant positive relationship between frequency of internet use and independent pattern of old-age support. This is consistent with the findings of the baseline regression.

Robustness tests

Replace independent variables

The baseline regression section uses internet usage frequency to represent an individual's internet usage. The indicator can cover the CGSS sample for all years 2012–2018. Additionally, the CGSS questionnaires for 2017 and 2018 include a series of questions on individuals' internet use from different perspectives. This section therefore tests the robustness of the baseline regression results by replacing the measure of the independent variable "internet use". The independent variables "minutes of internet use" and "internet use or not" are constructed from the question "In the past 12 months, how much time did you usually spend on the internet *via* a computer or various mobile applications each day?" and the question "In the last 6 months, did you go online?" The minutes of internet use is the logarithm of the number of minutes spent online per day. Internet use or not is a binary variable, taking a value of 1 if the internet is used and 0 otherwise. Table 4 shows the regression results after replacing the independent variables. The longer the people use the internet, the more likely they are to accept independent pattern of old-age support. Those who use the internet are more likely to embrace independent pattern of old-age support than those who do not. This is similar to the baseline results.

Replace database

In this section, a replacement database is chosen to test the robustness of the baseline regression results. The China Longitudinal Ageing Social Survey (CLASS) is a survey targeting Chinese people aged 60 and older. It systematically collects data on the social and economic background of China's older adult population, including their use of the internet and their attitude to independent pattern of old-age support. In terms of internet use, CLASS asks respondents about their use of the internet in the past 3 months, using a scale of 1–5 ranging from never to always. Regarding independent pattern of old-age support, CLASS asks respondents about their purchase of commercial pension insurance and their acceptance of formal care. For commercial pension insurance, as with the baseline regression, the value is taken as 1 if the respondent possesses commercial pension insurance, otherwise it is taken as 0. In terms of formal care, the question "Where do you plan to spend most of your time in your old age?" reflects respondents' attitude towards formal care. A value 1 is assigned if the respondent chooses to live in a community day-care station or a nursing home, because this option indicates a high level of acceptance of formal care. If the respondent chooses to live in their own home or in their children's home, which indicates a low level of acceptance of formal care, the variable takes the value of 0. The selection of control variables and the empirical methodology remains consistent with the baseline regression. Table 5 shows the regression results after replacing the database. There is still a significant positive relationship between internet use and independent pattern of old-age support after changing databases. The more frequently people use the internet, the more likely they are to embrace independent pattern of old-age support. This further supports the robustness of the basic regression results.

Channel analysis

The previous results show that internet use can have an impact on independent pattern of old-age support. The more frequently people use the internet, the more likely they are to accept this pattern. What are the pathways through which internet use influences people's acceptance of independent pattern of old-age support? According to cultivation theory, the internet can significantly influence people's perception and understanding of the real world through the information it conveys (23). Additionally, the internet's facilitation of social interaction has led to an increase in the frequency and intensity of herd behaviour (36), further influencing human thoughts and behaviour.

To verify the existence of the two channels, we construct two channel variables, information access and social interaction. The two channel variables are first replaced as dependent variables in the baseline regression to explore the impact of internet use on information access and social interaction. Then they are put into the baseline regression. If the channel makes sense,

TABLE 3 Endogeneity test results.

Variables	Commercial pension insurance		Formal care		Attitude towards independent old-age support pattern	
	First stage	Second stage	First stage	Second stage	First stage	Second stage
Internet use		0.439***		0.470**		0.225***
		(5.114)		(2.496)		(4.198)
Internet penetration	1.087***		1.116***		1.087***	
	(19.546)		(6.063)		(19.546)	
Control	Yes	Yes	Yes	Yes	Yes	Yes
Phase I *F*-test	1,304.55		127.49		1,304.55	
Wald test		14.8		4.63		13.55
Obs	31,049		2,436		31,049	
	Private pension		Formal care		Attitude towards independent old-age support pattern	
	First stage	Second stage	First stage	Second stage	First stage	Second stage
Internet use		0.663***		0.341***		0.322***
		(6.862)		(2.702)		(5.697)
Internet Use_mean	0.284***		0.621***		0.284***	
	(20.520)		(9.145)		(20.520)	
Control	Yes	Yes	Yes	Yes	Yes	Yes
Phase I F-test	1,300.92		133.65		1,300.92	
Wald test		35.03		4.30		28.44
Obs	31,049		2,436		31,049	

T-statistic value in parentheses. $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$.

TABLE 4 The results of replacing independent variables.

Variables	Commercial pension insurance		Formal care		Attitude towards independent old-age support pattern	
	(1)	(2)	(3)	(4)	(5)	(6)
Minutes of internet use	0.055***		0.055***		0.029***	
	(5.739)		(3.484)		(4.643)	
Internet use or not		0.212***		0.193***		0.110***
		(4.772)		(2.798)		(3.995)
Control	Yes	Yes	Yes	Yes	Yes	Yes
Obs	14,380	14,380	2,436	2,436	14,380	14,380
R square	0.111	0.109	0.056	0.055	0.032	0.032

T-statistic value in parentheses. $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$.

the following two conditions should be met: 1. Internet use is able to have a significant effect on both channel variables; 2. The coefficients on the channel variables are significant and as expected when the two channel variables are included in the baseline regression, and the main independent variable, internet use, is less significant or its coefficient is significantly smaller (53).

Information access is a binary variable in this study. It takes the value of 1 if the respondent mainly obtains information from the internet, otherwise it takes the value of 0. This variable captures the influence of the information conveyed by the internet on people. This is because people use the internet for various purposes, including study and work and social entertainment (54). Some people may not use the internet to access information. For these people, the information conveyed by the internet has limited impact on them. The influence of information on the internet is stronger for respondents, if their main source of information is the internet.

TABLE 5 The results of replacing the database.

Variables	Commercial pension insurance		Formal care	
	(1)	(2)	(3)	(4)
Internet use	0.221***	0.146***	0.230***	0.174***
	(12.368)	(6.672)	(16.941)	(10.935)
Control	No	Yes	No	Yes
Obs	11,281	11,281	11,281	11,281
R square	0.062	0.100	0.051	0.088

T-statistic value in parentheses. ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.

Contexts of interaction can be classified according to the purpose of the social interaction as work situations,[1] social situations,[2] and daily interactions with acquaintances (55). Based on this definition and the available data, we construct the channel variable of social interaction. This variable measures how often respondents shopped, participated in cultural activities, gathered with relatives, and met with friends during their free time in the past year. All the four activities are integer variables with values between 1 and 5, with higher values representing more frequent participation in the activity. After integration, social interactions are eventually constructed as continuous variables with values ranging from 4 to 20, with higher values being associated with higher frequency of social interactions.

Table 6 shows the results of the channel test. As shown in Table 6, the more frequently the internet is used, the more likely individuals are to obtain information from the internet and the more frequently they participate in social interactions. However, the two channels do not make sense in all cases. The coefficient on information access is significantly positive when the dependent variable is commercial pension insurance, however, insignificant when the dependent variables are formal care and attitude towards independent old-age support pattern. It suggests that access to information *via* the internet can facilitate the purchase of commercial pension insurance, however, does not increase the acceptance of formal care, and has a limited role in promoting an overall transformation in attitude towards old age. The internet's facilitation of social interactions can have a positive and significant effect on the three dependent variables, suggesting that the more frequently individuals participate in social interactions, the more likely they are to purchase commercial pension insurance, to accept formal care, and to agree that people should be independent in their old age. The results show that the internet can promote the purchase of commercial pension insurance through the information it conveys and the social interaction it facilitates. However, increased acceptance of formal care and a change in attitude towards independent old-age support pattern can only be achieved by promoting social interaction.

1 These situations include shopping, business negotiations, work meetings, and attending classes.

2 These situations include parties, balls, and outings.

Discussion

This study classifies old-age support patterns as dependent and independent patterns and for the first time incorporates commercial pension insurance, formal care, and attitude towards independent old-age support pattern into the framework of "independent pattern of old-age support", using longitudinal data on a nationally representative sample in China to investigate whether the use of the internet can promote the acceptance of independent pattern of old-age support. We find that more frequent internet use increases the likelihood of people purchasing commercial pension insurance, accepting formal care, and agreeing that people should be independent in old age. The use of instrumental variables enhances the effect of causal inference, and the robustness of the results is demonstrated by adopting various robustness tests, leading to the conclusion that the internet increases the acceptance of independent pattern of old-age support. There have been studies that classify the patterns of old-age support according to the different providers of financial support and daily care, however, do not emphasise the independence in ageing. These studies are limited to the influence of personal endowments (47), intergenerational support, social security (51), and other factors (56) on the choice of old-age support pattern, and do not examine internet use. Shi Hao et al. conducted a study on the relationship between media use and commercial insurance and found that using the internet can promote the purchase of commercial insurance (57). But the commercial insurance here is commercial medical insurance and not include commercial pension insurance. Some studies have focused on the impact of internet use on the purchase of commercial pension insurance, while the impact of internet use on attitude to formal care and independent pattern of old-age support is unexplored. Wu, Yang, and Yin (10) as well as Wu, Bian, and Nie (11) found that internet use can facilitate people's purchase of commercial pension insurance, which is consistent with the findings of our study.

Additionally, the study focuses on the information-mediated identity and interactive nature of the internet and examines both channels of information access and social interaction at an empirical level. Internet can facilitate the purchase of commercial pension insurance through the information it conveys. People's perceptions can be influenced by the wide range of information available on the internet about commercial pension insurance. This information can motivate individuals to prepare more actively for ageing in a different manner and to increase their purchases of commercial pension insurance (10, 58). Although studies have shown that prior knowledge and familiarity are also important contributors to the use of formal care services (59), we find that information delivered by the internet has a limited impact on formal care acceptance. This may be because the decision to receive formal care involves an evaluation of the conditions of the place of care, caregivers, etc., and relevant information is inadequate in the internet. Social interaction enables more information to be obtained through verbal communication and observational learning (11, 60), complementing the information obtained from the internet. Our findings also suggest that the internet's enhanced effect on social interactions promotes the purchase of commercial pension insurance and increases the acceptance of formal care, prompting a shift towards relying on themselves in old age. As the internet allows for customised information, people who access information on independent pattern

TABLE 6 Channel tests results.

Variables	Information access	Commercial pension insurance	Formal care	Attitude towards independent old-age support pattern
Internet use	0.761***	0.100***	0.077***	0.033***
	(66.597)	(8.471)	(2.908)	(4.017)
Information access		0.095**	0.081	−0.004
		(2.331)	(0.888)	(−0.123)
Control	Yes	Yes	Yes	Yes
Obs	31,049	31,049	2,436	31,049
R square	0.586	0.114	0.058	0.030
Variables	Social interaction	Commercial pension insurance	Formal care	Attitude towards independent old-age support pattern
Internet use	0.276***	0.106***	0.084***	0.030***
	(24.738)	(10.826)	(3.766)	(4.575)
Social interaction		0.039***	0.022*	0.008**
		(6.832)	(1.751)	(2.269)
Control	Yes	Yes	Yes	Yes
Obs	31,049	31,049	2,436	31,049
R square	0.171	0.117	0.058	0.030

T-statistic value in parentheses. $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$.

of old-age support *via* the internet are likely to be people who are already interested and have an open attitude towards it. Those who oppose independent pattern of old-age support may not follow the news about it at all. Therefore, they will not be influenced by the information conveyed through the internet, which will weaken our inferences about information access as a channel to some extent.

There are three limitations to this study. First, non-panel data prevent us from making more effective causal inferences by controlling for individual fixed effects. Second, the small amount of data available for formal care leaves a discrepancy in the persuasiveness of the results obtained compared to other results. Finally, in terms of influence channels, limited by data, we cannot consider the interference of the internet's personalised nature with information access as a channel. Additionally, the inventions using internet technology (40), the reduction of transaction costs by the internet, and the increased availability of insurance (61) are all potential pathways through which the use of the internet can influence the pattern of old-age support. Future studies could use analytics such as big data to produce more precise and specific analysis of the relationship between internet use and independent pattern of old-age support to generate more accurate results. Finding suitable variables to measure the impact of the internet on technological inventions, transaction costs, and insurance availability allows for a more diverse exploration of impact pathways.

Despite these limitations, this study has some theoretical and practical values. First, based on the definition of "independence" in the theory of active ageing, this study for the first time incorporates commercial pension insurance, formal care, and attitude towards independent old-age support pattern into the framework of "independent pattern of old-age support" and investigates the impact of internet use on the old-age support patterns of middle-aged and older people. Second, this study bridges the gap in existing research by demonstrating the impact of internet use on the acceptance of independent pattern of old-age support from different perspectives and exploring the channels. Finally, the findings demonstrate that the use of the internet can promote the acceptance of independent pattern of old-age support. This provides a practical direction for promoting rapid transition and optimisation of ageing and achieving active ageing in the current context of low acceptance of independent pattern of old-age support.

To make better use of the internet to facilitate the transformation of old-age support patterns, first, internet coverage and penetration should be ensured, especially in less developed areas and among the elderly. The government should accelerate the construction of digital infrastructure and increase subsidies for internet funding in poorer areas. Companies should develop user-friendly internet terminal devices to reduce barriers to internet use for older people. Equal, efficient and affordable internet access can help address the digital access divide. Second, the government and companies should focus on using the internet to propagate information about commercial pension insurance, formal care, and other related information to improve internet users' understanding of independent pattern of old-age support. Developing age-friendly digital financial products that are affordable and sustainable to meet the needs of older people. Third, while the society encourages older people to use the internet, it is also important for the elderly to learn to use the internet to obtain and exchange information with a positive, open and accommodating mindset. Fourth, internet regulation should be strengthened to avoid the negative impact of negative and inaccurate information on the acceptance of independent pattern of old-age support.

Data availability statement

Publicly available datasets were analysed in this study. This data can be found here: http://cgss.ruc.edu.cn; http://class.ruc.edu.cn.

Author contributions

JW: conception and design, writing—original draught, and preparation. LG and JW: methodology. LG, JW, GW, and BH: writing—review and editing. GW: funding acquisition. LG and GW: supervision. All authors contributed to the article and approved the submitted version.

Funding

This work was supported by the Major Program Project of National Social Science Foundation of China under Grant numbers 13&ZD042 and 17ZDA090 and the Research Foundation for Youth Scholars of Beijing Technology and Business University.

Conflict of interest

BH was employed by Sunshine Life Insurance Corporation Limited.

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.

Publisher's note

All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

References

1. Gierveld J, Dykstra PA, Schenk N. Living arrangements, intergenerational support types and older adult loneliness in Eastern and Western Europe. *DemRes.* (2012) 27:167–200. doi: 10.4054/DemRes.2012.27.7

2. Mohamad N, Alavi K, Mohamad MS, Aun NSM. Intergenerational support and intergenerational social support among elderly–A short review in Malaysian context. *Procedia Soc Behav Sci.* (2016) 219:513–9. doi: 10.1016/j.sbspro.2016.05.028

3. Lee WK. Living arrangements and informal support for the elderly: Alteration to intergenerational relationships in Hong Kong. *J Intergenerational Relat.* (2004) 2:27–49. doi: 10.1300/J194v02n02_03

4. Cowgill DO. The aging of populations and societies. *Ann Am Acad Pol Soc Sci.* (1974) 415:1–18. doi: 10.1177/000271627441500102

5. Forum WE. *We'll Live to 100-How Can We Afford it?* Available online at: https://www3weforumorg/docs/WEF_White_Paper_We_Will_Live_to_100pdf (2017). (accessed August 20, 2022).

6. Antolin P, Payet S, Yermo J. *Coverage of Private Pension Systems: Evidence and Policy Options. OECD Working Papers on Finance, Insurance and Private Pensions, No. 20.* Paris: OECD (2012).

7. Kim H, Choi WY. Willingness to use formal long-term care services by Korean elders and their primary caregivers. *J Aging Soc Policy.* (2008) 20:474–92. doi: 10.1080/08959420802160444

8. The CNNIC 47th China Statistical Report on Internet Development [Report]. http://www.gov.cn/xinwen/2021-02/03/5584518/files/bd16adb558714132a829f43915bc1c9e.pdf. China Internet Network Information Center (2021).

9. Valkenburg PM, Peter J, Walther JB. Media effects: theory and research. *Annu Rev Psychol.* (2016) 67:315–38. doi: 10.1146/annurev-psych-122414-033608

10. Wu Y, Yang C, Yin ZC. Financial literacy, retirement planning and family insurance decisions. *Econ Perspect.* (2017) 12:86–98.

11. Wu YF, Bian JL, Nie JL. Mass media, social interaction and commercial endowment insurance purchase. *Chin Econ Stud.* (2022) 01:94–106. doi: 10.19365/j.issn1000-4181.2022.01.07

12. Feng Z. Childlessness and vulnerability of older people in China. *Age Ageing.* (2018) 47:275–81. doi: 10.1093/ageing/afx137

13. Hsieh N, Zhang Z. Childlessness and social support in old age in China. *J Cross Cult Gerontol.* (2021) 36:121–37. doi: 10.1007/s10823-021-09427-x

14. Korinek K, Zimmer Z, Gu D. Transitions in marital status and functional health and patterns of intergenerational coresidence among China's elderly population. *J Gerontol B Psychol Sci Soc Sci.* (2011) 66:260–70. doi: 10.1093/geronb/gbq107

15. Niu G, Zhou Y, Gan H. Financial literacy and retirement preparation in China. *Pac Basin Financ J.* (2020) 59:101262. doi: 10.1016/j.pacfin.2020.101262

16. Liu ZW Yu Y, Fang L, Hu M, Zhou L, Xiao SY. Willingness to receive institutional and community-based eldercare among the rural elderly in China. *PLoS ONE.* (2019) 14:e0225314. doi: 10.1371/journal.pone.0225314

17. Fernandez-Ballesteros R. Positive ageing, Objective, subjective, and combined outcomes. *e-J Appl Psychol.* (2011) 7:22–30. doi: 10.7790/ejap.v7i1.238

18. Davey J, Glasgow K. Positive ageing: a critical analysis. *Policy Q.* (2006) 2:21–7. doi: 10.26686/pq.v2i4.4209

19. Sixsmith A, Sixsmith J. Ageing in place in the United Kingdom. *Ageing Int.* (2008) 32:219–35. doi: 10.1007/s12126-008-9019-y

20. Rowe JW, Kahn RL. Human aging: Usual and successful. *Science.* (1987) 237:143–9. doi: 10.1126/science.3299702

21. Crowther MR, Parker MW, Achenbaum WA, Larimore WL, Koenig HG. Rowe and Kahn's model of successful aging revisited: positive spirituality—the forgotten factor. *Gerontologist.* (2002) 42:613–20. doi: 10.1093/geront/42.5.613

22. Nassir S, Leong TW, Robertson T. Positive ageing: elements and factors for design. *Proceedings of the Annual Meeting of the Australian Special Interest Group for Computer Human Interaction.* New York: Association for Computing Machinery (2015). p. 264–8. doi: 10.1145/2838739.2838796

23. Gerbner G. Gross L. *Living with Television: The Violence Profile. The Fear of Crime.* Milton Park: Routledge (2017). p. 169–195. doi: 10.4324/9781315086613-10

24. Vergeer M, Lubbers M, Scheepers P. Exposure to newspapers and attitudes toward ethnic minorities: a longitudinal analysis. *Howard J Commun.* (2000) 11:127–43. doi: 10.1080/106461700246661

25. Williams D. Virtual cultivation: online worlds, offline perceptions. *J Commun.* (2006) 56:69–87. doi: 10.1111/j.1460-2466.2006.00004.x

26. Morgan M, Shanahan J. The state of cultivation. *J Broadcast Electron.* (2010) 54:337–55. doi: 10.1080/08838151003735018

27. Kohut A, Doherty C, Dimock M, Keeter S. In changing news landscape, even television is vulnerable. (flaglerlive.com). *Pew Internet & American Life Project.* (accessed September 9, 2022) (2012).

28. Sundar SS, Jia H, Waddell TF, Huang Y. "Toward a theory of interactive media effects (TIME)," In: *The Handbook of the Psychology of Communication Technology.* (2015). p. 47–86. doi: 10.1002/9781118426456.ch3

29. Hong S, Choi H, Kim TK. Why do politicians tweet? Extremists, underdogs, and opposing parties as political tweeters. *Policy Internet.* (2019) 11:305–23. doi: 10.1002/poi3.201

30. Ahmed S. Media portrayals of Muslims and Islam and their influence on adolescent attitude: an empirical study from India. *J Arab Muslim Media Res.* (2012) 5:279–306. doi: 10.1386/jammr.5.3.279_1

31. Walther JB. Interpersonal effects in computer-mediated interaction: a relational perspective. *Commun Res*. (1992) 19:52–90. doi: 10.1177/009365092019001003

32. Peter J, Valkenburg PM. Adolescents' exposure to sexually explicit internet material and notions of women as sex objects: assessing causality and underlying processes. *J Commun*. (2009) 59:407–33. doi: 10.1111/j.1460-2466.2009.01422.x

33. Lieberman A, Schroeder J. Two social lives: How differences between online and offline interaction influence social outcomes. *Curr Opin Psychol*. (2020) 31:16–21. doi: 10.1016/j.copsyc.2019.06.022

34. Räsänen P. Kouvo A. Linked or divided by the web? Internet use and sociability in four European countries. *Inf Commun Soc*. (2007) 10:219–41. doi: 10.1080/13691180701307461

35. Dutta-Bergman MJ. Access to the internet in the context of community participation and community satisfaction. *New Media Soc*. (2005) 7:89–109. doi: 10.1177/1461444805049146

36. Chang S. Herd behavior, bubbles and social interactions in financial markets. *Stud Nonlinear Dyn*. (2014) 18:89–101. doi: 10.1515/snde-2013-0024

37. Shiller RJ. Conversation, information, and herd behavior. *Am Econ Rev*. (1995) 85:181–5. Available online at: https://www.jstor.org/stable/2117915

38. Kamin ST, Lang FR. Internet use and cognitive functioning in late adulthood: Longitudinal findings from the Survey of Health, Ageing and Retirement in Europe (SHARE). *J Gerontol B Psychol Sci Soc Sci*. (2020) 75:534–9. doi: 10.1093/geronb/gby123

39. Kobayashi LC, Wardle J, von Wagner C. Internet use, social engagement and health literacy decline during ageing in a longitudinal cohort of older English adults. *J Epidemiol Community Health*. (2015) 69:278–83. doi: 10.1136/jech-2014-204733

40. Blaschke CM, Freddolino PP, Mullen EE. Ageing and technology: a review of the research literature. *Br J Soc Work*. (2009) 39:641–56. doi: 10.1093/bjsw/bcp025

41. Heo J, Chun S, Lee S, Lee KH, Kim J. Internet use and well-being in older adults. *Cyberpsychol Behav Soc Netw*. (2015) 18:268–72. doi: 10.1089/cyber.2014.0549

42. Bradley N, Poppen W. Assistive technology, computers and Internet may decrease sense of isolation for homebound elderly and disabled persons. *Technol Disabil*. (2003) 15:19–25. doi: 10.3233/TAD-2003-15104

43. Näsi M, Räsänen P, Sarpila O, ICT. activity in later life: internet use and leisure activities amongst senior citizens in Finland. *Eur J Ageing*. (2012) 9:169–76. doi: 10.1007/s10433-011-0210-8

44. Liu Z, Li W, Zhang T. Internet and private insurance participation. *Int J Fin Econ*. (2022) 27:1495–509. doi: 10.1002/ijfe.2227

45. Jang Y, Kim G, Chiriboga DA, Cho S. Willingness to use a nursing home: a study of Korean American elders. *J Appl Gerontol*. (2008) 27:110–7. doi: 10.1177/0733464807307313

46. Peng XZ, Wang XH. The effects of family structure and personal endowment on older adults' choice of aged care location-analysis based on cohort perspective. *Popul J*. (2021) 43:64–77. doi: 10.16405/j.cnki.1004-129X.2021.01.006

47. Jang Y, Rhee MK, Cho YJ, Kim MT. Willingness to use a nursing home in Asian Americans. *J Immigr Minor Health*. (2019) 21:668–73. doi: 10.1007/s10903-018-0792-8

48. The Whoqol Group. The World Health Organization quality of life assessment (WHOQOL): Development and general psychometric properties. *Soc Sci Med*. (1998) 46:1569–85. doi: 10.1016/S0277-9536(98)00009-4

49. Jin YA, Zhao MH. Internet use and the elderly's active aging in China-a study based on 2016 China Longitudinal aging social survey. *Popul J*. (2019) 41:44–55. doi: 10.16405/j.cnki.1004-129X.2019.06.004

50. Wang XJ, Nie WJ, Liu PC. The Internet usage and individual fertility intention: Based on the perspective of information cost and family intergeneration. *J Fin Econ*. (2021) 47:110–24. doi: 10.16538/j.cnki.jfe.20210715.401

51. Shang QS, Zhao YF. Intergenerational support, social security and rural endowment mode: Empirical analysis based on CHARLS. *Sci Decis Mak*. (2022) 02:68–79. doi: 10.3773/j.issn.1006-4885.2022.02.068

52. Yue W, Wang X, Zhang Q. Health risk, medical insurance and household financial vulnerability. *China Ind Econ*. (2021) 10:175–92. doi: 10.19581/j.cnki.ciejournal.2021.10.009

53. Persico N, Postlewaite A, Silverman D. The effect of adolescent experience on labor market outcomes: the case of height. *J Polit Econ*. (2004) 112:1019–53. doi: 10.1086/422566

54. Whiting A, Williams D. Why people use social media: a uses and gratifications approach. *Qual Mark Res*. (2013) 16:362–9. doi: 10.1108/QMR-06-2013-0041

55. Zheng HS, A. *New Introduction to Sociology. 5th ed*. Beijing: China Renmin University Press (2019).

56. Tao T, Cong C. An analysis of influencing factors on elder's preference for patterns of old-age support: some empirical evidence from Beijing Xicheng district. *Popul Econ*. (2014) 3:15–22. doi: 10.3969/j.issn.1000-4149.2014.03.002

57. Shi H, Gao L, Wang G. How does media use promote the purchase of private medical insurance? A moderated mediation model. *Front Psychol*. (2022) 13:1–15. doi: 10.3389/fpsyg.2022.894195

58. Zhou HZ, Wu MQ. Financial literacy, personal pension preparation and commercial pension insurance decisions policy framework of overcapacity governance. *Fin Econ*. (2020) 3:35–42. doi: 10.19622/j.cnki.cn36-1005/f.2020.03.005

59. Jang Y, Kim G, Hansen L, Chiriboga DA. Attitudes of older Korean Americans toward mental health services. *J Am Geriatr Soc*. (2007) 55:616–20. doi: 10.1111/j.1532-5415.2007.01125.x

60. Li T. Social interaction and investment choice. *Econ Res J*. (2006) 08:45–57.

61. Yang BY, Wu X, Yi XJ. Internet usage and household commercial insurance purchases-Evidence from CFPS. *Ins Stud*. (2019) 12:30–47. doi: 10.13497/j.cnki.is.2019.12.004

frontiers | Frontiers in Public Health

TYPE Original Research
PUBLISHED 26 January 2023
DOI 10.3389/fpubh.2023.1117518

OPEN ACCESS

EDITED BY
Wei Guo,
Nanjing University, China

REVIEWED BY
Victoria Ramos Gonzalez,
Carlos III Health Institute (ISCIII), Spain
Enhong Dong,
Shanghai University of Medicine and Health Sciences, China
Meng Ye,
Chinese Center for Disease Control and Prevention, China

*CORRESPONDENCE
Qinghe Tang
✉ peking301@outlook.com

SPECIALTY SECTION
This article was submitted to Aging and Public Health, a section of the journal Frontiers in Public Health

RECEIVED 06 December 2022
ACCEPTED 09 January 2023
PUBLISHED 26 January 2023

CITATION
Li W, Gui J, Luo X, Yang J, Zhang T and Tang Q (2023) Determinants of intention with remote health management service among urban older adults: A Unified Theory of Acceptance and Use of Technology perspective.
Front. Public Health 11:1117518.
doi: 10.3389/fpubh.2023.1117518

Determinants of intention with remote health management service among urban older adults: A Unified Theory of Acceptance and Use of Technology perspective

Wenjia Li[1], Jingjing Gui[1], Xin Luo[1], Jidong Yang[2], Ting Zhang[3] and Qinghe Tang[4]*

[1]College of Communication and Art Design, University of Shanghai for Science and Technology, Shanghai, China, [2]School of Creativity and Art, Shanghai Tech University, Shanghai, China, [3]School of Design and Art, Shanghai Dianji University, Shanghai, China, [4]Shanghai East Hospital, Tongji University, Shanghai, China

Background: Although older adults health management systems have been shown to have a significant impact on health levels, there remains the problem of low use rate, frequency of use, and acceptance by the older adults. This study aims to explore the significant factors which serve as determinants of behavioral intention to use the technology, which in turn promotes actual use.

Methods: This study took a total of 402 urban older adults over 60 years to explore the impact of the use behavior toward remote health management (RHM) through an online questionnaire. Based on the Unified Theory of Acceptance and Use of Technology (UTAUT), the author adds four dimensions: perceived risk, perceived value, perceived interactivity and individual innovation, constructed an extended structural equation model of acceptance and use of technology, and analyzed the variable path relationship.

Results: In this study, the factor loading is between 0.61 and 0.98; the overall Cronbach's Alpha coefficients are >0.7; The composite reliability ranges from 0.59 to 0.91; the average variance extraction ranges from 0.51 to 0.85, which shows the good reliability, validity, and discriminant validity of the constructed model. The influencing factors of the behavioral intention of the older adults to accept the health management system are: effort expectation, social influences, perceived value, performance expectation, perceived interactivity and perceived risk. Effort expectation has a significant positive impact on performance expectation. Individual innovation positively impacts performance expectation and perceived interactivity. Perceived interactivity and behavioral intention have a significant positive effect on the use behavior of the older adults, while the facilitating conditions have little effect on the use behavior.

Conclusions: This paper constructs and verifies the extended model based on UTAUT, fully explores the potential factors affecting the use intention of the older adult users. According to the research findings, some suggestions are proposed from the aspects of effort expectation, performance expectation, perceived interaction and perceived value to improve the use intention and user experience of Internet-based health management services in older adults.

KEYWORDS

remote health management, behavioral intention, UTAUT, structural equation model, user experience, aging design

1. Introduction

Aging has become one of the major problems faced by all countries in the world. In China, with the increase in the proportion and number of the older adult population, the serious aging, the coexistence of multiple chronic diseases, and the increase in medical expenses, this has brought a heavy burden of older adult care and huge economic challenges to medical institutions, older adults care institutions and even society. The health of the older adults has risen to a national strategic problem, and it is urgent to explore and open up new ways to manage the health of the older adults.

The concept of "health management" was first born in the United States and Canada. It specifically refers to the monitoring of health status, analysis of health data, evaluation and prediction of different populations, proposal of corresponding health plans, intervention and management of various potential risk factors, and supply of professional health guidance and services (1). The management system for the older adults derived from telemedicine (2) is based on Internet of Things, Internet of Systems and wireless body area networks, providing the older adults with an online self-health management platform to realize health information collection, health assessment, health consultation, emergency medical assistance and other functions. It has the advantages of real-time monitoring, two-way data transmission, online communication (3). Although older adults health management systems have been shown to have a significant physical and psychological impact on health levels (4) there remains the problem of low use rate, frequency of use, and acceptance of health management systems by the older adults. Therefore, it is meaningful to construct a health management system based on telemedicine for the older adults at present.

This study will focus on the potential older individuals who can actively use telemedicine, eliminate the special populations with senile dementia, trauma and tumors, and integrate previous studies to divide the health management content into four categories: health monitoring, chronic disease management, rehabilitation management, and accidental injury prevention. The Unified Theory of Acceptance and Use of Technology (UTAUT) is widely used to analyze users' usage behavior and intention. We will make appropriate expansion of the model and analyze the influencing factors of use behavior in older individuals through empirical research. The theoretical background and research hypotheses will be introduced in detail below, the results of the data and the final model will be analyzed, and the findings, significance, limitations, and future prospects of this study will be discussed.

2. Literature overview

2.1. Evolution of health management model and corresponding theoretical research

Health management is a systematic process of comprehensively monitoring, analyzing, evaluating, providing targeted scientific health information and intervening on potential health risk factors for the health of individuals or groups, and planning, organizing, directing, coordinating and controlling information and resources related to human health (5). Health management of the older adults is a relatively new concept derived from the concept of health management. The older individuals are characterized by susceptibility to disease and a high proportion of chronic diseases, and is the key population for health management. Health management of the older adults refers to the comprehensive detection, analysis and evaluation of the health status of the older individuals and groups, and then provide health counseling and guidance to the older adults, develop health risk factor intervention plans for the older adults and carry out the whole process of chronic disease prevention and control, disease diagnosis and treatment, rehabilitation nursing, long-term care, etc. for the older adults.

At present, there have been some studies on the health management of the older adults. Under the multiple burdens of aging and compression of health care resources, the United States government has shifted the focus of health management from "diagnosis and treatment" to "prevention and maintenance." A national health management program, the "Health People1990" program, was developed (6), which set the older adults as a national goal. The United Kingdom and other European countries have followed the relevant approach. The United Kingdom has established a variety of projects such as the National Health Service System and NSF for older people (7). Japan is a country with serious aging and early health management in Asia. The success of "u-Japan Strategy" has brought about the development of telemedicine in Japan (8).

In 1998, China introduced the concept of "health management" and based on the advanced experience of health management in the United States, and initially established a primary health management system from health examination, health file management, health risk assessment, health education, healthy lifestyle guidance, intervention of health risk factors, disease management. At present, most of the representative health management systems rely on Internet, cloud platform and other information and communication technologies, develop and integrate internal and external information resources, deepen the form and degree of cooperation with medical service providers through mobile application (WeChat, etc.) SMS, telephone and other means, and establish a core system for health management business. Nowadays, with the development of science and technology and the mature subdivision of health management, the Internet of Things, 5G network, cloud computing platform, wearable and implantable sensing technology are bringing a brand-new medical ecosystem that can rely on each other to China.

Although the health management system has become a link in the daily life of Chinese people, the search of the relevant literature (9, 10) revealed that there are significant deviations in its acceptance, which are susceptible to various factors such as age, education, income and self-perceived health status. Studies have shown that the applicability of telemedicine to the older adults has not become an obstacle to their acceptance of telemedicine services, and the older adults are very interested in the use of telemedicine services (11). There are many studies on the factors affecting the health acceptance of the older adults abroad, while the Chinese studies are not rich enough in this area. The content of this paper is the acceptance of the new health management model under the integration of telemedicine and the factors that affect the behavioral intention of the older adults to use the remote health management system.

2.2. Definition of telemedicine and its application in older health management

The World Health Organization defines telemedicine as "health care practice using interactive audiovisual and data communication."

This includes the supply of health care services, diagnosis, counseling, treatment, and health education and transfer of medical data (12). Telemedicine is divided into three types: synchronous and asynchronous, data transmission and storage, automatic and robotic telemedicine services (13). As an open, shared and evolving science, telemedicine continuously integrates new advances in information and communication technologies to meet socio-economic development and changing public health needs to achieve the key objectives of providing medical services and information exchange across regions and without time constraints (14).

With the development of various emerging technologies, as well as more powerful and convenient handheld devices (15), telemedicine has achieved the use of intelligent devices to record and upload health data at any time, and conduct information consultation with doctors anytime and anywhere (16). The transformation of telemedicine mode has changed health management from medical institution-led to "patient-centered" (17) individual spontaneous management. In this evolution trend, health management has been smoothly integrated into telemedicine, thus there is a saying of remote health management. Remote health management refers to a new health management model that combines Internet, Internet of Things, cloud computing and other technologies with monitoring equipment, transmits the collected health data to the monitoring platform, analyzes and evaluates the health data of patients through the monitoring platform, and gives individualized reminders, suggestions and interventions according to the health data of patients (18).

According to relevant statistics from the China National Committee on Aging, 75.8% of the older adults suffer from at least one chronic disease (19). This self-health management of chronic diseases in the older adults based on Internet of Things is to extend the coverage of medical services to families, emphasize the degree of individual independent participation on the basis of traditional health management, and shift the focus of monitoring, evaluation, intervention and tracking from medical institutions to families and individuals. With the help of Internet of Things, telemedicine and self-service medical model, older patients with chronic diseases may dynamically collect and analyze physiological signs information through physiological index monitors and health scales, monitor physical conditions in real time, and improve their self-health (20).

Remote rehabilitation is considered to be a means to provide rehabilitation services to patients at home, and its benefits lie in the ability to overcome geographical, physical, and cognitive impairments and compensate for the shortcomings of traditional treatments subject to hospitals (21). Such as remote rehabilitation using wearable muscle sensors and Kinect (22). Accidental injury, unlike common diseases, is physical injuries outside of everyday situations, and the prevention aims to provide personalized assistance services for the older adults in emergency situations (23). Falls tend to be the main cause of fatal and non-fatal injuries in the older adults (24), and remote fall monitoring allows the older adults to receive timely assistance (25). Remote monitoring can also be used to predict sudden hypertension in the older adults under special circumstances (26, 27). And instructional alerts are immediately sent to physicians in case of emergencies (28). Therefore, based on the above analysis, this paper defines telemedicine management in the older adults as health surveillance, chronic disease management, rehabilitation management, and accidental injury prevention.

2.3. Model analysis

The UTAUT theory model which was first proposed by Venkatesh et al. (29) is used in this study. It is a comprehensive model containing eight models and prominent theoretical models, which aims to predict and explain users' behavioral intention to use information technology and their use behavior. The model is composed of four core variables and four moderation variables. The four core variables are performance expectation, effort expectation, social influences and facilitating conditions, and the moderation variables include gender, age, experience, and voluntariness of use, of which performance expectation, effort expectation and social influences directly affect the behavioral intention, and the facilitating circumstances and behavioral intention directly affect the use behavior, and gender, age, voluntariness of use and experience play a moderating role (29). According to research, more than 40% of information technology failures may be due to lack of full recognition of how individuals or organizations accept and use technology, and information technology can better provide services only if it is accepted and used by users (30). The popularization and application of the health management system is not only related to technology and services, but also closely related to the acceptance of the older adults. At present, the use frequency of emerging health management systems by the older adults is not high, and the acceptance of emerging health management systems is far lower than that of other age groups. Therefore, this paper will use the UTAUT model combined with the characteristics of the older adults and health management system to study the factors affecting the behavioral intention of the older adults to use the health management system.

3. Hypothesis and research model

3.1. Model presentation

Acceptance refers to the behavioral intention within the user group to use ICT to accomplish tasks supported by their design. Among them, the Unified Theory of Acceptance and Use of Technology (UTAUT) model is a derived model of the Technology Acceptance Model (TAM) model, which is able to explain 69% of intention technology acceptance, while other models can explain only about 40% of technology acceptance (29). Many scholars have studied technology acceptance using the UTAUT model. Some scholars (31, 32) used modified UTAUT models to analyze health care professionals' acceptance of electronic medical records. Other scholars (33, 34) explored possible influencing factors of mobile medicine using the UTAUT model. Therefore, UTAUT is considered to be the most consistent model mentioned above, and it is also the most active model used in technology acceptance research in the field of healthcare (35). The application of UTAUT model to the acceptance and use of information and communication technologies (ICT) by the older adults within the healthcare domain will expand the understanding of the robustness of the model in explaining the acceptance and use.

To adapt to the research presented here, we will adjust these structures and definitions from the original UTAUT model. The UTAUT model was originally used to measure the acceptance of technology in the organizational environment. When adjusting the measurement factors of the model, the perspective of the older

adults and the background of health care must be considered (36). In this paper, we retain the four core elements in the original UTAUT model: Performance Expectancy (PE), Effort Expectancy (EE), Social Influence (SI), and Facilitating Conditions (FC). The reasons for retaining the core variables are as follows: these four core elements are important indicators of studying users' behavioral intention to use information technology. The original author concluded after validating the UTAUT model in six different organizations that performance expectation, effort expectation, and social influence are direct determinants of behavioral intention, and behavioral intention and facilitating conditions directly affect use behavior, so they are retained (29). The four moderation variables (gender, age, voluntariness of use and experience) are removed from the original model. The reasons for removing the moderation variables are as follows. The subject of this study is the older individuals over 60 years old, whose age is relatively concentrated, so the moderation variable of age is removed; secondly, the development of the older health management system in China is still not very mature, and there is less reference in practical experience and voluntariness of use in terms of acceptance, so the experience and voluntariness of use are not included. In order to more accurately and comprehensively explore the influencing factors of the older adults accepting health management system, four variables of perceived interactivity, perceived value, perceived risk and personal innovation are added according to the characteristics of the older adults and health management system to jointly construct the initial model framework suitable for this study. In order to verify the relationship between performance expectation, effort expectation, social influences, facilitating conditions, perceived risk, perceived value, perceived interactivity, personal innovation and their behavioral intention to use remote health management, we developed a conceptual model based on the UTAUT model outlined in the literature review (Model Figure 1), defining the relevant variables of the model and proposing research hypotheses.

3.2. Formulation of the research hypotheses

3.2.1. Performance expectancy

Performance expectancy refers to the degree to which an individual believes that using the system will help him or her to attain gains in job performance. Performance expectation comes from the perceived usefulness introduced in the original TAM model (29, 37). In the context of telemedicine, usefulness can be regarded as the degree to which the older adults subjectively believe that the use of remote health management systems can improve or help their own health benefits and reduce personal health threats. Of the 116 studies on the relationship between performance expectation and behavioral intention, 93 studies (80%) found a significant relationship between the two (38). The key for users to accept information technology is to perceive the usefulness of technology. The fear that technology does not achieve the expected performance usually leads to the behavior of older individuals unwilling to use the technology (39). Many studies in the medical field have proved that performance expectations have a positive impact on users' behavioral intention (40). When the older adults perceive that the health management system can improve the efficiency of their own health management, which is beneficial to themselves, the behavioral intention is strong. Therefore, the hypothesis is put forward:

H1: Performance expectation has a positive impact on the behavioral intention of the older adults to use remote health management.

3.2.2. Effort expectancy

Effort expectation refers to the degree of ease associated with the use of the system and come from perceived ease of use introduced in the TAM model (29). In this paper, it refers to the degree of ease that the older adults perceive to use the health management system. Previous studies have shown that effort expectation has a strong impact on the extent to which users accept new technologies, especially for the older individuals (41), who tend to encounter more barriers to use new technologies than other ages, and thus tend to have a lower behavioral intention to use new technologies (42). Mohammed-Issa demonstrated that perceived ease of use had a positive effect on perceived usefulness (43). That is the ease of use of telemedicine services by the older individuals strongly affects their behavioral intention to use the service and affects their acceptance behavior (36). If the health management system is simple and easy to operate, the older adults are willing to use it and will be easier to find the usefulness of the management system. Therefore, the hypothesis is put forward:

H2: Effort expectation has a positive impact on the behavioral intention of the older adults to use remote health management.
H3: The effort expectation of the older adults for remote health management positively affects the performance expectation.

3.2.3. Social influence

Social influence refers to the degree to which an individual perceives that important others believe he or she should use the new system (29). It here refers to the extent to which the older adults use health management systems because they are influenced by people around them. Of the 115 studies investigating the relationship between social influence and behavioral intention, 86 studies (75%) found that social influence had a significant impact on behavioral intention (38). In the field of medical health, Lu et al. found that social influence had a positive impact on users' behavioral intention to use information technology (44). Then, in the social environment where the older adults live, their subjective views on new technologies often depend on the evaluation of new technologies by their relatives and friends or children and grandchildren. When they feel support, encouragement or recommendation, the behavioral intention of older adults to use it will be relatively higher, and the older adults will be more willing to try it. Therefore, the hypothesis is put forward:

H4: Social influence has a positive impact on the behavioral intention of the older adults to use remote health management.

3.2.4. Facilitating conditions

Facilitating conditions refer to the degree to which an individual believes that an organizational and technical infrastructure exists to support use of the system (29). In this paper, it refers to the extent

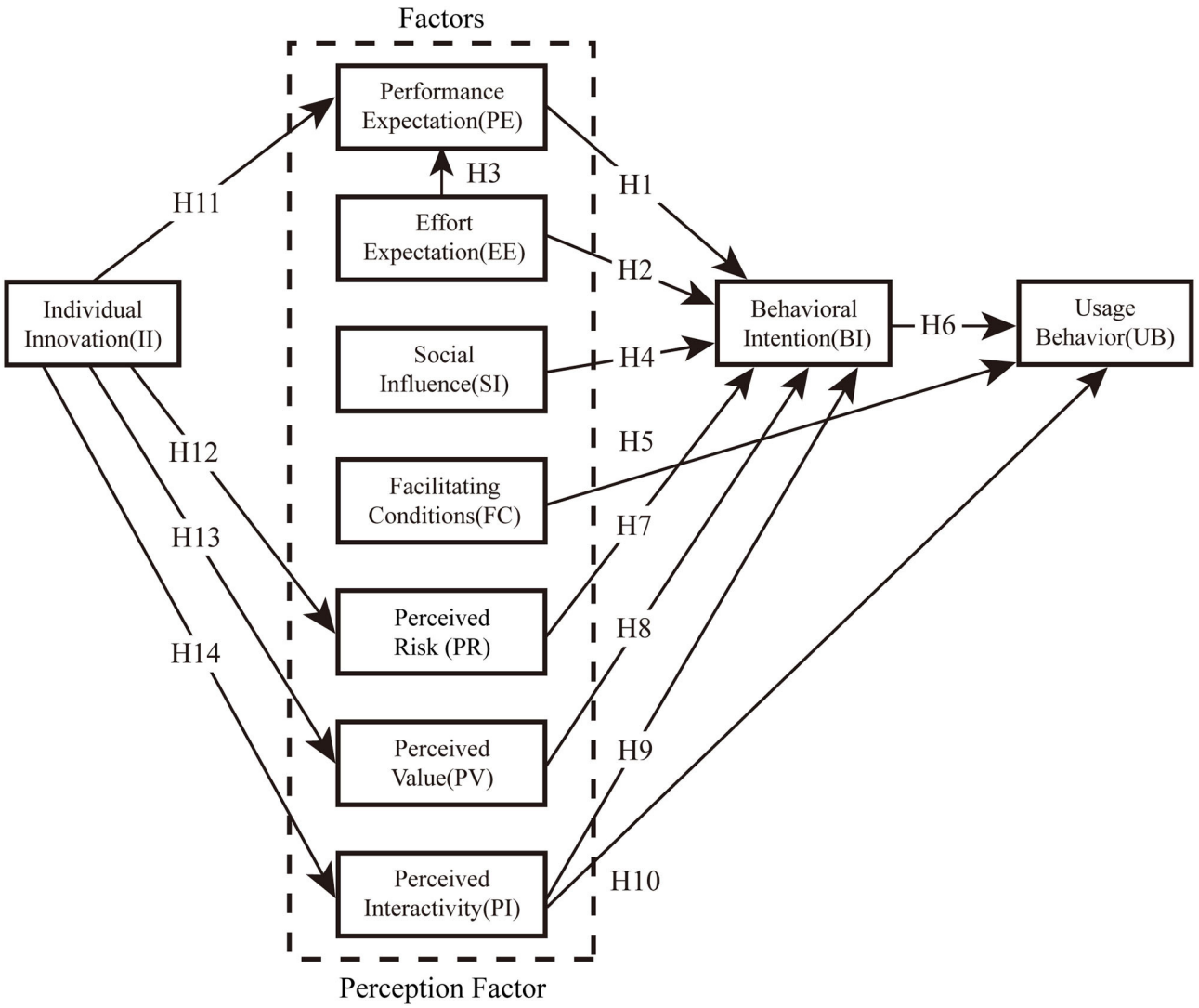


FIGURE 1
The proposed research model.

to which the older adults have conditions that can be supported when using remote health management systems. Williams et al. investigated 54 studies of the relationship between facilitating conditions and behavioral intention and stated that 36 studies (67%) demonstrated a significant impact of facilitating conditions on use behavior (38). Yi et al. demonstrated in their study that facilitating conditions are direct determinants of use behavior of technology (45). The older health management system in this study is a remote online service platform that needs to be used on devices that support networking, and having devices that support the use of health management systems will promote the use of this management system by the older adults. Therefore, the hypothesis is put forward:

H5: Facilitating conditions have a positive impact on the behavior of the older adults to use remote health management.

3.2.5. Behavioral intention

Behavioral intention refers to an indication of an individual's readiness to perform a given behavior. In this paper, it refers to the tendency of the older adults to use the remote health management systems. A review of the UTAUT model shows that of the 61 studies on the relationship between behavioral intention and use behavior, 51 (82%) studies proved that behavioral intention has a positive effect on use behavior (38). Venkatesh et al. (29) empirically demonstrated the significant positive effect of behavioral intention on the use behavior and suggested that behavioral intention is a valid influencing factor of actual use behavior. Therefore, the hypothesis is put forward:

H6: Behavioral intention of the older adults to use health management systems positively impacts their use behavior.

3.2.6. Perceived risk

The original concept of perceived risk comes from psychology. Perceived risk can be understood as uncertainty about the possible adverse consequences of using a product or service. Uncertainty refers to the user's perception of whether a risk will arise when performing a certain behavior, that is, the risk to be taken before the decision is made; adverse consequences mainly refer to the

dangerous consequences resulting from the occurrence of a risk (46). Considering the conservative psychological characteristics of the older adults and the relatively new characteristics of telemedicine, this paper defines the perceived risk as various risks that the older adults may subjectively judge before using telemedicine management, such as money risk, time risk, privacy risk, etc. Wu J et al. pointed out that perceived risk had a significant negative impact on behavioral intention of users, and users would hesitate or doubt due to problems such as asymmetry of information, diversification of information, and redundancy, which played a certain role in hindering the use of new things (47). As an emerging remote service platform, the older adults have various concerns due to technical barriers, which will reduce the behavioral intention to use remote health management systems. Therefore, the relevant hypothesis is put forward:

H7: Perceived risk has a negative impact on the behavioral intention of the older adults to use remote health management.

3.2.7. Perceived value

From the perspective of consumer psychology, the perceived value of consumers was an evaluation of the overall consumption experience of the utility of products or services by consumers by weighing the perceived benefits throughout the consumption process against the costs paid when obtaining products or services (48). Value is a subjective construct, and different people have different perceptions of value. For example, the older adults with chronic diseases will think that the most valuable part of remote health management is chronic disease management, but for the older adults without chronic diseases, daily health monitoring is the most valuable. Several studies in the retail field have demonstrated that the perceived value of users has a positive impact on behavioral intention (49, 50). This paper mainly studies the acceptance of health management systems by the older adults under telemedicine. The older adults are unfamiliar with telemedicine management, and if the older adults predict that the system can meet their needs for health management, it will increase the desire to use the system. Therefore, the hypothesis is put forward:

H8: Perceived value has a positive impact on the behavioral intention of the older adults to use remote health management.

3.2.8. Perceived interactivity

Perceived interactivity is defined as "the extent to which users perceive their experience as a simulation of interpersonal interaction and sense they are in the presence of a social other (51)." McMillan envisioned perceived interactivity as three overlapped dimensions: two-way communication, control of navigation/choices, and time to load/time to find (52). Since this paper explores the influence factors of the older adults' acceptance of remote health management, it is necessary to combine the characteristics that remote health management is a new concept in China, and define the perceived interactivity in this paper as "the information exchange experience that the older adults expect to perceive in the face of remote health management system." Jee and Lee (53) found that there is a positive relationship between perceived interactivity and attitudes toward the website. The older adults often need a straightforward and efficient experience due to physiological and psychological reasons. When they think that the information exchange method of the system is in line with their usage habits, they will be more willing to use the system. Therefore, the hypothesis is put forward:

H9: Perceived interactivity has a positive impact on the behavioral intention of the older adults to use remote health management.
H10: Perceived interactivity has a positive impact on the use behavior of the older adults to use remote health management.

3.2.9. Individual innovation

Individual innovation is the ability of an individual to be good at discovering and accepting new things. It is used to assess an individual's acceptance of new things (54). Individual innovation is an important indicator to measure the acceptance of new products or technologies by users. AI Busaidi found that in the context of e-learning, learners with more innovative spirit had a positive perception and usefulness of e-learning (50). This paper mainly studies the acceptance of health management systems by the older adults under telemedicine. Therefore, the older adults with strong individual innovation are more sensitive to new information technology and more easily accept and adapt to the integration of telemedicine and health management. Such older adults often pay more attention to the development of new technologies and can give feedback on the current development trend or service experience of telemedicine, and their risk perception ability is stronger than that of others. The older adults with strong individual innovation have relatively high operational ability, their interactive experience perception of the new system is also more real, and the tendency of use is higher. Therefore, the hypothesis is put forward:

H11: Individual innovation of patients positively impacts effort expectation of behavioral intention to use remote health management services.
H12: Individual innovation of patients positively impacts perceived risk of behavioral intention to use remote health management services.
H13: Individual innovation of patients positively impacts perceived value of behavioral intention to use remote health management services.
H14: Individual innovation of patients positively impacts perceived risk of behavioral interactivity to use remote health management services.

4. Materials and methods

4.1. Research objects and questionnaire

According to the preset model diagram (Figure 1) and the hypothesis analysis of satisfaction, the study questionnaire of hospital use for patients is divided into two parts. The first part is to collect the basic information and characteristic information of users, including gender, age, educational background, income, frequency of visits, and previous use. The second part is measurement items (Table 1) which are scored on a Likert 5-level scale from 1 to 5 (from strongly disagree to strongly agree). The study was conducted in a level-A tertiary hospital in Shanghai. Before the formal distribution of the

TABLE 1 Measurement items of patient satisfaction research questionnaire.

Construct	Item	Content
Performance expectation	PE1	RHM is helpful for me to judge my health status.
	PE2	The use of RHM can improve the efficiency of my daily health management.
	PE3	The use of RHM can improve the efficiency of medical service visits.
	PE4	The use of RHM services can improve my health level and quality of life.
Effort expectation	EE1	I am easy to accept RHM services.
	EE2	Learning to use RHM is easy for me.
	EE3	The telemedicine services I have been contacted with are easy to operate.
Social influence	SI1	Media publicity will promote my use of RHM.
	SI2	The use and recommendation of people around me (family members, friends and children) will promote my use of RHM.
	SI3	Hospitals, communities and policy implementation will promote my use of RHM.
Facilitating conditions	FC1	I have basic access devices such as smartphones or tablets, and the RHM platform is compatible with my existing devices.
	FC2	I have sufficient knowledge and experience in using Internet.
	FC3	If I encounter problems when using the RHM platform, I can get the necessary support and help.
	FC4	The use of RHM platform is very consistent with my health management method.
Individual innovation	II1	I am always curious about new things.
	II2	I will take the initiative to focus on new information products and technologies.
	II3	I think it is very interesting to try new and emerging products.
	II4	In my circle of friends, I am usually the first to try out new Internet peripherals.
Behavioral intention	BI1	Even if I have no health problems at present, I am willing to use health management services for monitoring and prevention.
	BI2	When I have health problems, I am willing to use RHM service for health management.
	BI3	I would like to recommend RHM service to others.
Usage behavior	UB1	I use RHM for remote rehabilitation.
	UB2	I use RHM for chronic disease management.
	UB3	I use RHM for health monitoring.
	UB4	I use RHM for accidental injury prevention.
Perceived risk	PR1	The use of RHM platform will cause property damage to me.
	PR2	It will take more time to use remote health management platform.
	PR3	I worry that the use of RHM platform will put psychological burden on me.
	PR4	The use of RHM platform will reveal my personal information, privacy and health data.
	PR5	I am worried that the RHM system is not fully functional, which will affect my health.
Perceived value	PV1	The health monitoring services in RHM are valuable to me.
	PV2	The use and recommendation of people around me (family members, friends and children) will promote my use of RHM.
	PV3	The use of RHM platform will put psychological burden on me.
	PV4	I think the accidental injury prevention services in RHM are valuable to me.
Perceived interactivity	PI1	I hope the doctor-patient communication path of the RHM platform is smooth.
	PI2	I hope to interact with other older individuals on the RHM platform.
	PI3	I hope that the structural framework of the RHM platform is reasonably distributed and easy to operate.
	PI4	I hope the visual performance of the RHM platform is clear.

PE, Performance expectation; EE, Effort expectation; SI, Social influence; FC, Facilitating conditions; II, Individual innovation; BI, Behavioral intention; UB, Usage behavior; PR, Perceived risk; PV, Perceived value; PI, Perceived interactivity.
RHM, remote health management.

questionnaire, on-site investigation and interview were conducted in the hospital to correct the unclear questions, and finally a large number of questionnaires were distributed to the target group. Inclusion criteria: (1) patients aged $\geq$ 60 years old; (2) patients who are able to answer the questionnaire independently; (3) patients who provide informed consent and are willing to participate in this study. Exclusion criteria: (1) patients with doctor-patient disputes; (2) critically ill emergency patients. A total of 402 valid questionnaires

were collected, including 249 males (61.9%) and 153 females (38.1%) with 73 years median age (IQR: 72–79). Among the respondents, 106 (26.4%) had education below junior high school, 117 (29.1%) had high school education, and 179 (44.5%) had were college education or above; 194 (48.3%) lived with their spouses, 142(35.3%) lived with their families, and 66 (16.4%) subjects lived alone.

4.2. Data analysis

The internal consistency of the construct was assessed by Cronbach's α reliability (acceptable if >0.7) and structural reliability (acceptable if >0.6) (55, 56). The convergence and discriminant validity of the measurement model were evaluated by confirmatory factor analysis. If all terms' factor loads were significant and >0.50, the convergence effectiveness was verified (57). Structural equation models were used to test hypothetical models. The eight most widely used fitting indexes in SSCI studies were used to evaluate the overall model fit. The ratio between chi-square statistics and the degree of freedom ($\chi^2/df < 3$), the χ^2 chi-square, the approximate root means square error (RMSEA), the normed fit index (NFI), the Tucker–Lewis index (TLI), the comparative fit index (CFI), the goodness of fit index (GFI), and the adjusted goodness of fit index (AGFI) were compared. The evaluation and analysis of the SEM in the present study was completed with AMOS24.0 (IBM Corporation Armonk, NY, USA) and SPSS 26.0 (IBM Corporation Armonk, NY, USA).

5. Results

5.1. Analysis of reliability and validity of data

In this study, the factor loading was between 0.61 and 0.98, showing that each question item had reliability; the overall Cronbach's Alpha coefficients in the study were >0.7, indicating high reliability of the data. The composite reliability (CR) ranged from 0.59 to 0.91, which showed good internal consistency for each construct; the average variance extraction (AVE) ranged from 0.51 to 0.85 (as shown in Table 2), which met the criteria, and therefore, all 10 dimensions had good reliability and convergent validity.

In this study, the rigorous AVE method was used to test the discriminant validity of the measurement model. If the square root of AVE for each construct is larger than the correlation coefficient between the constructs, it indicates that the model has discriminant validity. As shown in Table 3, the root mean square of AVE for diagonal constructs in this study is larger than the correlation coefficient outside the diagonal line, so the majority of constructs in this study have good discriminant validity.

TABLE 2 Reliability and validity analysis of the measurement model in this research.

	Item	Factor load	Cronbach's α	CR	AVE
II	II1	0.944	0.791	0.596	0.852
	II2	0.655			
	II3	0.770			
	II4	0.685			
EE	EE1	0.937	0.772	0.827	0.620
	EE2	0.721			
	EE3	0.680			
PE	PE1	0.984	0.854	0.919	0.740
	PE2	0.817			
	PE3	0.795			
	PE4	0.832			
SI	SI1	0.769	0.788	0.874	0.699
	SI2	0.798			
	SI3	0.932			
BI	BI1	0.931	0.801	0.896	0.743
	BI2	0.732			
	BI3	0.862			
UB	UB1	0.775	0.702	0.806	0.511
	UB2	0.612			
	UB3	0.719			
	UB4	0.744			
FC	FC1	0.782	0.734	0.898	0.787
	FC2	0.826			
	FC3	0.799			
	FC4	0.904			
PR	PR1	0.974	0.843	0.911	0.721
	PR2	0.816			
	PR3	0.761			
	PR4	0.831			
PV	PV1	0.742	0.788	0.862	0.612
	PV2	0.738			
	PV3	0.709			
	PV4	0.923			
PI	PI1	0.645	0.746	0.847	0.591
	PI2	0.677			
	PI3	0.878			
	PI4	0.931			

PE, Performance expectation; EE, Effort expectation; SI, Social influence; FC, Facilitating conditions; II, Individual innovation; BI, Behavioral intention; UB, Usage behavior; PR, Perceived risk; PV, Perceived value; PI, Perceived interactivity.

5.2. Structural model fit

The various fit indexes and allowable ranges as well as the model fit were as follows: Normed Chi-sqr (χ^2/df) had an allowable range of $1 < \chi^2/df < 3$ and a model fit of 2.78; RMSEA had an allowable range of < 0.08 and a model fit of 0.07; NFI had an allowable range of > 0.8 and a model fit of 0.89; TLI had an allowable range of > 0.8 and a model fit of 0.92; CFI had an allowable range of > 0.8 and a model fit of 0.84; GFI had an allowable range of > 0.9 and a model fit of 0.94; and AGFI had an allowable range of > 0.8 and a model fit of 0.92. According to the allowable ranges, each degree of fitting of this model meets the requirement.

TABLE 3 Discriminant validity of the measurement model.

	AVE	FC	SI	II	EE	PI	PV	PR	PE	BI	UB
FC	0.687	0.829									
SI	0.699	0.304	0.836								
II	0.852	0.151	0.129	0.923							
EE	0.620	0.048	0.041	0.321	0.787						
PI	0.591	0.027	0.023	0.182	0.058	0.769					
PV	0.612	0.058	0.049	0.381	0.122	0.069	0.782				
PR	0.721	−0.014	−0.012	−0.093	−0.030	−0.017	−0.036	0.849			
PE	0.740	0.020	0.017	0.132	0.411	0.024	0.050	−0.012	0.860		
BI	0.743	0.045	0.080	0.193	0.067	1.058	0.053	−0.018	0.046	0.862	
UB	0.511	0.739	0.261	0.223	0.074	0.655	0.074	−0.021	0.041	0.640	0.715

PE, Performance expectation; EE, Effort expectation; SI, Social influence; FC, Facilitating conditions; II, Individual innovation; BI, Behavioral intention; UB, Usage behavior; PR, Perceived risk; PV, Perceived value; PI, Perceived interactivity.

5.3. Validation of structural equation model hypothesis

Figure 2 shows the results of the estimated structural model and Table 4 summarizes the results of the hypothesis test. The results of the statistical analysis in this study basically supported the model hypothesis. From the structural path of Figure 2 and the hypothesis test of Table 4, it can be seen that individual innovation has no effect on perceived value and perceived risk, that is, H12 and H13 are invalid. H5 is not supported and facilitating conditions have no effect on applicable behavior. Except this, all other 11 hypotheses are supported. The standardized coefficient indicates that the influencing factors of the behavioral intention of the older adults to accept the health management system are: effort expectation (0.218), social influences (0.150), perceived value (0.129), performance expectation (0.071), perceived interactivity (0.015) and perceived risk (-0.026). At the same time, effort expectation has a significant positive impact on performance expectation. Individual innovation positively impacts performance expectation (0.649) with perceived interactivity (0.486). Perceived interactivity (0.848) and behavioral intention (0.827) have a significant positive effect on the use behavior of the older adults, while the facilitating conditions have little effect on the use behavior.

6. Discussion

6.1. Primary findings

With the rapid increase in demand for health/healthcare information and services, it has led to the global promotion of user-oriented and patient-centered healthcare in the era of information technology. In the global aging wave, telemedicine management systems are expected to play an important role in health care services for the older adults. However, to truly achieve this goal, many aspects, from the design of the application to the factors that affect the behavioral intention, should be carefully considered. In this study, the traditional UTAUT model is extended and four variables are added: individual innovation, perceived risk, perceived value, and perceived interactivity, so that it can more comprehensively explain the complex use behavior of specific populations in specific fields.

Performance expectation, effort expectation and social influences all positively impact the behavioral intention of the older adults to use remote health management in this study. This finding is consistent with previous studies (29, 58). The use of the health management system by the older adults is largely determined by the usefulness of the system itself. In China, traditional medical concepts are deeply rooted in the older adults and also affect the mode of medical treatment. In the system design, let the older individuals perceive that the health management system can improve their own health management efficiency, meet their own actual needs and is beneficial to their own health and is easily to use, the more motivated they are to use it. On the other hand, the perceived usefulness depends on the perceived ease of use, that is, the simpler the technology to use, the more useful it is (59). Telemedicine institutions should pay attention to the cultivation of skills and habits of the older individuals, optimize the process of telemedicine services, improve the perceived ease of use of older individuals, and meet the expectations of the older adults. The older adults live in a social environment, and the impact of society on the older adults cannot be ignored. The interaction between the older adults and their communication groups is one of the factors to encourage the use of health management, and can alleviate the resistance to new technologies brought about by technical pressure (60). When people around them (such as friends, family members and colleagues) mention or use the new system more, the older individuals will be influenced by them and subjectively increase their acceptance of the new system, resulting in their willingness to try, and their behavioral intention to use it will increase.

Perceived value and perceived interactivity positively affect the behavioral intention of the older adults to use remote health management, while perceived risk negatively impacts their behavioral intention to use remote health management. All of these variables reflect the intuitive perception of new technologies in the older individuals. In general, the needs of different older adults for health management are different. The perceived value transmitted by remote health management to the older individuals has a positive impact on the development of remote health management. In order to improve the perceived value, it is necessary to give priority to provide higher value to the older adults and guide the older adults to develop habits. The older adults are relatively sensitive to risk perception. In addition

10.3389/fpubh.2023.1117518

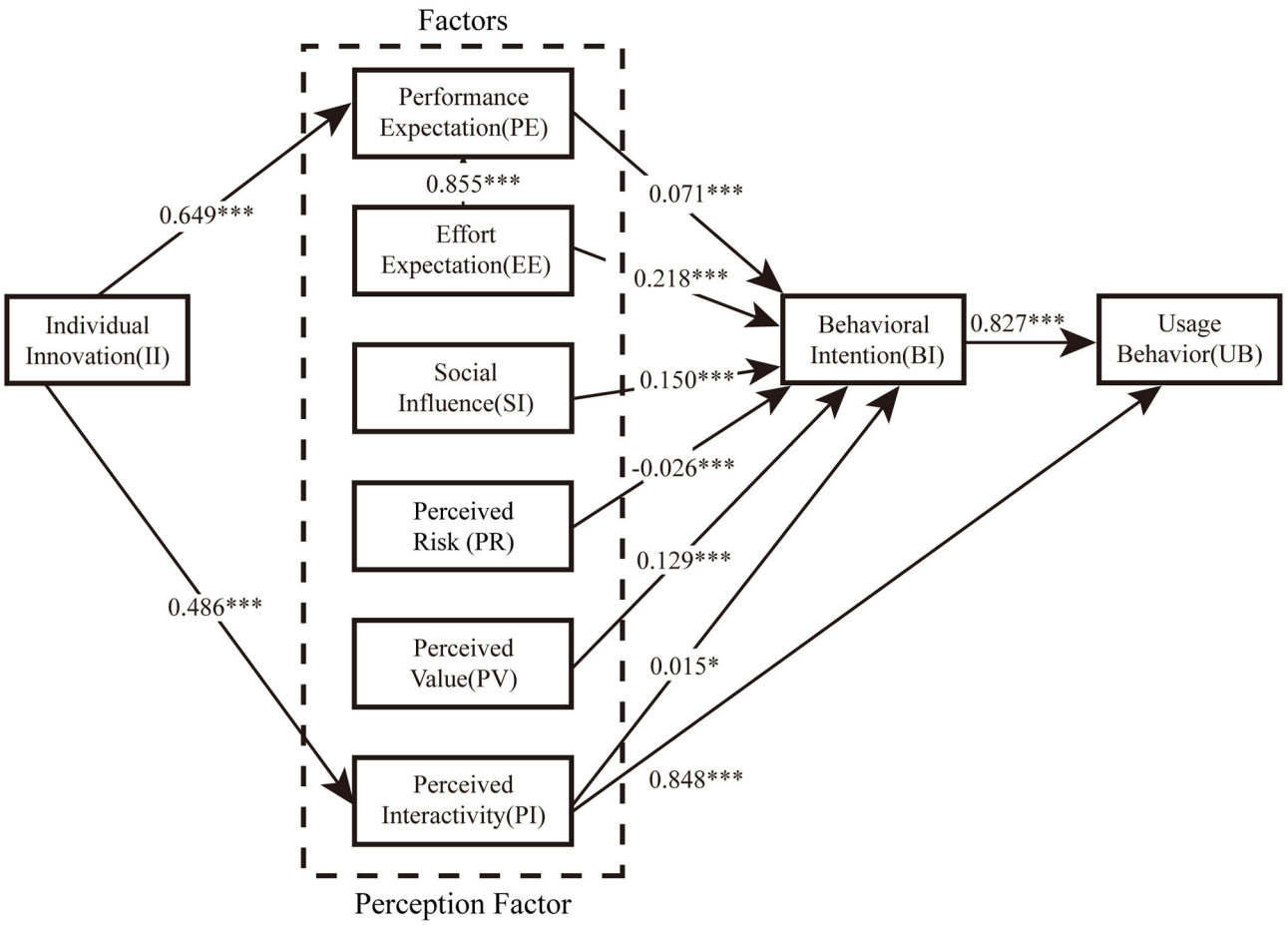


FIGURE 2
The final model with parameter estimates of the significant paths. *$p < 0.05$ and ***$p < 0.001$.

TABLE 4 Path analysis and detection results of the structural model.

Hypotheses	Structure pattern path	Estimate	SE	CR	*p*-value	Supported?
H1	PE→ BI	0.071	0.018	3.867	* * *	Support
H2	EE→ BI	0.218	0.033	6.511	* * *	Support
H3	EE→ PE	0.855	0.225	3.803	* * *	Support
H4	SI→ BI	0.150	0.014	10.661	* * *	Support
H5	FC→ UB	−0.028	0.024	−1.140	0.254	Not support
H6	BI→ UB	0.827	0.086	9.628	* * *	Support
H7	PR→ BI	−0.026	0.009	−2.811	0.005	Support
H8	PV→ BI	0.129	0.022	5.803	* * *	Support
H9	PI→ BI	0.015	0.008	1.906	0.047	Support
H10	PI→ UB	0.848	0.143	5.910	* * *	Support
H11	II→ PE	0.649	0.112	5.769	* * *	Support
H12	II→ PR	−0.179	0.096	−1.857	0.063	Not support
H13	II→ PV	0.240	0.063	3.783	0.061	Not support
H14	II→ PI	0.486	0.109	4.456	* * *	Support

PE, Performance expectation; EE, Effort expectation; SI, Social influence; FC, Facilitating conditions; II, Individual innovation; BI, Behavioral intention; UB, Usage behavior; PR, Perceived risk; PV, Perceived value; PI, Perceived interactivity.

to the security issues related to mobile payment, remote health management also stores a large amount of personal information of the older adults. Some older individuals will be skeptical about the information quality content in the remote health management system, or worry about misdiagnosis or diagnosis and treatment errors in online consultation, which will become hidden dangers affecting the promotion and use of remote health management. The older adults are more inclined to seek objective and verified sources of information, a feature that is more pronounced in technology-related activities. The use habits of the older adults in China are cautious and conservative. The remote health management system is a relatively new thing for them, they have a low trust in new things, and believe that they will experience errors and losses during use. Therefore, for the problems worried by the older adults, measures such as strengthening the construction of health management system and improving laws and regulations can ensure the basic rights and interests of the older adults, reduce their perception of risks, and improve their behavioral intention to use.

Perceived interactivity has previously been less analyzed in the context of telemedicine. In this study, it plays an important role in both behavioral intention and use behavior. Therefore, it is necessary to reflect characteristic services in functional design and interface design, pay attention to providing sufficient information tips for the older adults on the Interaction Point. The design should be conducted from perceived usefulness, perceived safety, perceived ease of use and perceived pleasure, so that users have strong curiosity and strong interest in remote health management service systems and user loyalty may be improved. It is worth noting that innovation in the older adults also affects the use behavior through perceived interactivity. Some older individuals with high acceptance of new things often have higher expectation for the applicability of emerging technologies and pay more attention to the innovation and development of technologies. They are usually eager to stay ahead of others and become the earliest adopters of new products with higher behavioral intention to use the health management system. Therefore, in the process of system popularization and use, we should give full play to the leading role of the older adults with strong individual innovation, and further strengthen the influence of social influences and facilitating conditions.

Unlike previous studies, facilitating conditions in this study do not influence use behavior. The reason for this is that in the current intelligent social situation, the use of smartphones by the older adults is increasing, with the resources and conditions for the use of health management systems; secondly, the population using the health management system is the older adults. The system design for the older adults is relatively simple and easy to operate, as well as the health management system is equipped with operating video and consultation services. In case of difficulties, the older adults can get help. With conditions and resources available, the older adults believe that the conditional factors no longer affect the use of the health management system.

6.2. Value of models in the design of Internet healthcare systems

Based on the technology integration model, perceived interactivity has a significant impact on behavioral intention to use and use behavior, which provides inspiration for optimizing remote health management design and implementation. It should consider the important role of interactive design and user experience in the process of product design of the remote health management system while using related technologies. The design of remote health management mainly starts from the following aspects: firstly, it should perform user analysis for the older individuals with strong individual innovation and high effort expectation to determine their interest preferences and attitude toward the development of telemedicine trends; secondly, it should conduct functional positioning based on performance expectation, and performance positioning of facilitating conditions based on perceived value; thirdly, in the design stage, it should comprehensively consider whether the design system process operation is simple, convenient and efficient based on perceived interactivity, and consider safety issues such as privacy protection, functional perfection, and diagnostic professionalism based on perceived risk.

By integrating UTAUT model and remote health management system design, the influencing factors of behavioral intention to use and subsequent design scheme can be considered in all directions and multiple levels. This model can guide researchers to tap the needs and preferences of older adults groups, so as to accurately grasp user needs, enhance user viscosity, improve service experience, and improve the value of remote health management system. For the functional positioning of remote health management systems, it requires to comprehensively consider task-orientation and social-orientation, simplify the process of using medical services and improve the efficiency of users' visits.

6.2.1. Optimizing the system design from the perspective of interactive design

The interaction process runs through the whole remote health management service. Doctors and patients achieve effective diagnosis and treatment results through the cooperation of software and hardware interaction system. It should optimize the telemedicine service process, so that patients can conveniently obtain telemedicine services, improve the perceived ease of use, and meet the efforts expectation. The design needs to be patient-oriented, from the perspective of "matching" to carry out the design and development of service equipment and systems. It should pay attention to the convenience and interface friendliness of telemedicine terminal service system operation for the adults, and continuously improve the functions and types of telemedicine services.

This study shows that the behavioral intention of the adults to use the remote health management system is largely affected by the effort expectation. In other words, ease of use has a more important impact on whether the adults use the remote health management system. With the increase of age, the adults have different psychological and physiological characteristics from other age groups. The user interface is the medium through which users and machines exchange information with each other, including the input and output of information. On the basis that the user interface and interaction conforming to the physiological characteristics of the adults, designers should also pay attention to the psychological feelings of the older adults during the use process, including cognitive load and user experience. Cognitive load refers to the working memory requirements caused by complex tasks in specific situations that require novel information or novel processing methods (61).

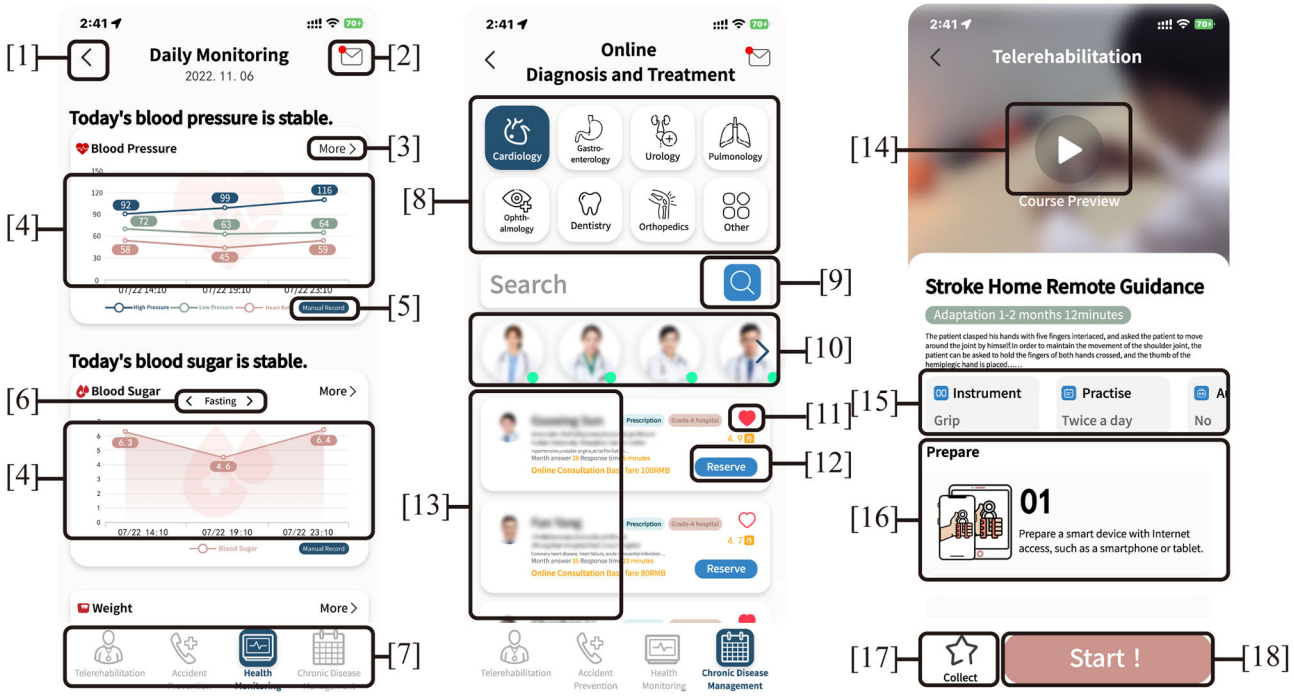


FIGURE 3
Design patterns of Interface: (1–3, 5, 6, 9, 11, 12, 14, 17, 18) assisted navigation buttons, (4) management interface, (7) tab menu, (8) springboard, (10) gallery, (13) lists, (15,16) cards.

It is an important indicator of cognitive feedback in the interactive process. In this paper, it refers to the cognitive processing degree of the adults using remote health management operations. In the design, it is necessary to enhance the acceptance of remote health management by the adults, reduce the cognitive load (62) by using the navigation structure of linear hierarchical navigation (63), and match the operation logic of remote health management with the interactive experience of the inherent linear visual exploration mode of the adults.

Physiologically, due to the decline in tactile sensitivity and muscle control, it will be very difficult for the older adults to complete certain fine movements such as button operations. At the same time, due to visual nerve degeneration and reduced pyramidal cells of the retina, the color identification ability of the adults becomes worse. Psychologically, the older adults believe that the remote health management system is a high-tech product and requires a new knowledge system to control, so there is a widespread technological gap in science and technology. In view of these characteristics, the steps in the use process should be simplified as much as possible to reduce the cognitive burden of older users, so that they can easily use the system; in the necessary information layered design, different colors are used to distinguish functional modules, and color systems with medium brightness and high brightness contrast are used; at the same time, for the fluency of the product, it needs to comprehensively consider finger operation, user thinking and page conversion to ensure smooth connection during operation; the combination of simple one-finger gestures (such as click and drag) with compatible user interface elements (such as buttons and scales) is more helpful for the learning, memory and execution of the system (64). The older individuals have significantly higher subjective preferences for specific type icons (i.e., skeuomorphic) than abstract type icons (i.e., flattened) (65), so when patients input information, it should minimize text input and improve voice input functions; when patients are searching for conditions for chronic disease management, it should provide relevant treatment experience sharing and relevant physical icons and data of the disease. At the same time, emergency medical consultation options or shortcuts should be set up, such as shortcut keys to alarm for help, voice for help, etc., to meet the consultation and rescue needs of some accidental injuries and sudden disease conditions. Meanwhile, the graphic layout of remote health management should respect the flow of sight in the Chinese reading context, especially when designing timelines and other graphic representations with flow direction, it should respect the reading habits of the older adults.

In order to meet the performance expectation, the functional modules mainly come from the requirements of hospitals and social needs, not only including the four core functions used by the older adults: health monitoring, chronic disease management, rehabilitation management, accidental injury prevention, but also considering the user's use habits, user experience, behavioral characteristics and visual effects in order to meet the multi-level needs of remote health management system such as usefulness, ease of use, availability, and convenience. Designers need to solve specific problems in user interface design to lower the cognitive threshold for initial use by the older users, enhance the visibility of current functions in the interface, and provide adequate support to users. The visualization and ease of use of various physiological data have an important impact on the reception and transmission

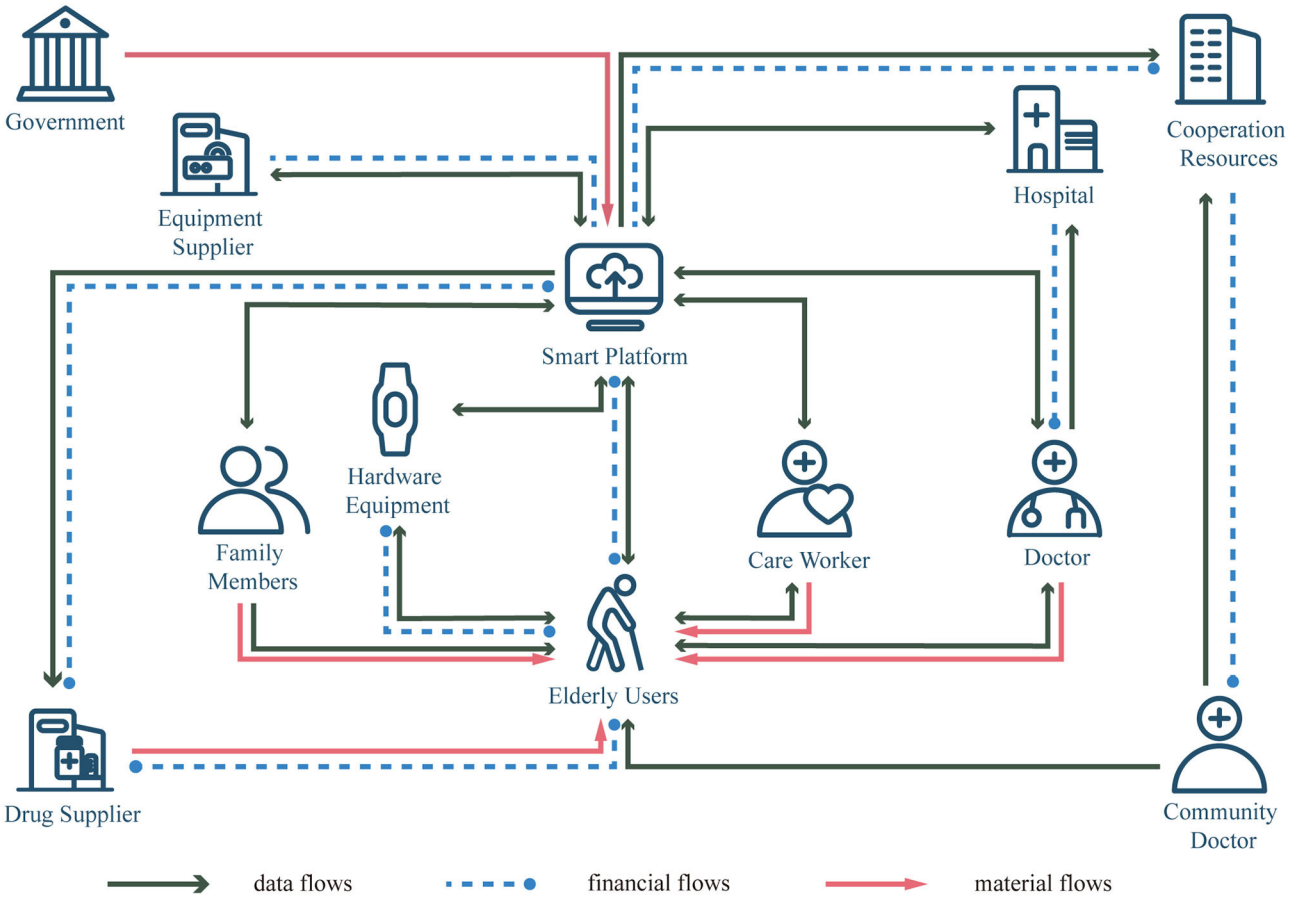


FIGURE 4
The whole interaction process of the telemedicine-based older adults remote health management service system.

of information by both doctors and patients. The operability and comfort of the hardware system are also the basis for efficient communication between both sides. System development designers can organize user interfaces in a meaningful and useful way by putting relevant content together and separating irrelevant content, and dividing different content with different colors and fonts. These optimized hierarchical interfaces can enable users to browse content and use functions in a simpler way. In terms of navigation, the user memory load should be reduced through information visualization and simplified user interface and following a hierarchical structure of step-by-step into details, especially those tasks that require more steps. Designers should clearly display the task status and name of the current interface, and let the user know the progress of the task to enhance the user's control (see Figure 3).

In conclusion, in health management services, it is necessary for patients to feel that the remote health management service systems can optimize the use process and improve the treatment experience, and perceive the value and convenience of the product service experience. Secondly, for the designed management system, some older individuals can be invited to use it, and then continue to explore, improve, innovate, and design a system that satisfies the older adults according to the feedback results of the older adults after use, and continuously improve the emotional design level of the operating system.

6.2.2. Apply the service design concept to remote health management services

Health management is a professional and complex medical service, which involves the systematic association and dynamic management of individuals, families, communities and hospitals. The older adults encounter many problems in the process of health management, and single products or services often fail to meet the diverse needs of older individuals and cannot ensure the continuity of service experience. Service design, as a social frontier system design theory for solving problems systematically, is a design phenomenon that includes tangible and intangible conditions and multiple interactions. It is necessary to integrate tangible products and intangible services into a complete service system to provide effective working ideas for the urban aging health management system. In the service system of older health management, the older adults are both service recipients and service providers, and they can realize their own value while receiving services. Due to the complexity of health management content, in order to meet the multi-dimensional needs of users for chronic disease health management, it is necessary to carry out whole-process design for health management, create service modules with different contents, build a closed-loop of whole-process service experience for sustainable development and all-round management, and provide the older adults users with a whole-life cycle health management program (Figure 4). In the older health management service system, it should mobilize the enthusiasm of

all stakeholders and stimulate creativity through various operations, enhance the viscosity between the system and users, and help all stakeholders establish a lasting and reliable relationship, so as to ensure the sustainable development of the service system, build a closed-loop of whole-process services for sustainable development, and establish a telemedicine-based older remote health management service system.

7. Limitations

Based on the UTAUT model, this study constructs the influence factor model of the acceptance of the health management system for the older adults, and through questionnaire and data analysis, some research conclusions are obtained, but there are still some shortcomings.

Firstly, this study only investigated the older adults attending a level-A tertiary hospital in Shanghai. in Shanghai. Although this group is representative, due to geographical limitations and research resources, fewer users in other provinces and cities are surveyed. In order to ensure that the findings are more general and generalizable, sample size should be expanded in future studies. At the same time, other countries or regions can also be considered to deeply explore the development mode of telemedicine in each country, so as to provide reference for the development of telemedicine in China, and gradually improve the unequal state of medical resources in various regions of China.

Secondly, this study uses a cross-sectional study to identify factors that affect the continuous acceptance of health management systems by the older adults, and later studies can use longitudinal studies to explore the degree of acceptance of the health management system by the older adults over time.

8. Conclusion

With the help of UTAUT model, this paper constructs the behavioral intention model of remote health management for the older adults, makes the research logic clearer and more reasonable, and excavates the new function and perspective of UTAUT model. This research model proves that effort expectation, performance expectation, perceived risk, perceived value and perceived interaction are the important factors that affect the older adults' use of remote health management services. Our findings are conducive to the online health management platform's selection of appropriate business methods and priorities, improvement of the service content and construction, so as to improve the medical experience and promote the use intention of older adult users. At the same time, it provides theoretical support for building a good Internet-based medical platform, which will promote better use of remote health management platform under in the future.

Based on the research results, this paper provides reference and basis for better use of remote health management services by the older adults under the internet environment, which has practical significance for optimizing the uneven distribution of resources in China's medical and health fields. In addition, this research also provides important insights for understanding the acceptance behavior of older adult users in the field of telemedicine and how to improve the older individuals experience from a design perspective.

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 Ethics Committee of Shanghai East Hospital. The patients/participants provided their written informed consent to participate in this study.

Author contributions

WL and JG designed the study question, performed the statistical analyses, and wrote the original version of the manuscript. WL, XL, TZ, and JY performed the investigation. WL, JY, and JG designed the questionnaire and tables. QT was responsible for the overall supervision of the study and the revision of the manuscript. All authors read and approved the final manuscript.

Funding

This study was sponsored by Shanghai Pujiang Program, grant number: 21PJC087.

Acknowledgments

We thank the participants, without whom this study would never have been possible.

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

References

1. Guo H, Zhang M. The experience of foreign elderly health management and its inspiration to our country. *Chin J Health Manag.* (2014) 8:213–4. doi: 10.3760/cma.j.issn.1674-0815.2014.03.020

2. Narasimha S, Madathil KC, Agnisarman S, Rogers H, Welch B, Ashok A, et al. Designing telemedicine systems for geriatric patients: a review of the usability studies. *Telemed e-Health.* (2016) 23:459–72. doi: 10.1089/tmj.2016.0178

3. Sharma D, Singh Aujla G, Bajaj R. Evolution from ancient medication to human-centered healthcare 4.0: a review on health care recommender systems. *J Int J Commun Syst.* (2019) e4058. doi: 10.1002/dac.4058. [Epub ahead of print].

4. Van den M Berg N, Schumann, Kraft W K, Hoffmann. Telemedicine and telecare for older patients—a systematic review. *Maturitas.* (2012) 73:94–114. doi: 10.1016/j.maturitas.2012.06.010

5. Chen J, Huang J. *Health Manager*. Peking: Peking Union Medical College Press. (2007). p.25.

6. Centers for Disease Control and Prevenion. *Healthy People 1990.* (2022). Available online at: https://www.cdc.gov/nchs/healthy_people/hp1990.htm (accessed November 19, 2022).

7. Oliver A. The english national health service: 1979-2005. *Health Econ.* (2005) 14:S75–99. doi: 10.1002/hec.1029

8. Obi T, Ishmatova D, Iwasaki N. Promoting Ict innovations for the ageing population in Japan. *Int J Med Inform.* (2013) 82:e47–62. doi: 10.1016/j.ijmedinf.2012.05.004

9. Fischer SH, David D, Crotty BH, Dierks M, Safran C. Acceptance and use of health information technology by community-dwelling elders. *Int J Med Inform.* (2014) 83:624–35. doi: 10.1016/j.ijmedinf.2014.06.005

10. Hsiao CH, Tang KY. Examining a model of mobile healthcare technology acceptance by the older adults in Taiwan. *J Glob Inf Technol Manag.* (2015) 18:292–311. doi: 10.1080/1097198X.2015.1108099

11. Jones RB, O'Connor A, Brelsford J, Parsons N, Skirton H. Costs and difficulties of recruiting patients to provide e-health support: pilot study in one primary care trust. *BMC Med Inform Decis Mak.* (2012) 12:25. doi: 10.1186/1472-6947-12-25

12. Craig J, Petterson V. Introduction to the Practice of Telemedicine. *J Telemed Telecare.* (2005) 11:3–9. doi: 10.1177/1357633X0501100102

13. Whitten P, Sypher BD. Evolution of telemedicine from an applied communication perspective in the United States. *Telemed e-Health.* (2006) 12:590–600. doi: 10.1089/tmj.2006.12.590

14. Al-Samarraie H, Ghazal S, Alzahrani AI, Moody L. Telemedicine in middle eastern countries: progress, barriers, and policy recommendations. *Int J Med Inform.* (2020) 141:104232. doi: 10.1016/j.ijmedinf.2020.104232

15. Dananjayan S, Raj GM. 5g in healthcare: how fast will be the transformation? *Irish J Med Sci.* (2021) 190:497–501. doi: 10.1007/s11845-020-02329-w

16. Mbunge E, Muchemwa B, Jiyane Se, Batani J. Sensors and healthcare 50: transformative shift in virtual care through emerging digital health technologies. *Glob Health J.* (2021) 5:169–77. doi: 10.1016/j.glohj.2021.11.008

17. Li J, Carayon P. Health care 40: a vision for smart and connected health care. *IISE Trans Healthc Syst Eng.* (2021) 11:171–80. doi: 10.1080/24725579.2021.1884627

18. Manogaran G, Varatharajan R, Lopez D, Kumar PM, Sundarasekar R, Thota C, et al. New architecture of internet of things and big data ecosystem for secured smart healthcare monitoring and alerting system. *Fut Gener Comput Syst.* (2018) 82:375–87. doi: 10.1016/j.future.2017.10.045

19. Wang H, Sun J, Wu S. Research progress on sedentary behavior in elderly patients with chronic disease. *Chin Nurs Res.* (2021) 35:110–4. doi: 10.12102/j.issn.1009-6493.2021.01.019

20. Sun Y, Li W, Ai Y, Zhang D, Liu Y. Construction of health self - management model of older people with chronic diseases based on internet of things. *Chin Gen Pract.* (2014) 17:1164–6+71. doi: 10.3969/j.issn.1007-9572.2014.10.021

21. Klamroth-Marganska V, Giovanoli S, Easthope CA, Schönhammer JG. Telerehabilitation Technology. In: Reinkensmeyer DJ, Marchal-Crespo L, Dietz V, editors. *Neurorehabilitation Technology*. Cham: Springer International Publishing (2022). p. 563–94.

22. Mousavi Hondori H, Khademi M. A review on technical and clinical impact of microsoft kinect on physical therapy and rehabilitation. *J Med Eng.* (2014) 2014:846514. doi: 10.1155/2014/846514

23. Reddy AR, Ghantasala GSP, Patan R, Manikandan R, Kallam S. Smart Assistance of Older Individuals in Emergency Situations at Home. In: Hemanth DJ, Anitha J, Tsihrintzis GA, editors. *Internet of Medical Things: Remote Healthcare Systems and Applications*. Cham: Springer International Publishing. (2021). p. 95–115.

24. Haddad YK, Bergen G, Luo F. Reducing fall risk in older adults. *Am J Nurs.* (2018) 118:21–2. doi: 10.1097/01.NAJ.0000541429.36218.2d

25. Mrozek D, Koczur A, Małysiak-Mrozek B. Fall detection in older adults with mobile iot devices and machine learning in the cloud and on the edge. *Inf Sci.* (2020) 537:132–47. doi: 10.1016/j.ins.2020.05.070

26. Camafort M, Chung WJ, Shin JH. Role of ambulatory blood pressure monitoring in older adults hypertensive patients. *Clin Hypertens.* (2022) 28:22. doi: 10.1186/s40885-022-00205-6

27. Kalid N, Zaidan AA, Zaidan BB, Salman OH, Hashim M, Muzammil H. Based real time remote health monitoring systems: a review on patients prioritization and related "Big Data" using body sensors information and communication technology. *J Med Syst.* (2017) 42:30. doi: 10.1007/s10916-017-0883-4

28. Thite TG, Bhalke DG. Real-time electrocardiogram monitoring for heart diseases with secured internet of thing protocol. *Int J Med Eng Inform.* (2022) 14:391–401. doi: 10.1504/IJMEI.2022.125311

29. Venkatesh V, Morris MG, Davis GB, Davis FD. User acceptance of information technology: toward a unified view. *MIS Q.* (2003) 27:425–78. doi: 10.2307/30036540

30. Kijsanayotin B, Pannarunothai S, Speedie SM. Factors influencing health information technology adoption in Thailand's community health centers: applying the utaut model. *Int J Med Inform.* (2009) 78:404–16. doi: 10.1016/j.ijmedinf.2008.12.005

31. Wills MJ, El-Gayar OF, Bennett D. Examining healthcare professionals' acceptance of electronic medical records using utaut. *Issues Inf Syst.* (2008) 9:396–401. doi: 10.48009/2_iis_2008_396-401

32. Cohen Jason F, Bancilhon JM, Jones M. South African Physicians' Acceptance of E-prescribing technology : an empirical test of a modified utaut model : research article. *South Afr Comput J.* (2013) 50:43–54. doi: 10.18489/sacj.v50i1.175

33. Garavand A, Samadbeik M, Nadri H, Rahimi B, Asadi H. Effective factors in adoption of mobile health applications between medical sciences students using the utaut model. *Methods Inf Med.* (2019) 58:131–9. doi: 10.1055/s-0040-1701607

34. Lee J, Rho MJ. Perception of influencing factors on acceptance of mobile health monitoring service: a comparison between users and non-users. *Healthc Inform Res.* (2013) 19:167–76. doi: 10.4258/hir.2013.19.3.167

35. Ben Arfi W, Ben Nasr I, Khvatova T, Ben Zaied Y. Understanding acceptance of ehealthcare by iot natives and iot immigrants: an integrated model of utaut, perceived risk, and financial cost. *Technol Forecast Soc Change.* (2021) 163:120437. doi: 10.1016/j.techfore.2020.120437

36. Cimperman M, Makovec Brenčič M, Trkman P. Analyzing older users' home telehealth services acceptance behavior—applying an extended utaut model. *Int J Med Inform.* (2016) 90:22–31. doi: 10.1016/j.ijmedinf.2016.03.002

37. Pai FY, Huang KI. Applying the technology acceptance model to the introduction of healthcare information systems. *Technol Forecast Soc Change.* (2011) 78:650–60. doi: 10.1016/j.techfore.2010.11.007

38. Williams MD, Rana NP, Dwivedi YK. The unified theory of acceptance and use of technology (Utaut): a literature review. *J Enterp Inf Manag.* (2015) 28:443–88. doi: 10.1108/JEIM-09-2014-0088

39. Page T. Touchscreen mobile devices and older adults: a usability study. *Int J Hum Factors Ergon.* (2014) 3:65–85. doi: 10.1504/IJHFE.2014.062550

40. Holtz B. Krein S. Understanding nurse perceptions of a newly implemented electronic medical record system. *J Technol Hum Serv.* (2011) 29:247–62. doi: 10.1080/15228835.2011.639931

41. Quaosar GMAA, Hoque MR, Bao Y. Investigating factors affecting older adults' intention to use m-health services: an empirical study. *Telemed e-Health.* (2017) 24:309–14. doi: 10.1089/tmj.2017.0111

42. Choudrie J, Pheeraphuttranghkoon S, Davari S. The digital divide and older adult population adoption, use and diffusion of mobile phones: a quantitative study. *Inf Syst Front.* (2020) 22:673–95. doi: 10.1007/s10796-018-9875-2

43. Jaradat M-IRM, Smadi ZMdA. Applying the technology acceptance model to the introduction of mobile healthcare information systems. *Int J Behav Healthc Res.* (2013) 4:123–43. doi: 10.1504/IJBHR.2013.057363

44. Lu J, Yao JE Yu CS. Personal innovativeness, social influences and adoption of wireless internet services *via* mobile technology. *J Strateg Inf Syst.* (2005) 14:245–68. doi: 10.1016/j.jsis.2005.07.003

45. Yi MY, Jackson JD, Park JS, Probst JC. Understanding information technology acceptance by individual professionals: toward an integrative view. *Inf Manag.* (2006) 43:350–63. doi: 10.1016/j.im.2005.08.006

46. Featherman MS, Pavlou PA. Predicting E-services adoption: a perceived risk facets perspective. *Int J Hum Comput Stud.* (2003) 59:451–74. doi: 10.1016/S1071-5819(03)00111-3

47. Wu J, Li S. The research on users'willingness to use information service in the online health community. *Inf Sci.* (2017) 35:119–25. doi: 10.13833/j.cnki.is.2017.04.022

48. Sánchez-Fernández R, Iniesta-Bonillo MÁ. The concept of perceived value: a systematic review of the research. *Mark Theory.* (2007) 7:427–51. doi: 10.1177/1470593107083165

49. Sweeney JC, Soutar GN, Johnson LW. The role of perceived risk in the quality-value relationship: a study in a retail environment. *J Retail.* (1999) 75:77–105. doi: 10.1016/S0022-4359(99)80005-0

50. Al-Busaidi KAJB, Technology I. An empirical investigation linking learners' adoption of blended learning to their intention of full e-learning. *Behav Inf Technol.* (2013) 32:1168–76. doi: 10.1080/0144929X.2013.774047

51. Thorson KS, Rodgers S. Relationships between blogs as ewom and interactivity, perceived interactivity, and parasocial. *Int J Interact Advert.* (2006) 6:5–44. doi: 10.1080/15252019.2006.10722117

52. McMillan SJ, Hwang JS. Measures of perceived interactivity: an exploration of the role of direction of communication, user control, and time in shaping perceptions of interactivity. *J Advert.* (2002) 31:29–42. doi: 10.1080/00913367.2002.10673674

53. Jee J, Lee WN. Antecedents and Consequences of Perceived Interactivity. *J Interact Advert.* (2002) 3:34–45. doi: 10.1080/15252019.2002.10722066

54. Ye J, Zheng J, Yi F. A study on users' willingness to accept mobility as a service based on utaut model. *Technol Forecast Soc Change.* (2020) 157:120066. doi: 10.1016/j.techfore.2020.120066

55. Ryu E. Model fit evaluation in multilevel structural equation models. *Front Psychol.* (2014) 5:81. doi: 10.3389/fpsyg.2014.00081

56. De Vet HC, Mokkink LB, Mosmuller DG, Terwee CB. Spearman–Brown prophecy formula and Cronbach's alpha: Different faces of reliability and opportunities for new applications. *J Clin Epidemiol.* (2017) 85:45–9. doi: 10.1016/j.jclinepi.2017.01.013

57. Elston RC. *Methods in Molecular Biology Statistical Human Genetics*. New York, NY: Humana New York Press (2017). p. 557–80.

58. Hoque R, Sorwar G. understanding factors influencing the adoption of mhealth by the older adults: an extension of the utaut model. *Int J Med Inform.* (2017) 101:75–84. doi: 10.1016/j.ijmedinf.2017.02.002

59. Mariano J, Marques S, Ramos MR, Gerardo F, Cunha CLd, Girenko A, et al. Too old for technology? Stereotype threat and technology use by older adults. *Behav Inf Technol.* (2022) 41:1503–14. doi: 10.1080/0144929X.2021.1882577

60. Cao Y, Li J, Qin X, Hu B. Examining the effect of overload on the mhealth application resistance behavior of older adults users: an sor perspective. *Int J Environ Res Public Health.* (2020) 17. doi: 10.3390/ijerph17186658. [Epub ahead of print].

61. Sweller J, van Merrienboer JJG, Paas FGWC. Cognitive architecture and instructional design. *Educ Psychol Rev.* (1998) 10:251–96. doi: 10.1023/A:1022193728205

62. Kalimullah K, Sushmitha D. Influence of design elements in mobile applications on user experience of older individuals. *Procedia Comput Sci.* (2017) 113:352–9. doi: 10.1016/j.procs.2017.08.344

63. Shi A, Huo F, Han D. Role of interface design: a comparison of different online learning system designs. *Front Psychol.* (2021) 12:681756. doi: 10.3389/fpsyg.2021.681756

64. Gao Q, Sun Q. Examining the usability of touch screen gestures for older and younger adults. *Hum Factors.* (2015) 57:835–63. doi: 10.1177/0018720815581293

65. Liu H, Wang W, Liu Y, Song F, Wang S, Guo H. Study on the differences of icon cognition of graphical interface for age-friendly design. *J Gerontol Soc Work.* (2022) 1–18. doi: 10.1080/01634372.2022.2139319

frontiers | Frontiers in Public Health

TYPE Original Research
PUBLISHED 03 March 2023
DOI 10.3389/fpubh.2023.1102773

OPEN ACCESS

EDITED BY
Xiangnan Chai,
Nanjing University, China

REVIEWED BY
Hervé Bassinga,
Institut Superieur Des Sciences De La Population, Burkina Faso
Ke Shen,
Fudan University, China

*CORRESPONDENCE
Yating Xie
✉ xyting2013@163.com

SPECIALTY SECTION
This article was submitted to Aging and Public Health, a section of the journal Frontiers in Public Health

RECEIVED 19 November 2022
ACCEPTED 13 February 2023
PUBLISHED 03 March 2023

CITATION
Nan Y, Xie Y and Hu Y (2023) Internet use and depression among Chinese older adults: The mediating effect of interpersonal relationship. *Front. Public Health* 11:1102773. doi: 10.3389/fpubh.2023.1102773

Internet use and depression among Chinese older adults: The mediating effect of interpersonal relationship

Yan Nan[1], Yating Xie[2]* and Yuqun Hu[1]

[1]Department of Social Security, School of Public Policy and Administration, Xi'an Jiaotong University, Xi'an, China, [2]Research Center for Social Governance Innovation, Henan Agricultural University, Zhengzhou, China

The number of elderly Internet users has increased significantly in the past few years, and the Internet has greatly changed the way that older adults access information and communicate. Generally, those who regularly use the Internet may expand their range of interpersonal interactions, which has positive effects on their health. Depression is the leading cause of ill health, and is closely related to people's mental health. We sought to investigate whether internet use help reduce depression level among older adults. Using data from the 2020 China Family Panel Studies (CFPS), a total of 4,714 respondents were included to explore the effects of Internet use on the elderly's depression levels in China, along with the mediating role of interpersonal relationship in the above relationship. Regression results indicated that Internet use significantly reduced depression levels among the elderly. Further analysis showed that different Internet usage had different effects on depression among the elderly. Wechat chatting, video browsing, and online shopping were positively correlated with lower levels of depression. However, playing online games and online learning did not predict reduced levels of depression. Moreover, interpersonal relationship mediated the relationship between Internet use and depression levels. Internet use was associated with a higher level of interpersonal relationship, which in turn reduced depression levels in older adults. Regarding gender and regional differences, the coefficient of Internet use for urban older adults was significantly negative at 0.001 level, while it was not significant for rural older adults. A mediating effect of interpersonal relationship between Internet use and depression levels was only found for male elderly. To reduce the level of depression and promote mental health in the course of aging, Internet use and the improvement of interpersonal relationships merit special attention.

KEYWORDS

Internet use, depression, older adults, interpersonal relationship, Chinese

1. Introduction

As China's population aging continues to deepen, an increasing number of Chinese older adults face health risks (such as loneliness, anxiety, and depression) (1). Depression, one of the most prevalent mental illnesses among the elderly, has a detrimental effect on their health (2). Data from the 2005 Chinese Population 1% Sample Survey showed that 13.6% of urban elderly population suffer from moderate or severe depression. Among the rural elderly, the proportion was 25.5% (3). The prevalence of depression increases with age, which not only impairs the mental and physical functioning of the elderly, leads to impaired cognitive

function, increases the risk of diseases such as heart disease and stroke (4), but also increases the risk of suicide and death (5, 6). Therefore, exploring the mechanism of reducing depression is of great significance to improving the mental health of the elderly and promoting healthy aging.

With the rapid development of Internet technology, the number of Internet users in China was 1.032 billion as of 2021, and the Internet penetration rate reached 73.0%.While the elderly population constitutes a relatively small proportion of this group of netizens, their proportion has continued to grow. The number of elderly netizens aged 60 and above in China has reached 119 million, accounting for 11.5% of the total netizens. The Internet penetration rate of the elderly population aged 60 and above is 43.2% (7). Risk factors for poor mental health among older adults may be potentially impacted by Internet use (8). Existing research shows that Internet use is strongly associated with health and can help reduce social isolation and loneliness among older people (9, 10). But there is uncertainty about the impact of Internet use on depression among older adults. Using a systematic review of quantitative and qualitative evidence, Forsman and Nordmyr (11) reported that Internet use was not associated with depression in 40% of cases. Jun and Hey investigated the effects of Internet use on satisfaction with social relationships and depression among Korean older adults. Their research showed that Internet use did not have direct effects on depression (12). A study on the mental health of older people in England also confirmed this conclusion. Lam et al. concluded that infrequent internet use was predictive of deteriorating life satisfaction but not depression (13). However, some evidence suggested that internet use was found to decrease depression significantly (14). In a survey of retired older adults in the United States, Cotten et al. found that prior internet use reduced the probability of depression by a third in a sample of 3,000 retired adults older than 50 (15). Based on data from the 2018 China Family Panel Studies, Yang et al. found that older Chinese who used the internet reported lower depression scores (16). At the same time, the relationship between Internet use and depression may be influenced by different categories of internet usage. Using data from the 2013 and 2016 waves of the Japan Gerontological Evaluation Study, Nakagomi et al. found that using the Internet to communicate had a protective effect on the probability of developing clinical depression (17). This conclusion was reinforced by other studies. Some literature showed that using the Internet for communication with friends and family was associated with small but reliable decreases in depression. In contrast, health-related internet use was associated with small but reliable increases in depression (18). And by using the Internet to learn, work, and conduct commercial activities, the relief of depression symptoms dissipated (16).

Several studies have explored the mechanisms linking Internet use and depression among older adults. Major and potentially modifiable risk factors for depression among older adults include social isolation, reduced social contact, and lack of emotional support (19). Internet use could reduce depression by promoting older people's social engagement and expanding their social networks, thereby reducing their risk of social isolation (14, 20). However, few studies have examined the role of interpersonal relationships in the association between Internet use and depression. Interpersonal relationship refers to an individual's relationship with others, which reflects the individual's social confidence and preference (21). Interpersonal relationships can be beneficial to health by promoting processes of exploration, personal growth, and goal-striving, all of which are essential to health and wellbeing (22). If people cannot forge a desirable relationship, they will feel isolated and lonely, which will affect their mental health (23). In fact, using the Internet to communicate is one of the key channels for older people to maintain their relationships. It allows them to stay in touch with their social networks, exchange social support and improve their health (15). Additionally, older people who use the Internet will increase their social connections, be more satisfied with the connections, and have better interpersonal relationships (24, 25).

Although some researchers have explored the link between Internet use and depression among older adults and reported mixed results, evidence examining the mechanisms linking Internet use to depression is limited. This study examines how internet use affects depression among Chinese older adults and investigates whether Internet use plays a role in depression by influencing interpersonal relationships. Moreover, the digital gap between urban and rural areas or between women and men in China is huge. Therefore, this paper also considers the heterogeneity of the elderly population in China and analyze the impact of Internet use on depression among different population groups.

2. Data and methodology

2.1. Data

Our data comes from 2020 China Family Panel Studies (CFPS) conducted by the China Social Science Survey Center of Peking University. It reflects the changes in China's society, economy, population, education and health. The project is a national, large-scale, multidisciplinary social tracking exercise. The CFPS sample covers 25 provinces/municipalities/autonomous regions, with a target sample size of 16,000 households, and the respondents include all family members in the sample households. It is a reliable data source for academic research and public policy analysis. The research object of this paper was the elderly. According to the World Health Organization, elderly people are defined as those 60 years of age or older (26). So we excluded the sample of respondents under 60 years old. In addition, we removed observations with missing data on respondents' demographic information. Our final dataset consisted of 4,714 observations.

2.2. Variables and measures

2.2.1. Dependent variable

According to the Chinese version of CES-D, participants were asked about their frequency of depressive symptoms in the past week. The CES-D scale is a commonly used measure of depression symptoms among older adults, which consists of 8 items (27, 28). Sample items include: "I feel depressed in the past week," "I feel it takes a lot of effort to do anything in the past week," " My sleep is

not good in the past week," "I feel happy in the past week," "I feel lonely in the past week," "I live happily in the past week," "I feel sad in the past week ," and question "I feel that life can't go on in the past week." Each item is scored on a scale from 1 (never) to 4 (almost every day). After the order was reversed for items with positive measures, the average score was calculated, the higher the score, the more serious the depression. Cronbach's α for the present sample was 0.78.

2.2.2. Independent variable

In our study, interpersonal relationship refers to the specific state of connection between an individual and others, usually measured by the quality of the relationship. The independent variable was internet use, obtained from the question, "Do you use mobile devices or computers to surf the internet?". The available answers were "Yes" and "No." we assigned 1 to "Yes" and 0 to "No."

2.2.3. Control variables

Referring to the relevant literature (16, 29, 30), we controlled the following variables: gender (Gender), marital status (Marriage), education attainment (Educ), household registration (Hr), retirement (Retirement), Membership of Communist Party of China (Party), self-assessed socio-economic status (Status), self-assessed social class (Class) and physical health (Health). All control variables and their definitions are shown in Table 1.

2.2.4. Mediating variable

The mediating variable was interpersonal relationship. According to Liu's research (21), interpersonal relationship refers to the specific state of connection between an individual and others, usually measured by the quality of the relationship. In this study, interpersonal relationship refers to the universal contact between individuals and others, including both the online relationship and the relationship in real life. Because the use of the Internet may not only have an impact on the online interpersonal relationship, but also may have an impact on the real interpersonal relationship. We measured the mediating variable with the question, "How about your relationship with others?". The available scores ranged from 0 ("Very poor") to 10 ("Very good").

2.3. Data analysis

In this study, all analyses were conducted in Stata 14.0 software. Firstly, we established ordinary least squares (OLS) model as a benchmark model to test the effect of Internet use on depression among the elderly. Secondly, we established propensity score matching (PSM) method to overcome the selective bias of Internet use, and further verified the conclusions of the OLS model to see whether this effect continues to exist. Thirdly, we constructed a mediation model with a bootstrap sample of 5,000 to examine the role of interpersonal relationships in the association between Internet use and depression. Finally, we examined the heterogeneous effect of Internet use on depression in different samples.

TABLE 1 Basic characteristics for variables.

Variables	Category	*N*	Percentage or mean (SD)
Dependent variable			
Depression scores from CES-D8		4,714	1.69
Independent variable			
Internet use	Yes	1,082	22.95%
	No	3,632	77.05%
Mediating variable			
Interpersonal relationship		4,714	7.39
Control variables			
Gender	Female	2,240	47.52%
	Male	2,474	52.48%
Age		4,714	68.12
Marital status	Married or living with a spouse	3,949	83.77%
	Divorced or widowed	765	16.23%
Education attainment	No formal education	1,860	39.46%
	Primary school	1,059	22.46%
	Junior high	1,033	21.91%
	Senior high	625	13.26%
	College or higher	137	2.91%
Household registration	Rural	2,345	49.75%
	Urban	2,369	50.25%
Retirement	Retired	2,545	53.99%
	Unretired	2,169	46.01%
Member of communist party of China	Yes	644	13.66%
	No	4,070	86.34%
Self-assessed socio-economic status		4,714	3.19
Self-assessed social class		4,714	3.48
Physical health		4,714	2.16

3. Empirical results

3.1. Sample details

As shown in Table 1, the mean depression score among the 4,714 older adults was relatively low (mean = 1.69). Of all respondents, 2,240 (47.52%) were women, and 2,474 (52.48 %) were men. The depression score of female seniors was 1.78, slightly higher than that of male seniors (1.62). The average age was 68.12. About 83.77% were married or living with their spouses. The

TABLE 2 The benchmark regression results on internet use and depression.

Variables	Model 1	Model 2
Internet use	−0.171***(0.019)	−0.070***(0.020)
Gender		−0.087***(0.016)
Age		−0.004*(0.001)
Marital status		−0.155***(0.021)
Education attainment		−0.037***(0.008)
Rural/urban residence		−0.124***(0.016)
Retirement		−0.060***(0.017)
Party member status		−0.042(0.023)
Self-assessed socio-economic status		−0.045***(0.008)
Self-assessed social class		−0.033***(0.008)
Physical health		−0.167***(0.008)
Constant	1.734***(0.009)	2.898***(0.108)
Observations	4,714	4,714
R-squared	0.016	0.178

*$p < 0.05$, ***$p < 0.001$; Standard errors are in parentheses.

majority of them were low educated, with 16.17% having a high school degree or higher. Nearly half (49.75%) of the respondents came from rural areas. The proportion of retired elderly people was 53.99%. Among the respondents, there were 644 Chinese Communist Party members. The average scores of self-assessed socio-economic status and self-assessed social class were 3.19 and 3.48, respectively.

3.2. Benchmark regression results

Model 1 in Table 2 showed the null model, reporting the results without control variables. And model 2 reported the results with control variables. As Model 1 showed, the coefficient of Internet use was significant and negative at 0.001 level. The result indicated that Internet use could reduce depression levels among the elderly in China. This conclusion was still supported when control variables were included.

As Model 2 in Table 2 showed, gender, age, marital cohabitation, education attainment, household registration, retirement, self-assessed socio-economic status, self-assessed social class, and physical health had varying degrees of influence on the level of depression among the elderly. Overall, the regression coefficients of gender, marital cohabitation, education attainment, household registration, retirement, self-assessed socio-economic status, self-assessed social class, and physical health were significant at 0.001 level. The effect of age on depression was significant at 0.05 level. However, party membership status had no significant effect on depression. The results demonstrated that respondents who are male ($\beta = -0.087$, $p < 0.001$), urban residents ($\beta = -0.124$, $p < 0.001$), not retired ($\beta = -0.060$, $p < 0.001$), married or living with a spouse ($\beta = -0.155$, $p < 0.001$), were more likely to report lower depression scores. And the higher the education, the lower the level of depression. In addition, respondents with higher self-rated socioeconomic status or social class had lower depression scores. At the same time, a negative relationship existed between physical health and depression scores among older adults.

3.3. Endogenous treatment and robustness test

According to relevant literature (31, 32), we used PSM method to deal with the endogeneity and test robustness in model estimation. The propensity score is the conditional probability of being affected by some explanatory variable when controlling for many observable confounding variables. The PSM method can put these confounding variables into the Logit model to predict the propensity score, and then control the propensity score to alleviate the biased causal inference caused by the confounding variables and selection bias (33). In this study, we used the PSM method to overcome the selective bias of Internet use among the elderly and further verify the conclusions of the OLS model to investigate whether the relationship between variables persisted. The first step was to predict the tendency value and build a regression model with a binary dummy variable as the dependent variable. In the binary dummy variable, 1 represented the treatment group (older people using the Internet) and 0 represented the control group (older people who were not using the Internet). Independent variables were the control variables of this paper. The second step was matching based on propensity value. PSM method includes k nearest neighbor matching, absolute distance limiting propensity score, nearest neighbor matching in caliper and kernel matching, etc. The difference between matching methods is that the distance calculation method is different, and each has its advantages and disadvantages. Usually, we can choose any matching method and choose the other two matching methods to test the robustness of the results. Kernel matching, radius matching, and local linear regression matching were used in our study. The third step was to estimate the causality coefficient. The estimation results of the above methods are shown in Table 3, where ATT (Average Treatment Effect on the treated) represents the average treatment effect on the treated (the average effect of actual Internet use on depression levels among older adults). The ATT values of kernel-based matching and radius-based matching were −0.059 and −0.044, respectively (significant at the 5% level). The ATT value of local linear-based regression matching was 0.044 (significant at the 1% level). These results indicated that after controlling for endogeneity, Internet use had a negative effect on depression level. The results showed that the net treatment effects were all significantly positive, further verifying that internet use could reduce depression among older adults. The PSM test proved that the previous benchmark regression results had a certain degree of robustness.

3.4. Mediating effect of interpersonal relationship

We further used the Bootstrap method with 5,000 bootstrap samples, proposed by Hayes (34), to test the mediating effect

TABLE 3 Endogenous test and robustness test results.

Matching method	Kernel-based matching	Radius-based matching	Local linear regression-based matching
ATT	−0.059*(0.020)	−0.044*(0.022)	−0.062**(0.021)

*p < 0.05, **p < 0.01. Standard errors are in parentheses.

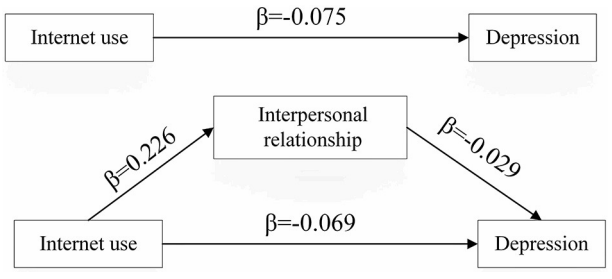


FIGURE 1
Mediating effects of interpersonal relationship in the association between Internet use and depression.

TABLE 4 Results of mediating effect.

Types	Observed coefficient	Bootstrap standard error	*P*-value	95% Conf. interval
Indirect effect	−0.006**	0.002	0.004	−0.011,−0.002
Direct effect	−0.069***	0.019	0.000	−0.106,−0.031
Total effect	−0.075***	0.019	0.000	−0.113,−0.037
The proportion of indirect effect	0.086			

Adjusting for gender, age, marital status, education attainment, household registration, retirement, party member status, self-assessed socio-economic status, self-assessed social class and physical health. **p < 0.01, ***p < 0.001. Confidence intervals do not cross zero means the relationship is significant.

of interpersonal relationship, and obtain the bias-corrected 95% confidence intervals for the indirect effect and total effect.

Figure 1 and Table 4 showed the mediating role of interpersonal relationship between internet use and depression level after controlling for socio-demographic characteristics. It could be seen that the coefficient of Internet use on depression was reduced after the inclusion of interpersonal relationship. The total effect of internet use on depression was −0.075 ($p < 0.001$). When perceived interpersonal relationship was included as a mediator, the effect decreased ($\beta = -0.069$, $p < 0.001$). We could see that the indirect effect of interpersonal relationship was significant at 0.01 level, and the proportion of indirect effect was 8.6%. These results indicated that interpersonal relationship partly mediated the relationship between internet use and depression among Chinese older adults.

3.5. Heterogeneity test

This section investigated the impacts of different Internet usage on depression among the elderly. We also examined heterogeneous effects of Internet use on depression among the elderly based on regional and gender differences. The results demonstrated that using Wechat, browsing short videos, and online shopping had significant negative effects on depression. However, playing online games and online learning had no significant effect on reducing depression (Table 5). Columns (3, 4) in Table 6 showed the effect of Internet use on depression among urban and rural elderly, respectively. The coefficient of Internet use for urban older adults was significantly negative at the 0.001 level, while it was not significant for rural older adults. Columns (5, 6) in Table 6 showed the effect of Internet use on depression among female and male older adults, respectively. The results demonstrated that Internet use could significantly reduce depression among female and male older adults, but the impact was greater for females. In addition, we examined the mediating effect of interpersonal relationship between Internet use and depression among female and male older adults, respectively. The results, shown in Table 7, indicated that interpersonal relationship significantly mediates the relationship between Internet use and depression, but only among male elderly, not female.

4. Discussion

This study confirmed that Internet use could reduce depression among older adults. The result supported some previous findings linking Internet use to lower depression scores (15, 35). The Internet provides social support and information access for individuals, thereby contributing to improvements in older peoples' mental health and social adaptation, such as improving their life satisfaction and happiness, and reducing their levels of depression (36, 37). We also identified the association between individuals' basic demographic characteristics and depression. This study showed that the incidence of depression was related to gender, marital status, education attainment, household registration, retirement, self-assessed socio-economic status, self-assessed social class, and physical health. We found that older men tended to have lower depression scores than older women. And the more educated the older adults, the lower their depression scores. Older adults with spouses had better mental health, and had lower depression scores than those without spouses. Older retirees, who have more free time for leisure activities and no job stress, have a lower risk of depression than non-retired seniors. In addition, higher self-rated socio-economic status, social class and physical fitness were associated with lower depression scores. These results were consistent with some previous results (25, 38). In addition, the relationship between different categories of Internet use and depression among the elderly was explored in this study. Wechat use, short video browsing and online shopping had a protective influence against depression. This conclusion was consistent with part of the findings of Nakagomi et al. (17) and Braun (39), whose findings showed that online communication with family and friends significantly reduced depression among older adults. It

TABLE 5 The regression results on different internet usage and depression.

Variables	Model 3	Model 4	Model 5	Model 6	Model 7
Internet use					
WeChat use	−0.082*** (0.021)				
Short video browsing		−0.063** (0.023)			
Online shopping			−0.070* (0.033)		
Online games				−0.012 (0.051)	
Online learning					−0.074 (0.044)
Constant	2.386*** (0.105)	2.358*** (0.105)	2.330*** (0.104)	2.306*** (0.103)	2.317*** (0.104)
Control variables	Yes	Yes	Yes	Yes	Yes
Observations	4,714	4,714	4,714	4,714	4,714
R-squared	0.179	0.177	0.177	0.176	0.176

*p < 0.05, **p < 0.01, ***p < 0.001; Standard errors are in parentheses. Due to space limitation, regression results on control variables were not listed.

TABLE 6 Results of heterogeneity test of the effect of Internet use on depression among older adults.

Variables	Region		Gender	
	Urban older adults	Rural older adults	Female older adults	Male older adults
Internet use	−0.088*** (0 0.024)	−0.151(0 0.035)	−0.093** (0 0.032)	−0.064** (0.025)
Control variables	Yes	Yes	Yes	Yes
Observations	2,369	2,345	2,240	2,474
R^2	0.169	0.153	0.154	0.177

**p < 0.01, ***p < 0.001. Standard errors are in parentheses. Due to space limitation, regression results on control variables are not listed.

TABLE 7 Results of mediating effect based on samples of female and male older adults.

Types	Gender			
	Female older adults ($N = 2,240$)		Male older adults ($N = 2,474$)	
	Observed coefficient	95% Conf. Interval	Observed coefficient	95% Conf. Interval
Indirect effect	−0.005 (0.003)	−0.012,0.001	−0.007**	−0.0135,−0.001
Direct effect	−0.088** (0.029)	−0.146,−0.030	−0.056*	−0.105,−0.008
Total effect	−0.093** (0.030)	−0.151,−0.035	−0.064**	−0.113,−0.015

Adjusting for gender, age, marita status, education attainment, household registration, retirement, party member status, self-assessed socio-economic status, self-assessed social class and physical health. *p < 0.05, **p < 0.01. Confidence intervals do not cross zero means the relationship is significant.

also corroborates Yang et al., who reported that online recreational activities were negatively associated with depression (16). While our study obtained a new view that among recreational activities, short video browsing could reduce depression, but online games could not. On the one hand, with the rapid development of short video software, elderly people in China enrich their daily life, relieving loneliness and benefiting their mental health by watching funny and health knowledge videos. On the other hand, the older elderlies may have little interest in online games, and learning online games consume a certain amount of energy and physical strength not conducive to rest and relaxation. Furthermore, online learning had no significant effect on depression among the elderly, which was consistent with the conclusion of some researchers (40). Depression is mostly related to psychological factors. The professional psychological knowledge of the elderly on the Internet was less, and it was difficult for the elderly to relieve their personal emotions and depression through online learning.

Moreover, only older adults in urban areas had statistically significantly lower depression scores when using the Internet. This was because the Internet was developing faster in urban areas than rural areas in China. Urban elderly were more familiar with online communication and online shopping. They were more likely to derive happiness through this means. Further, the reduced effect on depression was more apparent among female older adults than their male counterparts. This was possibly because females are more likely to derive emotional value from online activities such as online communication and shopping, thus increasing their sense of satisfaction and happiness.

Additionally, Internet use affected depression levels among older adults by improving the quality of their relationships. On the one hand, the Internet provides convenient conditions for the elderly to obtain interpersonal relations and maintain and expand their interpersonal network (41). On the other hand, the elderly could also engage in social interaction through the Internet to obtain emotional support and social recognition from others, thus reducing the risk of depression (42). However, the mechanism by which Internet use reduced depression by improving relationships was only found among older men, not women. This was possibly because elderly men are more inclined to use the Internet as a social tool to maintain or expand their social networks and meet their social needs. While elderly women use the Internet to shop and watch short videos to satisfy their consumption and entertainment needs and relieve their negative emotions (43).

5. Conclusion

Based on a national sample of Chinese older adults, this study explained the mechanism of how Internet use affects the depression level of older adults. This study unveiled that Internet use could significantly reduce depression levels among elderly individuals, and interpersonal relationship played a mediating role in the relationship between Internet use and depression. Furthermore, only certain types of Internet use (WeChat use, Short Video browsing, Online shopping) were associated with lower depression. Additionally, we found clear demographic differences in the impact of Internet use on depression. In conclusion, this study provides new empirical evidence for the relationship between Internet use and depression among older adults, and enriches the research on the mental health of the elderly in the context of the Internet era.

This study has some limitations. The amount and frequency of Internet use may also be related to depression outcomes, but we did not address this specific issue due to the limitation of data and sample size. We will conduct further analysis in the future.

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

YN conceived this research and conducted the first statistical analysis. YX and YH reviewed, edited the manuscript, and were responsible for visualization. All authors discussed paper structure, contributed to different part of the literature, contributed to the article, and approved the submitted version.

Funding

This work was supported by the National Social Science Foundation (Grant Number: 21CRK008).

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

All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

References

1. Zhu L, Zhang Q, Jing L, Zhang X, Wang F, Zhang P, et al. The relationship between loneliness and social care and health self-assessment among older adults in the community. *Chinese J Gerontol.* (2018) 38:3238–40.

2. Fan Z, Yuan Q. Percived stress and depression among elderly: a mediated moderation model. *Chinese J Clin Psychol.* (2020) 28:173–77+82.

3. Wu X, Li J, Wang L. Analysis on the depressive symptoms of elderly in China. *Popul J.* (2010) 5:43–7.

4. Chiao C, Weng LJ, Botticello AL. Social participation reduces depressive symptoms among older adults: an 18-year longitudinal analysis in Taiwan. *BMC Public Health.* (2011) 11:1–9. doi: 10.1186/1471-2458-11-292

5. Centers for Disease Control and Prevention (CDC). Suicide among older persons–United States, 1980-1992. *MMWR Morb Mortal Wkly Rep.* (1996) 45:3–6.

6. Rihmer Z. Can better recognition and treatment of depression reduce suicide rates?a brief review. *Eur Psychiatry.* (2015) 16:406–9. doi: 10.1016/S0924-9338(01)00598-3

7. China Internet Network Information Center. *The 49th Statistical Report on China's Internet Development.* (2020). Available online at: https://www.cnnic.cn/NMediaFile/old_attach/P020220721404263787858.pdf (accessed November 15, 2022).

8. Mellor D, Firth L, Moore K. Can the internet improve the well-being of the elderly? *Ageing Int.* (2008) 32:25–42. doi: 10.1007/s12126-008-9006-3

9. Nie P, Sousa-Poza A, Nimrod G. Internet use and subjective well-being in China. *Soc Indic Res.* (2017) 132:489–516. doi: 10.1007/s11205-015-1227-8

10. McMellon CA, Schiffman LG. Cybersenior mobility: why some older consumers may be adopting the Internet. *Adv Consum Res.* (2000) 27:139–44.

11. Forsman AK, Nordmyr J. Psychosocial links between internet use and mental health in later life: a systematic review of quantitative and qualitative evidence. *J Appl Gerontol.* (2017) 36:1471–518. doi: 10.1177/0733464815595509

12. Jun H, Kim M. The influence of internet use on satisfaction with social relationships and depression among older adults living alone in Seoul. *Korean Soc Welf Res.* (2015) 43:73–98.

13. Lam S, Jivraj S, Scholes S. Exploring the relationship between internet use and mental health among older adults in England: longitudinal observational study. *J Med Internet Res.* (2020) 22:e15683. doi: 10.2196/15683

14. Liu Q, Pan H, Wu Y. Migration status, internet Use, and social participation among middle-aged and older adults in China: consequences for depression. *Int J Environ Res Public Health.* (2020) 17:6007. doi: 10.3390/ijerph17166007

15. Cotten SR, Ford G, Ford S, Hale TM. Internet use and depression among retired older adults in the United States: a longitudinal analysis. *J Gerontol B Psychol Sci Soc Sci.* (2014) 69:76371. doi: 10.1093/geronb/gbu018

16. Yang H, Zhang S, Zhang S, Xie L, Wu Y, Yao Y, et al. Internet use and depressive symptoms among older adults in China. *Front Psychiatry.* (2021) 12:739085. doi: 10.3389/fpsyt.2021.739085

17. Nakagomi A, Shiba K, Kondo K, Kawachi I. Can online communication prevent depression among older people? A longitudinal analysis. *J Appl Gerontol.* (2022) 41:167–75. doi: 10.1177/0733464820982147

18. Bessière K, Pressman S, Kiesler S, Kraut R. Effects of Internet use on health and depression: a longitudinal study. *J Med Internet Res.* (2010) 12:e6. doi: 10.2196/jmir.1149

19. Eastman JK, Iyer R. The elderly's uses and attitudes towards the Internet. *J Consum Mark.* (2004) 21:208–20. doi: 10.1108/07363760410534759

20. Li Y, Bai X, Chen H. Social isolation, cognitive function, and depression among Chinese older adults: examining Internet use as a predictor and a moderator. *Front Public Health.* (2022) 10:809713. doi: 10.3389/fpubh.2022.809713

21. Liu B, Liu X. The impact of interpersonal relationship on life satisfaction of the elderly in the context of active aging. *Soc Secur Stud.* (2021) 5:49–59.

22. Pietromonaco PR, Collins NL. Interpersonal mechanisms linking close relationships to health. *Am Psychol.* (2017) 72:531–42. doi: 10.1037/amp0000129

23. Najarian K, Abdi R. The relationship between maladaptive personality traits and interpersonal problems in elderly people. *Iran J Ageing.* (2020) 14:422–35.

24. Bradley N, Poppen W. Assistive technology, computers and Internet may decrease sense of isolation for homebound elderly and disabled persons. *Technol Disabil.* (2003) 15:19–25. doi: 10.3233/TAD-2003-15104

25. Gatto SL, Tak SH. Computer, internet, and e-mail use among older adults: benefits and barriers. *Educ Gerontol.* (2008) 34:800–11. doi: 10.1080/03601270802243697

26. World Health Organization. *China Country Assessment Report on Ageing and Health*. (2020). Available online at: http://apps.who.int/iris/bitstream/handle/10665/194271/9789245509318-chi.pdf (accessed December 25, 2022).

27. Gallo WT, Bradley EH, Dubin JA, Jones RN, Falba TA, Teng HM. The persistence of depressive symptoms in older workers who experience involuntary job loss: results from the health and retirement survey. *J Gerontol B Psychol Sci Soc Sci.* (2006) 61:S221. doi: 10.1093/geronb/61.4.S221

28. Radloff LS, Teri L. Use of the enter for epidemiological studies depression scale with older adults. *Clin Gerontol.* (1986) 5:119–36. doi: 10.1300/J018v05n01_06

29. Nam SJ. Mediating effect of social support on the relationship between older adults' use of social media and their quality-of-life. *Curr Psychol.* (2019) 10:1007. doi: 10.1007/s12144-019-00399-3

30. Li Y, Lu J, Cheng Q, Gu D. Association between social participation and depression among older Alduts in China. *Popul Dev.* (2020) 26:86–97.

31. Shi GF Li M, Shen T-T, Ma Y. The impact of medical insurance on household stock market participation: evidence from China household finance survey. *Front Public Health.* (2021) 9:710896. doi: 10.3389/fpubh.2021.710896

32. Sun H, Yang Z, Zhang Q. Internet deepening and farmers income increase: impact mechanisms and empirical evidence. *Macroecon*. (2021) 5:104–22+41.

33. Hu A. Propensity score matching and causal inference: a methodological review. *Sociol Stud*. (2012) 27:221–42+46.

34. Hayes AF, Scharkow M. The relative trustworthiness of inferential tests of theindirect effect in statistical mediation analysis: does method really matter?*Psychol Sci.* (2013) 24:1918–27. doi: 10.1177/0956797613480187

35. Cotten SR, Ford GS, Ford SG, Hale TM. Internet use and depression among older adults. *Comp Hum Behav.* (2012) 28:496–9. doi: 10.1016/j.chb.2011.10.021

36. Vahedi Z, Zannella L. The association between self-reported depressive symptoms and the use of social networking sites (SNS): a meta- analysis. *Curr Psychol.* (2019) 40:2174–89. doi: 10.1007/s12144-019-0150-6

37. Elizabeth MS, Margaret LK, Nikki SR. Social Networking sites, depression, and anxiety: a systematic review. *Jmir Ment Health.* (2016) 3:e50. doi: 10.2196/mental.5842

38. Quittschalle J, Stein J, Luppa M, Pabst A, Löbner M, Koenig HH, et al. Internet use in old age: results of a German population-representative survey. *J Med Internet Res.* (2020) 22:e15543. doi: 10.2196/15543

39. Braun MT. Obstacles to social networking website use among older adults. *Comput Hum Behav.* (2013) 29:673–80. doi: 10.1016/j.chb.2012.12.004

40. Hou J, Zhou W. Mechanism and heterogeneity analysis of the impact of internet use on health status of the elderly in China. *Popul J.* (2022) 44:73–87.

41. Neves BB, Waycott J, Malta S. Old and afraid of new communication technologies? Reconceptualizing and contesting the age-based digital divide. *J Sociol.* (2018) 17:1–3. doi: 10.1177/1440783318766119

42. Meng J, Martinez L, Holmstrom A, Chung M, Cox J. Research on social networking sites and social support from 2004 to 2015: a narrative review and directions for future research. *Cyberpsychol Behav Soc Netw.* (2016) 20:44–51. doi: 10.1089/cyber.2016.0325

43. Qin J, Li C, Zhuang S, Wang J. Will online consumption make you happy? evidence from the data of CHFS 2015. *Consum Econ*. (2019) 35:13—22.

frontiers | Frontiers in Public Health

TYPE Original Research
PUBLISHED 21 March 2023
DOI 10.3389/fpubh.2023.1111208

OPEN ACCESS

EDITED BY
Abdolvahab Samavi,
University of Hormozgan, Iran

REVIEWED BY
Bardia Karim,
Babol University of Medical Sciences, Iran
Meijuan Cao,
Huzhou University, China

*CORRESPONDENCE
Linping Liu
✉ linpingl@163.com

†These authors have contributed equally to this work and share first authorship

SPECIALTY SECTION
This article was submitted to Aging and Public Health, a section of the journal Frontiers in Public Health

RECEIVED 29 November 2022
ACCEPTED 27 February 2023
PUBLISHED 21 March 2023

CITATION
Ren M, Chang X, Du S and Liu L (2023) Who would rescue the dilemma of Chinese elderly care? An evolutionary game analysis and simulation research on the formalization of the domestic service industry with subsidy policy. *Front. Public Health* 11:1111208. doi: 10.3389/fpubh.2023.1111208

Who would rescue the dilemma of Chinese elderly care? An evolutionary game analysis and simulation research on the formalization of the domestic service industry with subsidy policy

Meina Ren[1†], Xiaozhu Chang[1†], Shasha Du[2] and Linping Liu[1*]

[1]School of Social and Behavioral Sciences, Nanjing University, Nanjing, Jiangsu, China, [2]Department of Social and Cultural Studies, Party School of C.P.C. Jiangsu Committee, Nanjing, Jiangsu, China

Since China entered the aging society, the surging demand for elderly care and the industrial upgrading of "silver economy" has forced the domestic service industry to face endogenous challenges. Among them, the formalization of the domestic service industry can effectively reduce the transaction costs and risks of actors, innovate the endogenous vitality of the industry, and promote the improvement of elderly care quality through a triangular employment relationship. By constructing a tripartite asymmetric evolutionary game model of clients, domestic enterprises and governmental departments, this study uses the stability theorem of differential equations to explore the influencing factors and action paths of the system's evolutionary stable strategies (ESS), and uses the research data collected from China to assign values to models for simulation analysis. This study finds that the ratio of the initial ideal strategy, the difference between profits and costs, subsidies to clients, and subsidies or punishments for breach of contract to domestic enterprises are the key factors affecting the formalization of the domestic service industry. Subsidy policy programs can be divided into long-term and periodic programs, and there are differences in the influence paths and effects of the key factors in different situations. Increasing domestic enterprises' market share with employee management systems, formulating subsidy programs for clients, and setting up evaluation and supervision mechanisms are efficient ways through which to promote the formalization of the domestic service industry in China. Subsidy policy of governmental departments should focus on improving the professional skills and quality of elderly care domestic workers, and also encourage domestic enterprises with employee management systems at the same time, to expand the scope of service beneficiaries by running nutrition restaurants in communities, cooperating with elderly care institutions, etc.

KEYWORDS

elderly care demands, formalization of domestic service industry, subsidy policy, evolutionary game model, numerical simulation

1. Introduction

In the background of surging aging, establishing formalized domestic service markets is considered more cost-effective, with rising population dependency ratios and increasing female employment rates (1). As a result, it has emerged as the primary coping mechanism used by nations to address rising social and economic expenses of care, as well as rising demand for elderly care (2–4). Home-based, community-based, and institutional elderly care are three major parts of China's elderly care system. Among them, home-based elderly care accounts for ∼90% (5). The absolute dominant position of it is a typical feature of Chinese elderly care.

On the one hand, the "filial piety" in traditional Chinese Confucian culture is the spiritual core of Chinese elderly care. Confucian culture believes that "the body, hair and skin, all have been received from the parents" *(shen ti fa fu, shou zhi fu mu)*, and correspondingly, parents need to be taken care personally by their children with full attention. Only in this way, can they be said to have lived a wonderful life in their senior years according to Confucianism. The care of children has become a critical criterion for measuring their degree of filial piety. Therefore, the elders without kinship care are defined as being in a pitiable state. Even based on several sayings in a current Confucianism practice, they will be losers in their own lives without support for future generations. Undoubtedly, with the continuous advancement of modernization, the fast-paced work and life have made the children lose the realistic conditions for personal care. The emergence of paid domestic services has just become a compensatory strategy for personal care. And it has gradually become the mainstream of Chinese elderly care, which would balance the dilemma of the practice of "filial piety" in modern social structure.

On the other hand, intergenerational property relations solidify Chinese elderly care. Owning real estate is a key factor in measuring the interpersonal status of modern Chinese. At the same time, renting means a lack of economic capabilities and social status, and even being called "homelessness" by surrounding people. Therefore, real estates are common gifts given by Chinese parents to their children, so that it would form a bond based on economic relationship of real estates full of legal and moral meaning between them. As we can see, it is difficult to change this absolute high-proportion home-based elderly care model in a short period. Among them, paid domestic services are the main form of market-oriented home-based elderly care, and also an important way to support the current situation of Chinese elderly care. The trend of the standardized development of the domestic service industry is called the formalization of the domestic service industry. It can effectively reduce the transaction costs and risks of actors through a triangular employment relationship. Elderly care services are an important part of domestic services. Under a huge shortage of workers accompanied by a low level of service, the formalization of the domestic service industry would help improve the quality of elderly care. Furthermore, it would also promote the positive work experience for elderly care workers, and significantly rescue the urgent dilemma of Chinese elderly care.

The formalization of the domestic service industry could be seen as the premise for the improvement of elderly care services marketization. At present, there are many problems in the domestic service market in China, such as a high market share of domestic enterprises with employee management systems (6), lack of professional quality, lack of professionalism and low education levels of domestic workers (7–9), and lack of labor rights protection for domestic workers (10). Domestic workers' professional quality is low, in our case, their work experience is poor, and the inferior competition is severe; clients lack consumer rights protection, limiting their consumption options; and domestic enterprises' functions are single and lack supervision. The problems above lead to a disorder of internal development of the domestic service industry resulting in the blockage of mechanism practice, which directly affects the market's ability to meet the elderly care needs. It is imperative to seek an effective way to promote the formalization of the domestic service industry.

Policy plays an instructive role in the development of industries frequently. In recent years, Chinese governmental departments have implemented subsidy policy for domestic enterprises with employee management systems and domestic workers. It has become an important method to promote the formalization of the domestic service industry. As such, the Opinions of the General Office of the State Council on Promoting the Quality and Expanding the Capacity of Domestic Service Industry (No. 30 [2019] of the General Office of the State Council) (referred to as "36 Articles of Domestic Service") provide subsidy methods and objectives. This document defines domestic enterprises with employee management systems, as those "enterprises that directly sign service contracts with clients, sign labor contracts or service agreements with domestic workers in accordance with the law and pay social insurance premiums. Meanwhile, enterprises arrange domestic workers to provide services to clients, pay labor wages not lower than local minimum wage to domestic workers directly or on behalf of clients, and conduct continuous trainings and management for domestic workers."

The facts that domestic enterprises tend to have employee management systems, and clients tend to purchase domestic services through domestic enterprises, are reflections of the development of the domestic service industry toward a healthy situation. Domestic enterprises with employee management systems can adjust the effectiveness of different strategies for domestic workers and clients, through reward and punishment settings, to achieve the formalization of the industry (11).

Can subsidy policy truly promote the formalization of the domestic service industry? How can subsidies be implemented more efficiently? Because the formalization of the domestic service industry is closely related to the strategies of governmental departments, domestic enterprises, and clients, the process of formalization can be regarded as a dynamic result of game strategies with constant adjustment by various actors. Therefore, evolutionary game theory provides an efficient analytical perspective from another research logic to evaluate the current relevant policies and, moreover, beyond the previous analysis logic based only on variable interpretation.

The main issues of this paper are as follows:

(1) In the case of government subsidies and supervision, what are the key factors affecting the healthy and orderly development

of the domestic service industry? How do these factors affect the evolutionary path of the system?

(2) Subsidies as the long-term or periodic methods of governmental departments, will they affect the healthy operation of the domestic service industry? If so, what are the variables that governmental departments should prioritize in different situations?

(3) Is the current subsidy policy efficient? Does it promote the labor quality and occupational health of domestic workers? Does it really improve the quality of elderly care?

2. Literature review

2.1. Formalization of the domestic service industry

The triangular employment relationship established by the transaction actors in the domestic service market is the foothold of the formalization of domestic work, which is an important prerequisite for the realization of the formalization of the industry. This triangular employment relationship refers to the tripartite relationship established among service provider organizations, domestic workers and clients (12).

The triangular employment relationship facilitates more structured employment arrangements and establishes more formal working relationships while also promoting the formalization of the domestic service industry in four ways. First, domestic enterprises sign contracts with clients to control the workload of their domestic workers and avoid additional unpaid work (13, 14). Moreover, the constraints of domestic enterprises placed on clients can effectively improve the bargaining ability of domestic workers (15). However, the effectiveness of such contracts is a matter of concern because heterogeneity exists among domestic enterprises (16). Second, the labor wages of domestic workers are paid by domestic enterprises, which is beneficial for them to avoid the occurrence of unauthorized deductions from domestic workers' paychecks by clients (17, 18). Third, domestic workers employed by domestic enterprises are more likely to resist abuse and harassment by clients because they receive support from colleagues, ask for help from domestic enterprises, continue working by changing clients, etc., (19–21). Fourth, domestic enterprises provide trainings and other services to build domestic workers' confidence in the labor market. Usually, domestic workers also expect to earn higher wages after completing the trainings from domestic enterprises (22, 23). For example, Cai et al. (24) used data from China and found that trainings increased the monthly wages of domestic workers by 11.9%.

Previous studies have paid attention to the role of domestic enterprises in promoting the formalization of the domestic service industry, such as by signing contracts and providing vocational trainings. However, researchers are usually more inclined to explore the impact of domestic enterprises on domestic workers at the micro level, to ignore the impact of those services provided by domestic enterprises on clients, and to seldom discuss the impact of relevant policies on the choices of those functions undertaken by domestic enterprises. In fact, the formalization of the domestic service industry involves multiple actors, including relevant governmental departments, domestic enterprises and clients, all of whom interact with each other.

2.2. Government subsidy policy and the domestic service industry

Government policies in the field of domestic services can be divided into three categories: first, employment and immigration policies directly targeting domestic workers, which are usually implemented through domestic enterprises and/or domestic workers; second, policies that indirectly affect domestic workers by reducing taxes for clients and/or issuing service vouchers; and third, no policy (25). For example, the policy orientation of Denmark, Sweden, and Finland is tax relief, while that of Belgium and Austria is to issue service vouchers. Moreover, France and Germany have both of the above-mentioned policy orientations, while the United States is a typical example of having no policy. The main purpose of such policies is to increase the number of legally protected domestic workers by changing the way domestic services are purchased, thereby creating employment opportunities for private enterprises and reducing informal employment (3, 25).

The evaluation of the effect of policy implementation considers mainly the impact on the labor market, organizational transformation and households. For example, Windebank (26) found that the positive impact of French policies on households and domestic workers was negligible, while Bailly et al. (27) argued that the policies implemented in France to achieve the goal of job creation emphasize the number of jobs at the expense of quality of care services, and the increase in the proportion of direct employment reduces the positive effect of the policy. Moreover, Jokela (28) conducted a quantitative comparative study on the relationship between paid domestic work and precarious employment in Germany, Luxembourg, Italy, Spain and the United States at the micro level, finding that although policies were different, compared with other industries, the domestic service industry was more unstable. In addition, in the United States, which has no relevant policies, and other countries with subsidy policy, there is weak supervision of the domestic service market.

Since subsidy policy is often demand-driven, its goal is to make it easier for households to hire domestic workers, and the policy beneficiaries are often first those households that are able to pay for services. While reducing the burden of housework for dual-earner households, such policy also exacerbates gender inequality in housework, shifting housework from wealthier women to less wealthy women (3, 21, 26). Based on the empirical research of Belgium, France, Switzerland and Brazil, Tomei (29) found that working conditions for domestic workers improved slightly after governments offered an incentive to increase the number of licensed domestic enterprises, but the quality of domestic services remained uneven. Jokela (25) argued that relevant policies reflected the underestimation of paid domestic work in the regulation of visa restrictions and residency requirements and that practices such as limiting hours of service and failing to distinguish between different types of domestic work exacerbated the disadvantage of domestic workers' employment insecurity. Additionally, studies by

van Walsum (30), Morel (31), and Jokela (28) drew conclusions similar to those of Jokela. Shutes and Walsh (32) argued that market-oriented policies may deepen the negative effects of identity differences such as race and citizenship differences. Furthermore, Tomei (29) argued that a more standardized employment relationship weakened the bargaining power of self-employed domestic workers with their employers, making domestic workers more competitive.

Governmental departments, domestic enterprises and clients are the main actors in promoting the formalization of the domestic service industry, but the relevant literature studies mainly the role of subsidy policy in a certain aspect of the domestic service industry through quantitative research or policy analysis. There is a lack of perspectives that can integrate different actors and of mathematical models to study the stability of triangular strategy combinations.

2.3. Application of evolutionary game theory in government subsidy policy

Evolutionary game theory combines game theory and Darwinian biological evolution theory to compensate for the lack of time evolution inherent in previous game theory. The core of evolutionary game theory is an evolutionary stable strategy (33). The research on actors' action strategies and operation mechanisms under subsidy policy or supervision by applying evolutionary game models focused on the fields of technological innovation and drug production. By constructing evolutionary game models, it can be seen that the government's innovation input and product subsidies have different impact mechanisms in terms of their effect on cost-advantage and cost-disadvantage enterprises in terms of choosing different innovation models (34). Because subsidies can reduce costs incurred by enterprises, policy subsidies are usually beneficial for the development of industries (35, 36). However, subsidy policy is usually only a short-term regulatory measure, so subsidy withdrawal mechanisms still need to be formulated by the relevant departments (37, 38). In addition, the government's supervision of various transaction actors in the market has positive significance in terms of promoting buyers and sellers in fulfilling contracts (39–41).

Evolutionary game models are suitable for studies of actors' action strategies and operation mechanisms under subsidy policy or supervision. The implementation of subsidy policy and government supervision has positive significance in emerging industries as well as those industries that are in urgent need of formalization. Subsidy structures, subsidy intensity, punishment mechanisms, and reward and punishment settings are important variables that affect the evolutionary stability of the system, and subsidy programs planned for the long term or periodically may also affect the realization paths of policy objectives.

Previous studies have considered evolutionary game theory because the theoretical perspective lacks attention to the domestic service industry; actually, the process of the formalization of the domestic service industry can also be regarded as a dynamic result of the constant adjustment of game strategies by various actors. Therefore, this study constructs a tripartite asymmetric evolutionary game model of governmental departments, domestic enterprises and clients; incorporates government subsidies and supervision as variables in the model; and uses the stability theorem of differential equations to explore the systematic evolutionary stability strategy, influencing factors and mechanisms of the formalization of the domestic service industry.

3. Data resources

The data reference information used in the initial value setting part of the simulation analysis of this research was from two sources. First, a questionnaire survey was conducted in Nanjing, Guangzhou, Foshan and Wuxi by the research group of Research on the Employment Relationship of Domestic Workers in the Internet Age of School of Social and Behavioral Sciences, Nanjing University, in 2019. The survey obtained 1,007 valid questionnaires through respondent-driven sampling, and was verified by the RDS estimator and other testing methods to obtain an approximate random sample, that is, this data can be regarded as a representative sample. Second, 51 documents, including those on domestic service subsidies, were collected from the official websites of the relevant departments of provinces (including autonomous regions and municipalities directly under the Central Government) and municipal governments in Mainland China (covering 15 provinces, autonomous regions, and municipalities). The direct subsidy targets of policies are mainly domestic enterprises with employee management systems and their domestic workers. Usually, domestic workers' subsidies must be implemented by domestic enterprises with employee management systems.

4. Model description and construction

4.1. Model description

Clients purchase domestic services through domestic enterprises or by hiring self-employed domestic workers. The management modes of domestic enterprises can be divided into employee management systems and agency management systems. Domestic enterprises with employee management systems sign labor contracts or service agreements with domestic workers, pay social insurance premiums, provide trainings to and pay labor wages of domestic workers, sign service contracts with clients, and establish clients rewards and feedback evaluation mechanisms. Domestic enterprises with employee management systems generally only provide order-taking and dispatching services. In addition to providing incentives through subsidy policy, governmental departments also need to set up regulatory mechanisms to restrict the behavior of actors, such as punishments for cheating in subsidies. The main goals of governmental departments are to gain a positive reputation and to improve the well-being of society; the latter includes protections for the job market, consumer rights and workers. In addition, governmental departments can also choose loose management approaches, for example, only providing market behavior regulations. Figure 1 shows the schematic diagram of structural relationship formed by the three actors.

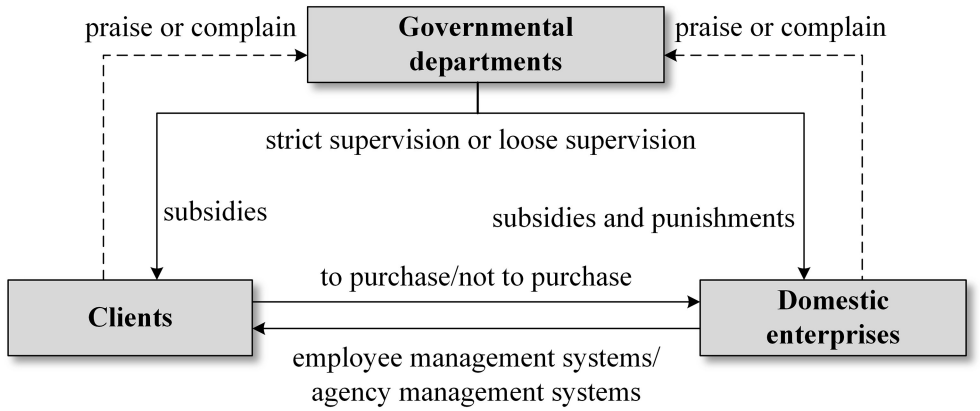


FIGURE 1
Schematic diagram of structural relationship.

4.2. Model construction

To construct evolutionary game models, the following assumptions are made: the strategic space of clients is {to purchase, not to purchase}, the proportion of those choosing to purchase domestic services is x ($0 \leq x \leq 1$), and the proportion of those choosing not to purchase domestic services is $1-x$. The strategic space of domestic enterprises is {employee management systems, agency management systems}, the proportion of those choosing employee management systems is y ($0 \leq y \leq 1$), and the proportion of those choosing agency management systems is $1-y$. The strategic space of governmental departments is {strict supervision, loose supervision}, the proportion of those with strict supervision is z ($0 \leq z \leq 1$), and the proportion of those with loose supervision is $1-z$. The relevant parameters are set as in Table 1.

It is assumed that the sum of the profit and cost differences for different choices of clients is less than that of the rewards received from domestic enterprises, which is $R_{en} - R_{eb} + V^{eb} - V^{en} < L_{ec}$, where $V^{eb} - V^{en} > 0$. The sum of cost and profit differences for different choices of domestic enterprises and the rewards from purchasing domestic services for clients from domestic enterprises with employee management systems is less than the difference between subsidies and punishments imposed by governmental departments for domestic enterprises with employee management systems, which is $Q^{ce} - Q^{cn} + W_{cn} - W_{ce} + L_{ec} < \vartheta\Gamma - \theta C^{cp}$, where $Q^{ce} - Q^{cn} > 0$. The costs of governmental departments choosing strict supervision are higher than the costs of them choosing loose supervision, which is $B^{gr} - B^{gl} > 0$. The positive reputation obtained by governmental departments when they choose strict supervision is greater than their cost differences under different choices, which is $D > B^{gr} - B^{gl}$. The subsidies from governmental departments to domestic enterprises with employee management systems are higher than the punishments for the irregular behavior of domestic enterprises with employee management systems, which is $\vartheta\Gamma > \theta C^{cp}$. According to the above model assumptions and parameter settings, a tripartite game payoff matrix can be obtained (see Table 2).

5. Model analysis

5.1. Stability analysis of clients' strategic choices

The expected profits when clients choose "to purchase" and "not to purchase" are π_{e1} and π_{e2}, respectively:

$$\begin{cases} \pi_{e1} = I^b(y-1) + \varphi\Psi z + L_{ec}y + R_{eb} - V^{eb} \\ \pi_{e2} = I^b(y-1) + R_{en} - V^{en} \end{cases} \quad (1)$$

The average expected profit is $\overline{\pi_e}$:

$$\overline{\pi_e} = x\left[I^b(y-1) + \varphi\Psi z + L_{ec}y + R_{eb} - V^{eb}\right] + (1-x)\left[I^b(y-1) + R_{en} - V^{en}\right] \quad (2)$$

According to the Malthusian growth equation (42), the change rate of clients' choice "to purchase" is equal to the difference between the fitness of the strategy and average fitness. From Equations (1) and (2), the replicator dynamic equation of clients can be written as follows:

$$\begin{aligned} F(x) &= \frac{dx}{dt} = x(\pi_{e1} - \overline{\pi_e}) \\ &= x(1-x)\left(\varphi\Psi z + L_{ec}y - V^{eb} + V^{en} + R_{eb} - R_{en}\right) \end{aligned} \quad (3)$$

$\frac{dx}{dt}$ represents the change rate of the proportion of clients choosing "to purchase" with time t to make the strategy exist in a stable situation; it must satisfy $F(x) = 0$ and $\frac{\partial F(x)}{\partial x} < 0$. According to Equation (3), the partial derivative of $F(x)$ is as follows:

$$\frac{\partial F(x)}{\partial x} = (1-2x)\left(\varphi\Psi z + L_{ec}y - V^{eb} + V^{en} + R_{eb} - R_{en}\right) \quad (4)$$

(a) When $z = \frac{V^{eb} - L_{ec}y - V^{en} - R_{eb} + R_{en}}{\varphi\Psi} = z^*$, for any x, $F(x) \equiv 0$. At this time, any clients' strategy is a stable strategy.

(b) If $z \neq z^*$, then set $F(x) = 0$ to obtain two stable points, $x = 0$ and $x = 1$. When $z < z^*$, $\frac{\partial F(x)}{\partial x}|_{x=0} < 0$, *and* $\frac{\partial F(x)}{\partial x}|_{x=1} > 0$, at this time, $x = 0$ is the evolutionary stable point; that is,

TABLE 1 Model parameters.

Stakeholders	Parameters	Descriptions
Governmental departments	B^{gr}	costs of strict supervision by governmental departments
	B^{gl}	costs of loose supervision by governmental departments
	Γ	subsidy amount for domestic enterprises with employee management systems
	ϑ	subsidy intensity for domestic enterprises with employee management systems ($\vartheta > 0$)
	Ψ	subsidy amount for clients
	φ	subsidy intensity for clients ($\varphi > 0$)
	C^{cp}	punishments for the irregular behavior of domestic enterprises with employee management systems
	θ	punishment strength for the irregular behavior of domestic enterprises with employee management systems ($\theta > 0$)
	D	positive reputation and positive impact on society under strict supervision (regarded as constant)
	N^g	loss of governmental departments for clients choosing not to purchase domestic services from domestic enterprises
Domestic enterprises	Q^{ce}	costs of implementing employee management systems
	Q^{cn}	costs of implementing agency management systems
	W_{ce}	profits from implementing employee management systems
	W_{cn}	profits from implementing agency management systems
	Λ_p	when governmental departments choose strict supervision, punishments for the irregular behavior of domestic enterprises with employee management systems
	N^c	loss of domestic enterprises for clients choosing not to purchase domestic services from domestic enterprises
Clients	V^{eb}	costs of purchasing domestic services from domestic enterprises
	V^{en}	costs of not purchasing domestic services from domestic enterprises
	R_{eb}	profits from purchasing domestic services from domestic enterprises
	R_{en}	profits from not purchasing domestic services from domestic enterprises
	L_{ec}	when domestic enterprises choose employee management systems, rewards from purchasing domestic services from domestic enterprises
	I^b	loss of clients when domestic enterprises implement agency management systems

TABLE 2 Payoff matrix of three actors.

		Clients	Governmental departments	
			Strict supervision	Loose supervision
Domestic enterprises	Employee management systems	To purchase	$R_{eb} - V^{eb} + \varphi\Psi + L_{ec}$	$R_{eb} - V^{eb} + L_{ec}$
			$W_{ce} - Q^{ce} + \vartheta\Gamma - \theta C^{cp} - L_{ec}$	$W_{ce} - Q^{ce} - L_{ec}$
			$D - B^{gr} - \varphi\Psi - \vartheta\Gamma + \theta C^{cp}$	$-B^{gl}$
		Not to purchase	$R_{en} - V^{en}$	$R_{en} - V^{en}$
			$W_{ce} - Q^{ce} + \vartheta\Gamma - \theta C^{cp} - N^c$	$W_{ce} - Q^{ce} - N^c$
			$D - B^{gr} - \vartheta\Gamma + \theta C^{cp} - N^g$	$-B^{gl} - N^g$
	Agency management systems	To purchase	$R_{eb} - V^{eb} + \varphi\Psi - I^b$	$R_{eb} - V^{eb} - I^b$
			$W_{cn} - Q^{cn} - \Lambda_p$	$W_{cn} - Q^{cn}$
			$D - B^{gr} - \varphi\Psi + \Lambda_p$	$-B^{gl}$
		Not to purchase	$R_{en} - V^{en} - I^b$	$R_{en} - V^{en} - I^b$
			$W_{cn} - Q^{cn} - \Lambda_p - N^c$	$W_{cn} - Q^{cn} - N^c$
			$D - B^{gr} - N^g + \Lambda_p$	$-B^{gl} - N^g$

when the proportion of governmental departments choosing "strict supervision" is lower than a certain degree, "not to purchase" is the optimal strategy for clients. When $z > z^*$, $\frac{\partial F(x)}{\partial x}|_{x=1} < 0$, *and* $\frac{\partial F(x)}{\partial x}|_{x=0} > 0$, at this time, $x = 1$ is the evolutionary stable point; that is, when the proportion of governmental departments choosing "strict supervision" is higher than a certain degree, "to purchase" is the optimal strategy for clients. The related phase diagram is shown in Figure 2.

Figure 2 shows the volume V_{e1} of the probability that clients will not purchase, and the volume V_{e2} of the probability that clients will purchase, which can be calculated by the following:

$$\begin{aligned} V_{e1} &= \int_0^1 \int_0^{\frac{V^{eb}-V^{en}-R_{eb}+R_{en}}{L_{ec}}} \left[\frac{V^{eb}-V^{en}-R_{eb}+R_{en}-L_{ec}y}{\varphi\Psi}\right] dydx \\ &= \frac{\left(V^{eb}-V^{en}-R_{eb}+R_{en}\right)^2}{2\varphi\Psi L_{ec}} \end{aligned} \tag{5}$$

$$V_{e2} = 1-V_{e1} \tag{6}$$

Inference I: The probability of clients choosing "to purchase" is positively related to subsidies from governmental departments to clients and purchase incentives given to clients by domestic enterprises and is negatively related to the cost and profit differences between clients choosing "to purchase" and "not to purchase."

Proof: Since $\frac{\partial V_{e2}}{\partial \varphi\Psi} > 0$, $\frac{\partial V_{e2}}{\partial L_{ec}} > 0$, $\frac{\partial V_{e2}}{\partial \Delta V_e} < 0$, *and* $\frac{\partial V_{e2}}{\partial \Delta R_e} < 0$, when $\varphi\Psi$ and L_{ec} increase, the volume of V_{e2} grows, and the probability of clients choosing "to purchase" increases at this time. When ΔV_e and ΔR_e decrease, the volume of V_{e2} shrinks, and the probability of clients choosing "to purchase" decreases at this time.

From Inference I, governmental departments are shown to be able to guide clients' choices by subsidizing purchasing behavior through domestic enterprises with employee management systems.

Inference II: The probability of clients choosing "to purchase" increases with the increase in the probability that domestic enterprises choose "employee management systems" and governmental departments choose "strict supervision."

Proof: When $z > z^*$ or $y > \frac{V^{eb}-\varphi\Psi z-V^{en}-R_{eb}+R_{en}}{L_{ec}}$, $\frac{\partial F(x)}{\partial x}|_{x=1} < 0$, *and* $F(x) > 0$, at this time, $x = 1$ is the evolutionary stable strategy. Therefore, as y or z increases, clients' stable strategy increases from $x = 0$ to $x = 1$.

From Inference II, it can be seen that when governmental departments choose "strict supervision" and when domestic enterprises implement "employee management systems," they increase clients' purchase profits and reduce purchase costs through approaches like subsidies and incentives.

5.2. Stability analysis of domestic enterprises' strategic choices

The expected profits when domestic enterprises choose "employee management systems" and "agency management systems" are π_{c1} and π_{c2}, respectively:

$$\begin{cases} \pi_{c1} = \left(\theta C^{cp} - \vartheta\Gamma\right) z + \left(N^c - L_{ec}\right) x - N^c - Q^{ce} + W_{ce} \\ \pi_{c2} = N^c\left(x-1\right) - \Lambda_p z - Q^{cn} + W_{cn} \end{cases} \tag{7}$$

The average expected profit is $\overline{\pi_c}$:

$$\begin{aligned} \overline{\pi_c} &= y\left[\left(\theta C^{cp} - \vartheta\Gamma\right) z + \left(N^c - L_{ec}\right) x - N^c - Q^{ce} + W_{ce}\right] \\ &+ \left(1-y\right)\left[N^c\left(x-1\right) - \Lambda_p z - Q^{cn} + W_{cn}\right] \end{aligned} \tag{8}$$

From Equations (7) and (8), the replicator dynamic equation of domestic enterprises can be written as follows:

$$\begin{aligned} F\left(y\right) &= \frac{dy}{dt} = y\left(\pi_{c1} - \overline{\pi_c}\right) = y\left(1-y\right)\left[\left(\vartheta\Gamma - \theta C^{cp} + \Lambda_p\right) z - L_{ec}x\right. \\ &- \left. Q^{ce} + Q^{cn} - W_{cn} + W_{ce}\right] \end{aligned} \tag{9}$$

To make domestic enterprises choose "employee management systems" strategy in a stable situation, it must satisfy $F\left(y\right) = 0$

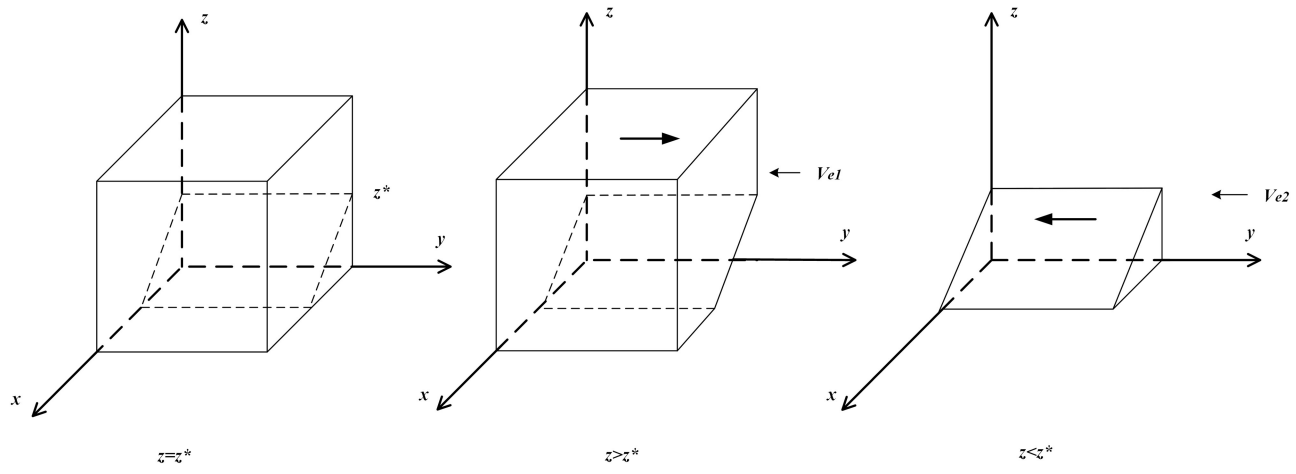


FIGURE 2
Phase diagram of clients' strategy.

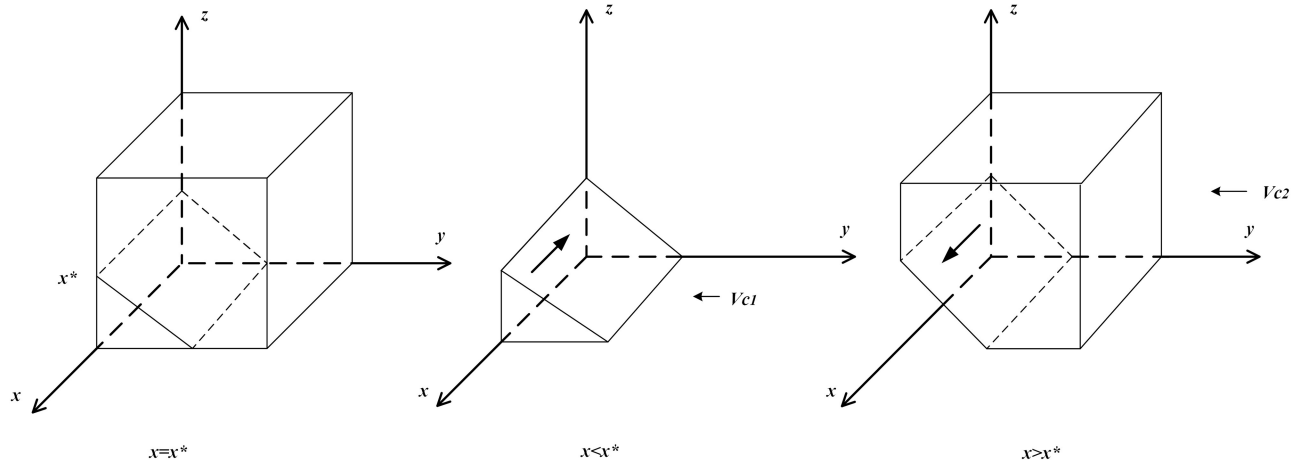


FIGURE 3
Phase diagram of domestic enterprises' strategy.

and $\frac{\partial F(y)}{\partial y} < 0$. According to Equation (9), the partial derivative of $F(y)$ is as follows:

$$\frac{\partial F(y)}{\partial y} = (1-2y)\left[\left(\vartheta\Gamma - \theta C^{cp} + \Lambda_p\right) z - L_{ec}x - Q^{ce} + Q^{cn} - W_{cn} + W_{ce}\right] \quad (10)$$

(a) When $x = \frac{(\vartheta\Gamma - \theta C^{cp} + \Lambda_p) z - Q^{ce} + Q^{cn} - W_{cn} + W_{ce}}{L_{ec}} = x^*$, for any y, $F(y) \equiv 0$. At this time, any domestic enterprises' strategy is a stable strategy.

(b) If $x \neq x^*$, then set $F(y) = 0$ to obtain two stable points, $y = 0$ *and* $y = 1$. When $x > x^*$, $\frac{\partial F(y)}{\partial y}|_{y=0} < 0$, and $\frac{\partial F(y)}{\partial y}|_{y=1} > 0$, then $y = 0$ is the evolutionary stable point; that is, when the probability of clients choosing "to purchase" is larger than a certain degree, "agency management systems" are the optimal strategy for domestic enterprises. When $x < x^*$, $\frac{\partial F(y)}{\partial y}|_{y=1} < 0$,*and* $\frac{\partial F(y)}{\partial y}|_{y=0} > 0$, then $y = 1$ is the evolutionary stable point; that is, when the probability of clients choosing "to purchase" is less than a certain degree, "employee management systems" are the optimal strategy for domestic enterprises. The related phase diagram is shown in Figure 3.

Figure 3 shows the volume V_{c1} of the probability of domestic enterprises choosing "employee management systems" and the volume V_{c2} of the probability of them choosing "agency management systems," which can be calculated by the following:

$$V_{c1} = \int_0^1 \int_0^{\frac{Q^{ce}+Q^{cn}-W_{cn}+W_{ce}}{\vartheta\Gamma-\theta C^{cp}+\Lambda_p}} \frac{\left(\vartheta\Gamma - \theta C^{cp} + \Lambda_p\right) z - Q^{ce} + Q^{cn} - W_{cn} + W_{ce}}{L_{ec}} dzdy$$
$$= -\frac{\left(\vartheta\Gamma + 3\theta C^{cp} + \Lambda_p\right)\left(Q^{ce} + Q^{cn} - W_{cn} + W_{ce}\right)^2}{2L_{ec}\left(\vartheta\Gamma + \theta C^{cp} + \Lambda_p\right)^2} \quad (11)$$

$$V_{c2} = 1 - V_{c1} \quad (12)$$

Inference III: The probability of domestic enterprises choosing "employee management systems" is positively related to governmental departments' subsidies to domestic enterprises with employee management systems, rewards from domestic enterprises given to clients, and punishments for the irregular behavior of domestic enterprises with employee management systems and is negatively related to cost differences of domestic enterprises choosing "employee management systems" and "agency management systems," profit differences between "agency management systems" and "employee management systems," and governmental departments' punishments for the irregular behavior of domestic enterprises with employee management systems.

Proof: Since $\frac{\partial V_{c2}}{\partial \vartheta\Gamma} > 0$, $\frac{\partial V_{c2}}{\partial L_{ec}} > 0$, $\frac{\partial V_{c2}}{\partial \Lambda_p} > 0$, $\frac{\partial V_{c2}}{\partial \Delta Q_c} < 0$, $\frac{\partial V_{c2}}{\partial \Delta W_c} < 0$, *and* $\frac{\partial V_{c2}}{\partial \theta C^{cp}} < 0$, when $\vartheta\Gamma, L_{ec}$, and Λ_p increase, the volume of V_{c1} increases. At this time, the probability of domestic enterprises choosing "employee management systems" increases, and when ΔQ_c, ΔW_c, and θC^{cp} decrease, the volume of V_{c1} decreases, and the probability of domestic enterprises choosing "employee management systems" decreases.

From Inference III, it is shown that the implementation of punishments for the irregular behavior of domestic enterprises with employee management systems by governmental departments will help domestic enterprises implement more standardized employee management systems. Moreover, punishments for the irregular behavior of domestic enterprises with employee management systems should be less than their subsidies, which is conducive to the expansion of the market share of domestic enterprises with employee management systems.

Inference IV: The probability of domestic enterprises choosing "employee management systems" is positively related to the probability of governmental departments choosing "strict supervision" and is negatively related to the probability of clients choosing "to purchase."

Proof: When $x < x^*$ or $z > \frac{L_{ec}x + Q^{ce} - Q^{cn} + W_{cn} - W_{ce}}{\vartheta\Gamma - \theta C^{cp} + \Lambda_p}$, $\frac{\partial F(y)}{\partial y}|_{y=1} < 0$, *and* $F(y) > 0$; at this time, $y = 1$ is the evolutionary stable strategy. Therefore, as x decreases or z increases, the stable strategy of domestic enterprises increases from $y = 0$ to $y = 1$.

From Inference IV, it is shown that clients tend not to choose to purchase services from domestic enterprises and that domestic enterprises set up incentives and provide better after-sales services to attract clients. If governmental departments subsidize domestic enterprises with employee management systems and implement punishments to domestic enterprises with employee management systems for their irregular behavior, then domestic enterprises are more inclined to implement "employee management systems."

5.3. Stability analysis of governmental departments' strategic choices

The expected profits when governmental departments choose "strict supervision" and "loose supervision" are π_{g1} and π_{g2}, respectively:

$$\begin{cases} \pi_{g1}=N^g\,(x-1)-\varphi\Psi x+\left(\theta C^{cp}-\vartheta\Gamma-\Lambda_p\right)y+D+B^{gr}+\Lambda_p \\ \pi_{g2}=N^g\,(x-1)-B^{gl} \end{cases} \tag{13}$$

The average expected profit is $\overline{\pi_g}$:

$$\begin{aligned} \overline{\pi_g} &= z\left[N^g\,(x-1)-\varphi\Psi x+\left(\theta C^{cp}-\vartheta\Gamma-\Lambda_p\right)y+D+B^{gr}+\Lambda_p\right] \\ &+ (1-z)\left[N^g\,(x-1)-B^{gl}\right] \end{aligned} \tag{14}$$

From Equations (13) and (14), the replicator dynamic equation of governmental departments can be written as follows:

$$\begin{aligned} F(z) &= \frac{dz}{dt}=z\left(\pi_{g1}-\overline{\pi_g}\right) \\ &= z(1-z)\left[B^{gl}-B^{gr}+\Lambda_p+D-\varphi\Psi x-\left(\vartheta\Gamma-\theta C^{cp}+\Lambda_p\right)y\right] \end{aligned} \tag{15}$$

To make governmental departments choose the strategy of "strict supervision" in a stable situation, they must satisfy $F(z)=0$ *and* $\frac{\partial F(z)}{\partial z}<0$. According to Equation (9), the partial derivative of $F(z)$ is as follows:

$$\frac{\partial F(z)}{\partial z}=(1-2z)\left[B^{gl}-B^{gr}+\Lambda_p+D-\varphi\Psi x-\left(\vartheta\Gamma-\theta C^{cp}+\Lambda_p\right)y\right] \tag{16}$$

(a) When $y=\frac{B^{gl}-B^{gr}+\Lambda_p+D-\varphi\Psi x}{\vartheta\Gamma-\theta C^{cp}+\Lambda_p}=y^*$, for any z, $F(z)\equiv 0$. At this time, any governmental departments' strategy is a stable strategy.

(b) If $y\neq y^*$, then set $F(z)=0$ to obtain two stable points, $z=0$ and $z=1$. When $y>y^*$, $\frac{\partial F(z)}{\partial z}|_{z=0}<0$, *and* $\frac{\partial F(z)}{\partial z}|_{z=1}>0$, then $z=0$ is the evolutionary stable point; that is, when the proportion of domestic enterprises choosing "employee management systems" is larger than a certain degree, "loose supervision" is the optimal strategy for governmental departments. When $y<y^*$, $\frac{\partial F(z)}{\partial z}|_{z=1}<0$, and $\frac{\partial F(z)}{\partial z}|_{z=0}>0$, then $z=1$ is the evolutionary stable point; that is, when the proportion of domestic enterprises choosing "employee management systems" is less than a certain degree, "strict supervision" is the optimal strategy for governmental departments. The related phase diagram is shown in Figure 4.

Figure 4 shows the volume V_{g1} of the probability that governmental departments choose to implement "strict supervision" and the volume V_{g2} of the probability of choosing to implement "loose supervision," which can be calculated by the following:

$$\begin{aligned} V_{g1} &= \int_0^1\int_0^{\frac{B^{gl}-B^{gr}+\Lambda_p+D}{\varphi\Psi}}\left[\frac{B^{gl}-B^{gr}+\Lambda_p+D-\varphi\Psi x}{\vartheta\Gamma-\theta C^{cp}+\Lambda_p}\right]dxdz \\ &= \frac{\left(B^{gl}-B^{gr}+\Lambda_p\right)^2}{2\varphi\Psi\left(\vartheta\Gamma-\theta C^{cp}+\Lambda_p\right)} \end{aligned} \tag{17}$$

$$V_{g2} = 1-V_{g1} \tag{18}$$

Inference V: The probability of governmental departments choosing "strict supervision" is positively related to the positive reputation obtained during strict supervision, punishments for the irregular behavior of domestic enterprises with employee management systems and punishments for the irregular behavior of domestic enterprises with employee management systems and is negatively related to cost differences between the strict and loose supervision of governmental departments and subsidies to clients and domestic enterprises with employee management systems.

Proof: Since $\frac{\partial V_{g2}}{\partial D}>0$, $\frac{\partial V_{g2}}{\partial\Lambda_p}>0$, $\frac{\partial V_{g2}}{\partial\theta C^{cp}}>0$, $\frac{\partial V_{g2}}{\partial\Delta B_g}<0$, $\frac{\partial V_{g2}}{\partial\varphi\Psi}<0$, *and* $\frac{\partial V_{g2}}{\partial\vartheta\Gamma}<0$, when D, Λ_p, and θC^{cp} increase, the volume of V_{g1} increases, and the probability of governmental departments choosing "strict supervision" increases. When ΔB_g, $\varphi\Psi$, and $\vartheta\Gamma$ decrease, the volume of V_{g1} decreases, and the probability of governmental departments choosing "strict supervision" decreases.

From Inference V, it can be seen that when governmental departments set higher punishments for the irregular behaviors of domestic enterprises or set lower subsidies for domestic enterprises and clients, it is more likely to prompt governmental departments to choose "strict supervision." The higher the amounts of subsidies issued are, the more likely governmental departments are to choose "loose supervision."

Inference VI: The probability of governmental departments choosing "strict supervision" is negatively related to the probability of clients choosing "to purchase" and is also negatively related to the probability of domestic enterprises choosing "employee management systems".

Proof: When $y<y^*$ or $x<\frac{B^{gl}-B^{gr}+\Lambda_p+D-(\vartheta\Gamma-\theta C^{cp}+\Lambda_p)y}{\varphi\Psi}$, $\frac{\partial F(z)}{\partial z}|_{z=1}<0$, *and* $F(z)>0$; at this time, $z=1$ is the evolutionary stable strategy. Therefore, as x or y decreases, the stable strategy of governmental departments increases from $z=0$ to $z=1$.

From Inference VI, it can be seen that if the probability of clients choosing "to purchase" from domestic enterprises or the probability of domestic enterprises choosing "employee management systems" is low, then it indicates that the market lacks benign development conditions, governmental departments are more needed to guide consumption at this time, and the profits are greater both in terms of reputation gain and punishments for the irregular behavior of domestic enterprises. Conversely, when the degree of formalization of the domestic service market is relatively high, governmental departments are more likely to choose "loose supervision".

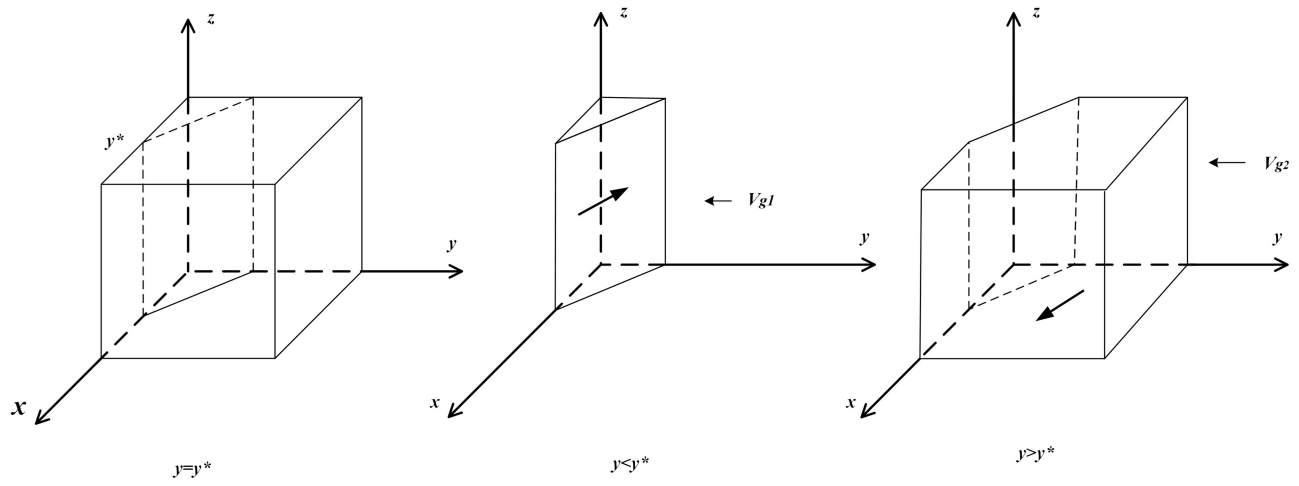


FIGURE 4
Phase diagram of governmental departments' strategy.

5.4. Strategic stability analysis of the co-evolution of clients, domestic enterprises and governmental departments

According to Equations (3), (9) and (15), the replicator dynamic system is as follows:

$$\begin{cases} F(x) = x(1-x)\left(\varphi\Psi z + L_{ec}y - V^{eb} + V^{en} + R_{eb} - R_{en}\right) \\ F(y) = y(1-y)\left[\left(\vartheta\Gamma - \theta C^{cp} + \Lambda_p\right)z - L_{ec}x - Q^{ce} + Q^{cn} - W_{cn} + W_{ce}\right] \\ F(z) = z(1-z)\left[B^{gl} - B^{gr} + \Lambda_p + D - \varphi\Psi x - \left(\vartheta\Gamma - \theta C^{cp} + \Lambda_p\right)y\right] \end{cases} \quad (19)$$

Equation (19) should be solved to obtain the equilibrium point of the systematic evolutionary game:

$$\begin{aligned} &E_1(0,0,0), E_2(0,1,0), E_3(0,0,1), E_4(1,0,0), E_5(1,0,1), E_6(1,1,0), \\ &E_7(0,1,1),\ E_8(1,1,1), E_9\left(0, \frac{B^{gl} - B^{gr} + \Lambda_p + D}{\vartheta\Gamma - \theta C^{cp} + \Lambda_p}, \right. \\ &\left. \frac{Q^{ce} - Q^{cn} - W_{ce} + W_{cn}}{\vartheta\Gamma - \theta C^{cp} + \Lambda_p}\right), E_{10}\left(\frac{Q^{cn} - Q^{ce} - W_{cn} + W_{ce}}{L_{ec}}, \right. \\ &\left. \frac{V^{eb} - V^{en} - R_{eb} + R_{en}}{L_{ec}}, 0\right), E_{11}\left(\frac{B^{gl} - B^{gr} + \Lambda_p + D}{\varphi\Psi}, 0, \right. \\ &\left. \frac{V^{eb} - V^{en} - R_{eb} + R_{en}}{\varphi\Psi}\right), E_{12}\left(\frac{B^{gl} - B^{gr} + \Lambda_p + D - \vartheta\Gamma + \theta C^{cp} - \Lambda_p}{\varphi\Psi}, \right. \\ &\left. 1, \frac{V^{eb} - V^{en} - R_{eb} + R_{en} - L_{ec}}{\varphi\Psi}\right), \\ &E_{13}\left(\frac{Q^{cn} - Q^{ce} - W_{cn} + W_{ce} - \vartheta\Gamma + \theta C^{cp} - \Lambda_p}{L_{ec}}, \right. \\ &\left. \frac{V^{eb} - V^{en} - R_{eb} + R_{en} - \varphi\Psi}{L_{ec}}, 1\right), E_{14}\left(1, \frac{B^{gl} - B^{gr} + \Lambda_p + D - \varphi\Psi}{\vartheta\Gamma - \theta C^{cp} + \Lambda_p}, \right. \\ &\left. \frac{Q^{ce} - Q^{cn} - W_{ce} + W_{cn} + L_{ec}}{\vartheta\Gamma - \theta C^{cp} + \Lambda_p}\right). \end{aligned} \quad (20)$$

In an asymmetric multigroup evolutionary game, the stability of its equilibrium point is a strict Nash equilibrium (43), which is a pure strategy equilibrium. Therefore, in Equation (19), there are only 8 equilibrium points (E_1 to E_8) in the dedomain $R = \{(x, y, z)|0 \le x \le 1, 0 \le y \le 1, 0 \le z \le 1\}$. Only E_1 to E_8 are studied in this paper. The local stability analysis of the Jacobian matrix of the replicator dynamic system can obtain the stability of the equilibrium point of the evolutionary system (44). According to Equation (19), the Jacobian matrix (**J**) of the system is as follows:

$$J = \begin{bmatrix} J_1 & J_2 & J_3 \\ J_4 & J_5 & J_6 \\ J_7 & J_8 & J_9 \end{bmatrix} = \begin{bmatrix} \frac{\partial F(x)}{\partial x} & \frac{\partial F(x)}{\partial y} & \frac{\partial F(x)}{\partial z} \\ \frac{\partial F(y)}{\partial x} & \frac{\partial F(y)}{\partial y} & \frac{\partial F(y)}{\partial z} \\ \frac{\partial F(z)}{\partial x} & \frac{\partial F(z)}{\partial y} & \frac{\partial F(z)}{\partial z} \end{bmatrix} \quad (21)$$

The eigenvalues of each equilibrium point can be obtained from the Jacobian matrix of the system. According to Lyapunov's indirect method (45), if the eigenvalues are positive or negative, then the equilibrium point is a saddle point; if the eigenvalues are all positive, then the equilibrium point is an unstable point; and if the eigenvalues are all negative, then the equilibrium point is an asymptotic stable point. This strategic combination is an evolutionary stable strategy. Accordingly, stability analysis can be carried out for each equilibrium point. Due to space limitations, the case in which λ is a positive number is not shown in Table 3.

E_6 and E_8 are the ideal combination of strategies for the regularization of the domestic service industry, and only these two situations are analyzed below.

Inference VII: When governmental departments choose "loose supervision," (1, 1, 0) is the combination of evolutionary stable strategy.

Proof: When $L_{ec} + Q^{ce} - Q^{cn} + W_{cn} - W_{ce} < 0$ and $B^{gl} - B^{gr} + D - \varphi\Psi - \vartheta\Gamma + \theta C^{cp} < 0$, E_6 is the evolutionarily stable strategy.

From Inference VII, it can be shown that this situation exists in the stage of high marketization of the domestic service industry. Even when subsidy intensity is low, clients still tend to choose to purchase services from domestic enterprises with employee management systems, and domestic enterprises are more inclined to implement "employee management systems". Since the marketization of domestic services is the general trend of industry development, this situation is ideal for the formalization of the domestic service industry.

TABLE 3 Local stability analysis for equilibrium point.

Equilibrium points	λ	Characteristic equations	Symbols
$E_1(0,0,0)$	λ_1	$V^{en} - V^{eb} + R_{eb} - R_{en}$	Uncertain
	λ_2	$Q^{cn} - Q^{ce} - W_{cn} + W_{ce}$	Uncertain
	λ_3	$B^{gl} - B^{gr} + \Lambda_p + D$	Uncertain
$E_4(1,0,0)$	λ_1	$V^{eb} - V^{en} - R_{eb} + R_{en}$	Uncertain
	λ_2	$Q^{cn} - Q^{ce} - W_{cn} + W_{ce} - L_{ec}$	Uncertain
	λ_3	$B^{gl} - B^{gr} + \Lambda_p + D - \varphi\Psi$	Uncertain
$E_6(1,1,0)$	λ_1	$V^{eb} - V^{en} - R_{eb} + R_{en} - L_{ec}$	–
	λ_2	$L_{ec} + Q^{ce} - Q^{cn} + W_{cn} - W_{ce}$	Uncertain
	λ_3	$B^{gl} - B^{gr} + D - \varphi\Psi - \vartheta\Gamma$	Uncertain
$E_8(1,1,1)$	λ_1	$V^{eb} - V^{en} - R_{eb} + R_{en} - \varphi\Psi$	–
	λ_2	$\theta C^{cp} - \Lambda_p + L_{ec} + Q^{ce} - Q^{cn}$	–
	λ_3	$\vartheta\Gamma + \varphi\Psi - D - B^{gl} + B^{gr}$	Uncertain

Inference VIII: When governmental departments choose "strict supervision," (1, 1, 1) is the combination of evolutionary stable strategy.

Proof: When $\Gamma + \varphi\Psi - D - B^{gl} + B^{gr} - \theta C^{cp} < 0$, E_8 is the evolutionarily stable strategy.

From Inference VIII, it is shown that if governmental departments' subsidies are relatively high for domestic enterprises and clients and the profits of "strict supervision" by governmental departments are also relatively high, then governmental departments tend to guide the formalization of the domestic service industry through policies. At this time, domestic enterprises choose to implement "employee management systems" due to the increase in profits, and clients tend to choose to purchase services from domestic enterprises due to the increase in profits. Therefore, this situation is also the ideal situation for the formalization of the domestic service industry.

The validity tests of the system evolution stability of E_6 and E_8 are shown in Figure 5, the results of which show that they can both converge to the stable situation. In the next section, we explore these two situations through systematic simulation analysis.

6. Simulation results

In this paper, we use Stata17 for descriptive statistics of the data and use MATLAB R2021b to simulate the dynamic evolution process of the system.

From the survey data, the distribution of types of domestic enterprises is as follows: the employee management system accounts for 1.10%, the quasi-employee management system accounts for 13.10%, the agency management system accounts for 56.41%, and the self-employed (without domestic enterprises) account for 29.39%. The proportion of clients who choose to purchase domestic services through domestic enterprises is 60.28%. Therefore, the initial ideal strategy values of x, y , and z are set to 0.6, 0.1, and 0.5, respectively, in this paper.

According to the research assumptions and survey data, we set two sets of parameter values to carry out the system simulation analysis for E_6 and E_8. The initial values of System L (E_8) are set as follows: $B^{gr} = 300$, $B^{gl} = 50$, $\Gamma = 130$, $\vartheta = 1$, $\Psi = 50$, $\varphi = 1$, $L_{ec} = 32$, $R_{en} = 80$, $R_{eb} = 60$, $V^{en} = 50$, $V^{eb} = 60$, $\Lambda_p = 70$, $W_{cn} = 200$, $W_{ce} = 126$, $Q^{cn} = 60$, $Q^{ce} = 100$, $D = 400$, $\theta = 1$, *and* $C^{cp} = 80$. The initial values of System P (E_6) are set as follows: $B^{gr} = 320$, $\Gamma = 141$, $\Psi = 60$, $C^{cp} = 50$, *and* $W_{cn} = 100$. The remaining values are set the same as those of System L.

6.1. Impact on changes in the proportion of the initial ideal strategy for three actors

Under the condition that the ideal strategy of the other two actors has a constant value of 0.3, the ideal strategy ratio of a certain actor is set to 0.1, 0.3, and 0.6, the 100 simulation results of replicator dynamic equations of System L and P in time t are shown in Figures 6–8.

Figure 6 shows that the increase in the initial proportion of clients' ideal strategy in the two systems has a significant positive impact on the system evolution process; that is, the higher the initial proportion of clients' ideal strategy is, the faster the system converges to an asymptotic stable point.

Figure 7 shows that the increase in the initial proportion of the ideal strategy of domestic enterprises in the two systems positively impacts the system evolution process. Relatively speaking, the change in y has a greater impact on System P than on System L. The tendency of domestic enterprises to implement employee management systems has an obvious positive effect on the formalization of the domestic service industry; in particular, governmental departments should focus on increasing the market share of domestic enterprises with employee management systems when they want to adopt loose supervision strategies.

Figure 8 shows that the initial proportion of strict supervision implemented by governmental departments in the two systems has different effects on the system evolution process.

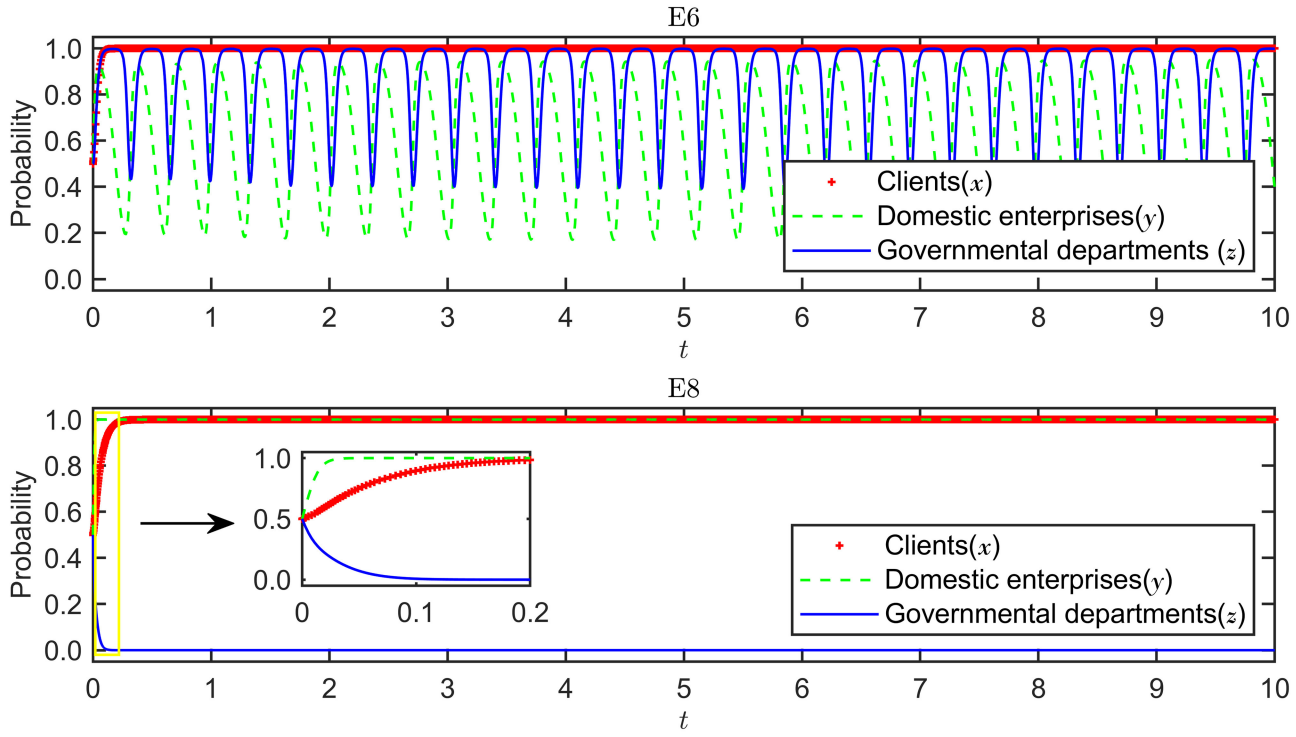


FIGURE 5
Evolutionary stability of E_6 and E_8.

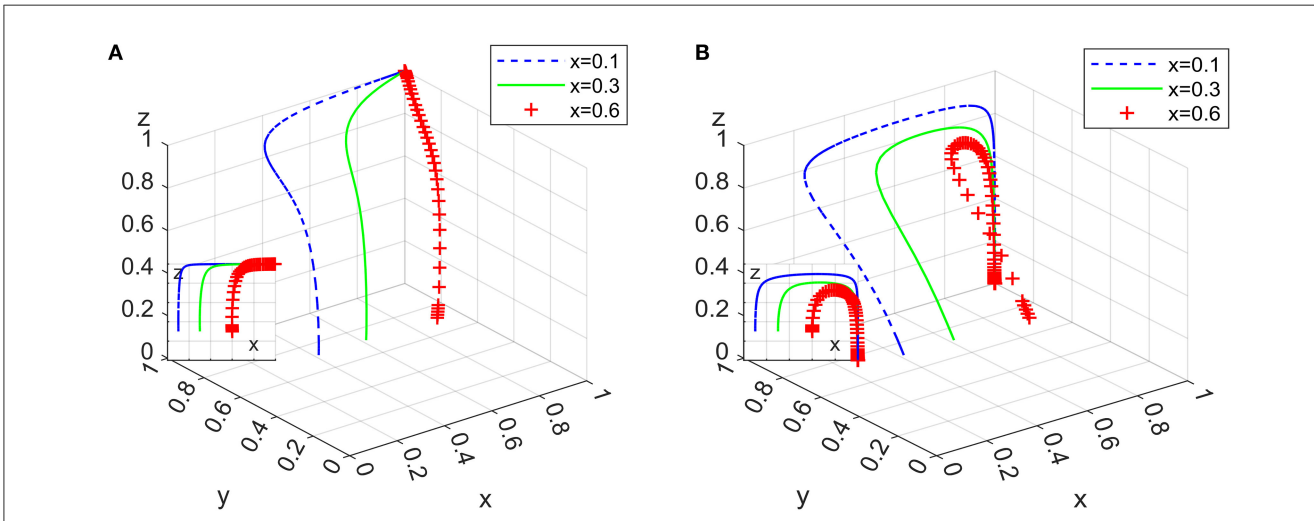


FIGURE 6
Impact of clients' strategies in system L **(A)** and system P **(B)**.

In System L, the change in z has no significant effect on the system converging to an asymptotically stable point. In System P, however, the increase in z slows down the rate at which the system converges to an asymptotic stable point, which shows that the proportion of those governmental departments implementing strict supervision should be appropriately reduced if domestic enterprises with employee management systems have a certain market share and if governmental departments implement subsidy policy as a periodic strategy.

Figures 6–8 show that in the two systems, compared with other actors in the game, the initial proportional change in clients' ideal strategy has the greatest impact on the convergence to an asymptotic stable point. This means that governmental departments' subsidies for clients are effective to speed up the system evolutionary rate.

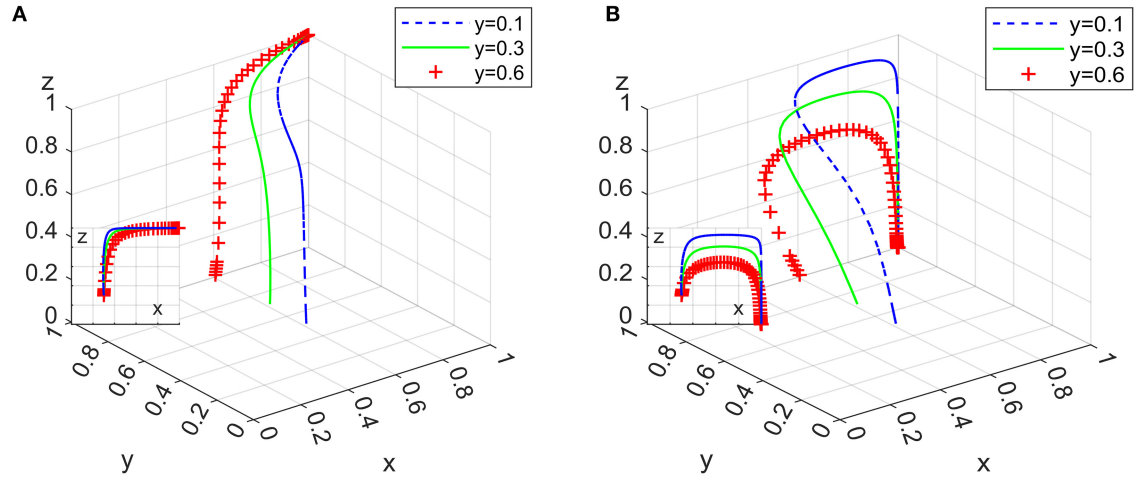


FIGURE 7
Impact of domestic enterprises' strategies in system L **(A)** and system P **(B)**.

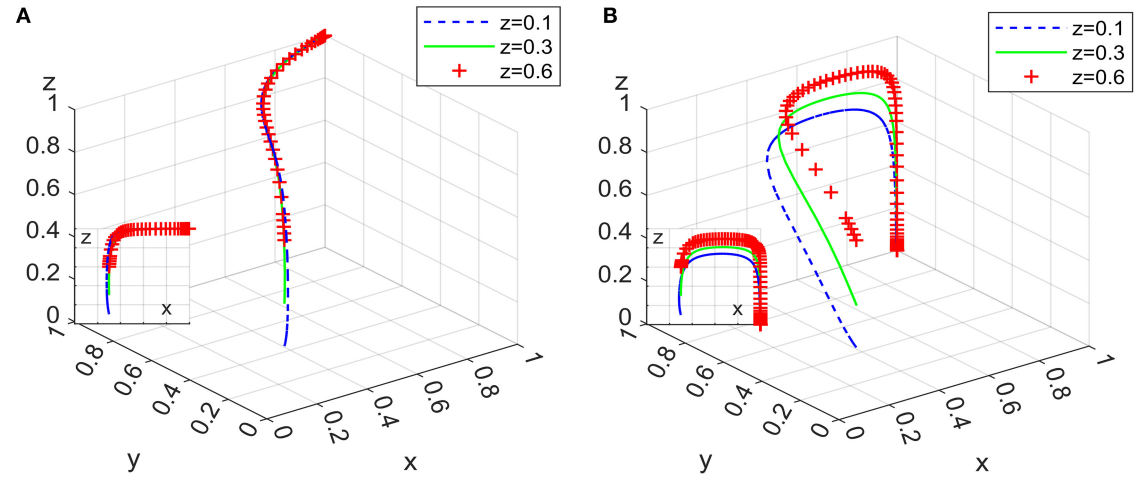


FIGURE 8
Impact of governmental departments' strategies in system L **(A)** and system P **(B)**.

6.2. Impact of governmental departments on subsidy intensity for domestic enterprises and clients

Under the condition that other parameters remain unchanged, assigning ϑ as 1, 1.15, and 1.3, the 100 simulation results of replicator dynamic equations in System L and P in time $t$are shown in Figure 9.

Figure 9 shows that for System L, the increase in the subsidy intensity of governmental departments for domestic enterprises with employee management systems slows down the rate of its evolution to an asymptotic stable point, while for System P, it speeds up the evolutionary rate. Additionally, the increase in y has a greater impact on System P than on System L. Combining Inferences V and VI, it can be seen that the increase in the total cost of "strict supervision" by governmental departments reduces the probability of governmental departments adopting this strategy, thereby reducing the probability of employers purchasing services through domestic enterprises. Therefore, when governmental departments implement "strict supervision" as a long-term strategy, subsidies for domestic enterprises should be properly controlled. When the implementation of "strict supervision" is a periodic strategy for governmental departments, subsidies for domestic enterprises should be increased as appropriate to promote the formalization of the domestic service industry.

Under the condition that other parameters remain unchanged, assigning φ as 1, 1.5, and 2, the 100 simulation results of replicator dynamic equations in Systems L and P in time t are shown in Figure 10.

Figure 10 shows that the increase in subsidy intensity for clients in the two systems has a positive impact on the process of system evolution. Combining Inferences I and VI, it can be seen that the increase in the subsidy intensity for clients can effectively increase their purchase probability, thereby speeding up the rate at which

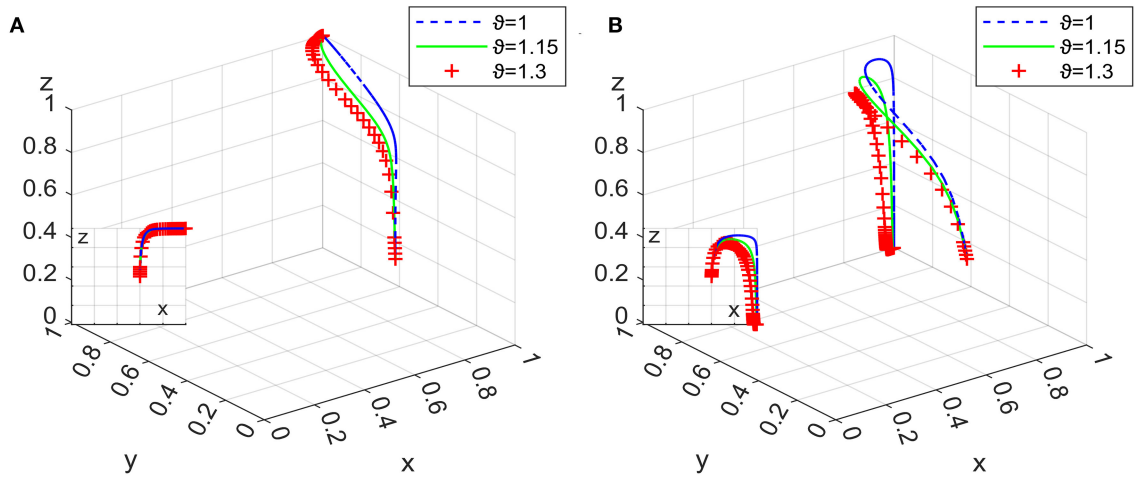


FIGURE 9
Impact on subsidy intensity for domestic enterprises in system L **(A)** and system P **(B)**.

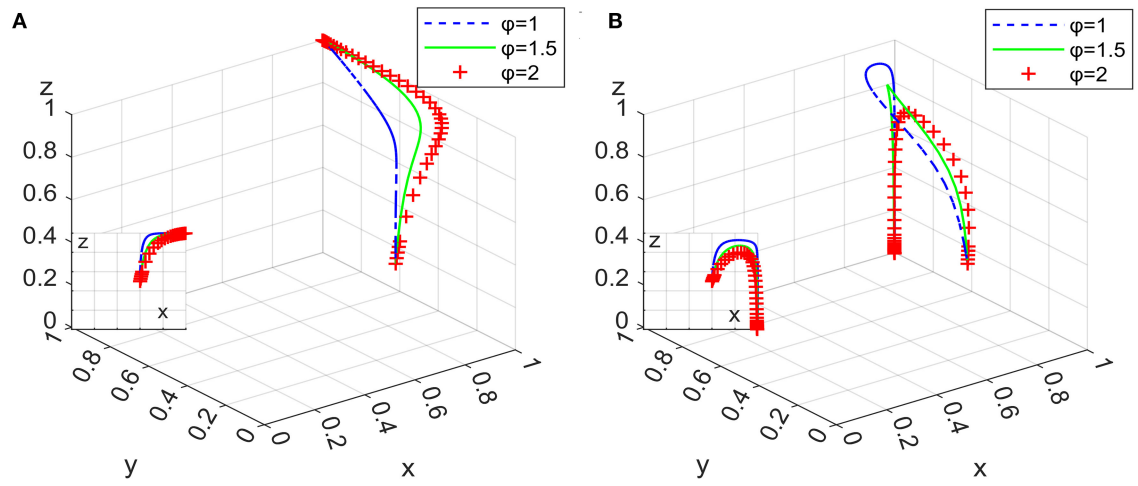


FIGURE 10
Impact on subsidy intensity for clients in system L **(A)** and system P **(B)**.

the system converges to an asymptotically stable point, meaning that regardless of whether governmental departments take subsidy policy as a long-term or periodic strategy, they should attach importance to subsidies for clients. In addition, Figures 9, 10 show that there are different degrees of marginal diminishing effects on the increase in the amount of subsidies for domestic enterprises and clients.

6.3. Impact of governmental departments on punishment intensity for domestic enterprises

Under the condition that other parameters remain unchanged, assigning θ as 0.5, 1, and 1.5, the 100 simulation results of replicator dynamic equations in System L and System P in time t are shown in Figure 11.

Figure 11 shows that there are differences in the impact of increasing the punishment intensity on irregular behavior for domestic enterprises with employee management systems in terms of convergence to an asymptotic stable point in different systems, and System L is more sensitive to such changes than System P is. In the process of converging to the asymptotic stable point of System L, the positive effect of increasing punishment intensity increases first and then decreases, while in System P, it shows a decreasing trend. Combining Inferences I and III, it can be seen that increasing the punishment intensity for the irregular behavior of domestic enterprises with employee management systems reduces their market share, thereby reducing the probability of clients' ideal strategy and extending the evolutionary path of the system. Moreover, compared with the situation in which governmental departments set up exit mechanisms with supervision and

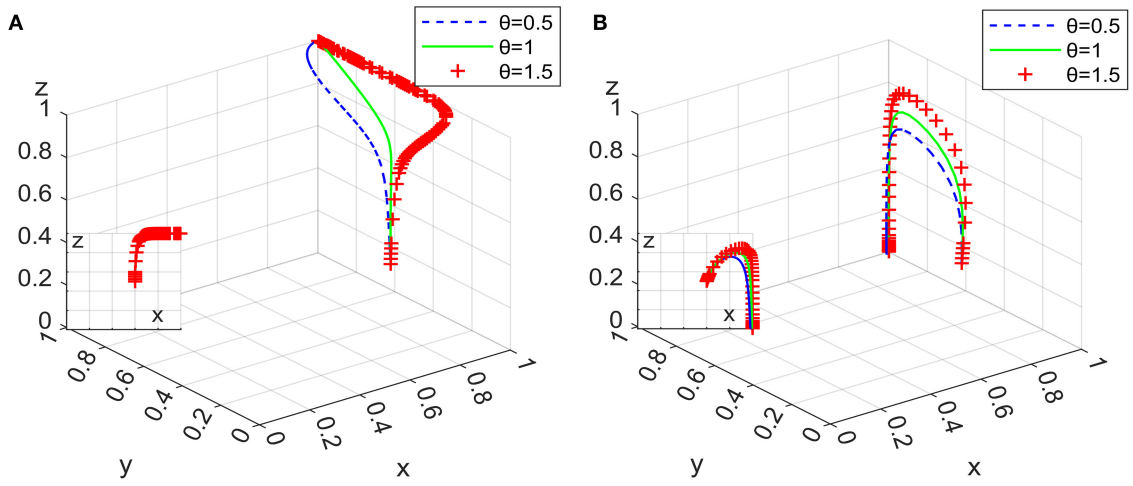


FIGURE 11
Impact on punishment intensity in system L **(A)** and system P **(B)**.

subsidies, when strict supervision is implemented by governmental departments as a long-term strategy, changes in punishment intensity for domestic enterprises have a more significant impact on the evolutionary path of the system.

7. Conclusions and contributions

By constructing a tripartite evolutionary game model of clients, domestic enterprises and governmental departments, this study conducts a theoretical analysis of the key factors that affect the choices and co-evolutionary strategies of actors and their mechanisms and uses the field survey data of domestic workers in four cities to assign values to the evolutionary game models for simulation analysis, and strive to reveal the mechanisms for the upgrading of the domestic service industry and the optimization of the business structure in China. The formalization of the domestic service industry is beneficial to improve the quality of elderly care, further promote the positive work experience of domestic workers engaged in home-based elderly care, provide market-oriented and standardized industrial support to the elderly care model with a high proportion of home-based elderly care, and establish a compensatory social network to support this elderly care model, which rescue the urgent dilemma of Chinese elderly care significantly.

7.1. Conclusions

The main conclusions of this study are presented below.

First, the initial ideal strategy ratios and differences between the profits and costs of each actor, subsidies to clients, and subsidies and punishments for the irregular behavior of domestic enterprises are the key factors that cause the system to converge to a gradual stable point, reflecting the formalization of the domestic service industry. The lower the initial proportion of the ideal strategy of clients and/or domestic enterprises is, the higher the probability that governmental departments choose to implement strict supervision. In addition, the punishment of irregular behavior for domestic enterprises with employee management systems by governmental departments should be less than the setting of its subsidies, which is more conducive to the realization of the formalization of the domestic service industry.

Second, policy planning can be divided into long-term or periodic planning, and the effect of certain key factors on the evolution of the system is different in different situations. Thus, the priorities of policies under different programs should be different. When governmental departments regard the implementation of subsidies and supervision as a long-term strategic plan, they should appropriately control subsidies to domestic enterprises. The rising costs of governmental departments reduce the probability of their choice to implement strict supervision, thereby reducing the probability of clients purchasing services through domestic enterprises and delaying the realization of the formalization of the domestic service industry. When governmental departments formulate exit mechanisms with subsidies and supervision, it is more efficient to promote the formalization of the domestic service industry by focusing on increasing the proportion of domestic enterprises with employee management systems to a certain market share and gradually reducing the proportion of those implementing strict supervision.

Third, the current subsidy policy only focuses on domestic enterprises, which is, to some extent, inefficient in promoting the formalization of the domestic service industry, because the initial proportional change in clients' ideal strategy has the greatest impact on the convergence to an asymptotic stable point.

7.2. Policy implications

Based on research conclusions and social reality, this study puts forward the policy recommendations presented below.

First, the subsidy structure should be continuously optimized. Initially, the subsidy targets at this moment are mainly domestic enterprises and domestic workers, and the emphasis on clients

should be increased. For example, governmental departments can issue consumer vouchers to households with home-based elderly care needs to reduce the purchase costs, and attract clients to purchase domestic services through domestic enterprises with employee management systems, which it could, formulate more targeted subsidy plans consequently. Compared with other kinds of domestic workers, elderly care workers generally have larger age structures and lower educational levels, and the advantages of domestic enterprises with employee management systems in providing social security and skills training may be difficult to realize. In this regard, it is possible to attract elderly care workers to choose to be employed through domestic enterprises with employee management systems by purchasing domestic accidental insurance for them. Specifically, governmental departments could expand the scope of services for the elderly by encouraging domestic enterprises with employee management systems to open community restaurants and cooperate with elderly care institutions.

Second, relevant governmental departments at all levels should adapt to local and time-sensitive conditions in the process of policy refinement and implementation. For example, domestic enterprises with employee management systems have a management model with high costs and profits. In regions with a low degree of the formalization of the domestic service market, domestic enterprises whose main business is elderly care services can be subsidized preferentially to encourage the development of a few typical enterprises, and there is no need to be vigorously promoted in the short term. As in small cities, with typical acquaintance society characteristics, households in need of elderly care services and elderly care workers are both more inclined to be introduced by familiar people to establish market relationship. In such cases, it is more difficult to popularize domestic enterprises with employee management systems. In some developed regions, policies can be more focused on exploring how to subsidize households in the need of elderly care services, accordingly with establishing policy supervision as well as evaluation mechanisms, with a principle cause that the larger the urban population, the faster the population mobility, and the stronger the population heterogeneity. In such a situation, it is easier to implement employee management systems which need higher professional standards.

Third, governmental departments should pay a great deal of attention to measures that can improve the quality of elderly care services. On the one hand, it is possible to develop domestic training materials and courses that are suitable for the current situation of home-based elderly care in Chinese society by cooperating with excellent domestic enterprises and universities to improve the professional skills and quality of elderly care workers. On the other hand, the elderly care service demand side can be included to establish long-term evaluation mechanisms to improve subsidy policy.

Fourth, executive branches cooperate with market organizations to implement evaluation and supervision programs. For example, it is possible for authorities in the field of domestic services to cooperate with relevant units, such as big data resource administrations, to establish domestic platforms that require real-name authentication. The content of the platforms should include the integrity management records of domestic enterprises, details of subsidy implementation, personal certification of domestic workers and clients, service evaluations, etc.

7.3. Limitations

This study also has certain limitations. First, the construction and analysis of evolutionary game models are based on relevant assumptions. Social phenomena are complex, and some important factors are abstract and difficult to represent numerically. The processing of these factors affects the process of system evolution to stable points. Although this study makes assumptions based on theory and reference to the previous literature in the process of constructing evolutionary game models, it cannot be guaranteed to be sufficiently perfect. Second, since it takes a certain period of time from the setting of subsidy policy to their implementation, the current subsidy policy has been implemented for a relatively short period of time, and there is still a lack of data on the financial expenditures of relevant governmental departments for verification purposes.

Data availability statement

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

Author contributions

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

Funding

This work was supported by the Philosophy and Social Science Foundation of China under grant no. 18ASH007.

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

References

1. Ungerson C, Yeandle S. *Cash for Care in Developed Welfare States*. New York, NY: Palgrave Macmillan (2007). p. 227.

2. Simonazzi A. Care regimes and national employment models. *Camb J Econ*. (2009) 33:211–32. doi: 10.1093/cje/ben043

3. Kvist E. Changing social organizations of care: a comparison of European policy reforms encouraging paid domestic work. *Eur J Age*. (2012) 9:111–7. doi: 10.1007/s10433-012-0225-9

4. Michel S, Peng I. All in the family? Migrants, nationhood, and care regimes in Asia and North America. *J Eur Soc Policy*. (2012) 22:406–18. doi: 10.1177/0958928712449774

5. Cui SY, Du TT. Research on the integrated development of home-based, community-based and institutional elderly care. *Dongyue Tribune*. (2021) 42:36–44. doi: 10.15981/j.cnki.dongyueluncong.2021.11.004

6. Zhao W, Sa ZW. Suggestions on promoting the quality and capacity expansion of the domestic service industry. *Soc Govern Rev*. (2021) 11:32–4. doi: 10.16775/j.cnki.10-1285/d.2021.11.006

7. Wang XY, Liu LP. Professional quality of domestic workers: problems and influencing factors—a qualitative study based on interview data. *Acad Bimestris*. (2020) 02:100–6. doi: 10.16091/j.cnki.cn32-1308/c.2020.02.015

8. Huang J. "Informalization" and development strategies in domestic service industry. *Soc Sci Res*. (2004) 05:112–4.

9. Zhang L, Yang Y. Investigation on the survival and development status of rural female domestic workers under the background of "new normal" population: based on sample analysis of Beijing, Guangzhou, Wuhan and Xi'an. *Hubei Soc Sci*. (2016) 05:51–7. doi: 10.13660/j.cnki.42-1112/c.013590

10. Zhang L, Xu AQ. The rights protection and social support for domestic workers: an example from household service in Shanghai. *J Soc Sci*. (2011) 02:83–90.

11. Ren MN, Liu LP. The conversion of rural idle laborers' housekeeping service and its employment stability. *J Northwest A&F Univ*. (2022) 22:109–22. doi: 10.13968/j.cnki.1009-9107.2022.04.12

12. Farvaque N. *Developing Personal and Household Services in the EU: A Focus on Housework Activities*. Luxembourg: Publications Office of the European Union (2013).

13. Devetter FX, Rousseau S. The impact of industrialization on paid domestic work: the case of France. *Eur J Ind Relat*. (2009) 15:297–316. doi: 10.1177/0959680109339414

14. Lin S, Bélanger D. Negotiating the social family: migrant live-in elder care-workers in Taiwan. *Asian J Soc Sci*. (2012) 40:295–320. doi: 10.1163/156853112X650854

15. Mousaid S, Bosmans K, Vanroelen C. Empowering domestic workers: a critical analysis of the Belgian service voucher system. *Societies*. (2017) 7:36. doi: 10.3390/soc7040036

16. Farris S R. The business of care: private placement agencies and female migrant workers in London. *Gend Work Org*. (2020) 27:1450–67. doi: 10.1111/gwao.12520

17. Meagher G. Is it wrong to pay for housework? *Hypatia*. (2002) 17:52–66. doi: 10.1111/j.1527-2001.2002.tb00765.x

18. Pande A. "The paper that you have in your hand is my freedom": migrant domestic work and the sponsorship (Kafala) system in Lebanon. *Int Migrat Rev*. (2013) 47:414–41. doi: 10.1111/imre.12025

19. Glenn EN. From servitude to service work: Historical continuities in the racial division of paid reproductive labor. *Signs J Women Cult Soc*. (1992) 18:1–43. doi: 10.1086/494777

20. Gavanas A. *Who Cleans the Welfare State? Migration, Informalization, Social Exclusion and Domestic Services in Stockholm*. Stockholm: Institute for Futures Studies (2010).

21. Bowman JR, Cole AM. Cleaning the 'People's home': the politics of the domestic service market in Sweden. *Gend Work Org*. (2014) 21:187–201. doi: 10.1111/gwao.12029

22. Palmer E, Eveline J. Sustaining low pay in aged care work. *Gend Work Org*. (2012) 19:254–75. doi: 10.1111/j.1468-0432.2010.00512.x

23. Johnson EK. The business of care: the moral labour of care workers. *Sociol Health Illness*. (2015) 37:112–26. doi: 10.1111/1467-9566.12184

24. Cai JY, Yang P, Guo XY, Zhang TL. The impact of training on the incomes of domestic workers. *Econ Forum*. (2016) 03:102–5.

25. Jokela M. The role of domestic employment policies in shaping precarious work. *Soc Policy Admin*. (2017) 51:286–307. doi: 10.1111/spol.12288

26. Windebank J. Outsourcing women's domestic labour: the Cheque Emploi-Service Universel in France. *J Eur Soc Policy*. (2007) 17:257. doi: 10.1177/0958928707078368

27. Bailly F, Devetter FX, Horn F. Can working and employment conditions in the personal services sector be improved? *Camb J Econ*. (2013) 37:299–321. doi: 10.1093/cje/bes071

28. Jokela M. Patterns of precarious employment in a female-dominated sector in five welfare states: the case of paid domestic labor sector. *Soc Polit Int Stud Gend State Soc*. (2019) 26:30–58. doi: 10.1093/sp/jxy016

29. Tomei M. Decent work for domestic workers: reflections on recent approaches to tackle informality. *Can J Women Law*. (2011) 23:185–212. doi: 10.3138/cjwl.23.1.185

30. van Walsum S. Regulating migrant domestic work in the Netherlands: opportunities and pitfalls. *Can J Women Law*. (2011) 23:141–65. doi: 10.3138/cjwl.23.1.141

31. Morel N. Servants for the knowledge-based economy? The political economy of domestic services in Europe. *Soc Polit Int Stud Gend State Soc*. (2015) 22:170–92. doi: 10.1093/sp/jxv006

32. Shutes I, Walsh K. Negotiating user preferences, discrimination, and demand for migrant labour in long-term care. *Soc Polit Int Stud Gend State Soc*. (2012) 19:78–104. doi: 10.1093/sp/jxr025

33. Smith J, Price GR. The logic of animal conflict. *Nature*. (1973) 246:15–8. doi: 10.1038/246015a0

34. Sheng GH, Zhang ZY. Allowance method's influence on the innovation model choice in evolutionary game. *J Manag Sci China*. (2015) 18:34–45.

35. Cao X, Xing ZY, Zhang LP. An evolutionary game analysis of new energy vehicle industry development under government regulations. *Manag Rev*. (2018) 30:82–96. doi: 10.14120/j.cnki.cn11-5057/f.2018.09.008

36. Zhou XY, Zhao F, Liu Y, Wang SY. How do government subsidies and cost sharing affect platform and enterprise strategy choice: based on tripartite evolutionary game. *Control Dec*. (2022) 37:293–302. doi: 10.13195/j.kzyjc.2021.0853

37. Ji SF, Zhao D, Luo RJ. Evolutionary game analysis on local governments and manufacturers' behavioral strategies: Impact of phasing out subsidies for new energy vehicles. *Energy*. (2019) 189:116064. doi: 10.1016/j.energy.2019.116064

38. Xiao ZD, Cao QY, Lang QX, Shu WJ, Li JL. Evolutionary game and empirical analysis of the local governments and the upstream and downstream enterprises in the industrial symbiosis chain under environmental regulations. *Syst Eng*. (2020) 38:1–13.

39. Zhu LL, Rong JM, Zhang SY. Three-party evolutionary game and simulation analysis of drug quality supervision under the government reward and punishment mechanism. *Chin J Manag Sci*. (2021) 29:55–67. doi: 10.16381/j.cnki.issn1003-207x.2019.0481

40. Wang S, Chen Z, Xiao Y, Lin C. Consumer privacy protection with the growth of AI-empowered online shopping based on the evolutionary game model. *Front Public Health*. (2021) 9:5777. doi: 10.3389/fpubh.2021.705777

41. He H, Zhang S, Zhu L. Green product quality supervision strategy in online shopping with consumer evaluation and complaint. *Front Environ Sci*. (2021) 340:2151. doi: 10.3389/fenvs.2021.702151

42. Galor O, Weil DN. Population, technology, and growth: from Malthusian stagnation to the demographic transition and beyond. *Am Econ Rev*. (2000) 90:806–28. doi: 10.1257/aer.90.4.806

43. Ritzberger K, Weibull JW. Evolutionary selection in normal-form games. *Economet J Economet Soc*. (1995) 63:1371–99. doi: 10.2307/2171774

44. Friedman D. Evolutionary games in economics. *Economet J Economet Soc*. (1991) 59:637–66. doi: 10.2307/2938222

45. Hofbauer J, Sandholm WH. Stable games and their dynamics. *J Econ Theory*. (2009) 144:1665–93. doi: 10.1016/j.jet.2009.01.007

frontiers | Frontiers in Public Health

TYPE Original Research
PUBLISHED 21 June 2023
DOI 10.3389/fpubh.2023.1200722

OPEN ACCESS

EDITED BY
Ronald W. Berkowsky,
California State University Channel Islands, United States

REVIEWED BY
Sylva Bártlová,
University of South Bohemia in České Budějovice, Czechia
Cindy Davis,
University of the Sunshine Coast, Australia

*CORRESPONDECE
Yu Luo
✉ luoyuhlgl@tmmu.edu.cn

†These authors have contributed equally to this work

RECEIVED 05 April 2023
ACCEPTED 26 May 2023
PUBLISHED 21 June 2023

CITATION
Liu S, Lu Y, Wang D, He X, Ren W, Kong D and Luo Y (2023) Impact of digital health literacy on health-related quality of life in Chinese community-dwelling older adults: the mediating effect of health-promoting lifestyle. *Front. Public Health* 11:1200722. doi: 10.3389/fpubh.2023.1200722

Impact of digital health literacy on health-related quality of life in Chinese community-dwelling older adults: the mediating effect of health-promoting lifestyle

Siqi Liu†, Ya Lu†, Dan Wang, Xiaochong He, Wei Ren, Dehui Kong and Yu Luo*

School of Nursing, Army Medical University (Third Military Medical University), Chongqing, China

Background: In the context of aging and digitalization, the development and application of digital health can help meet the growing health needs of older adults. Improving digital health literacy of older adults may be an effective way to alleviate the shortage of public health resources and improve their health-related quality of life (HRQoL). However, the impact of digital health literacy on HRQoL in older adults and the underlying mechanism remain unclear. This study intends to explore whether digital health literacy has an effect on HRQoL in community-dwelling older adults, and whether health-promoting lifestyle plays a mediating role between digital health literacy and HRQoL, while providing a theoretical basis for the scientific construction of HRQoL intervention programs for older adults.

Methods: The cross-sectional study was conducted in Chongqing, China from September 2020 to April 2021. 572 community-dwelling older adults were surveyed by stratified sampling. Data on sociodemographic characteristics, digital health literacy, health-promoting lifestyle and HRQoL were collected. Univariate analysis was used to compare the differences in HRQoL among community-dwelling older adults with different sociodemographic characteristics. Pearson correlation analysis was used to explore the correlation between digital health literacy, health-promoting lifestyle and HRQoL. SPSS PROCESS macro was used to examine the mediating effect of health-promoting lifestyle between digital health literacy and HRQoL.

Results: The mean score of HRQoL was 97.97 (SD 11.45). Univariate analysis showed that there were statistically significant differences in HRQoL among community-dwelling older adults with different gender, age, educational level, marital status, and monthly household income *per capita* ($p<0.05$). There were positive correlations between digital health literacy, health-promoting lifestyle and HRQoL, with correlation coefficients ranging from 0.416 to 0.706 ($p<0.001$). Digital health literacy was positively associated with HRQoL ($\beta=0.210$, $p<0.001$), and health-promoting lifestyle mediated the relationship between digital health literacy and HRQoL, with an indirect effect of 0.175 (95% Bootstrap CI 0.135–0.214).

Conclusion: Digital health literacy can affect HRQoL through the mediating effect of health-promoting lifestyle. It is suggested that relevant management institutions, communities and families should strengthen the cultivation of the digital health literacy of older adults, promote their development of health-promoting lifestyle, and ultimately improve HRQoL.

KEYWORDS

health-related quality of life, digital health literacy, electronic health literacy, eHealth literacy, health-promoting lifestyle, mediating effect, older adults

1. Introduction

Global aging is progressing at an unprecedented rate and will further accelerate in the coming decades (1), directly resulting in a significant increase in the demand for public health services and medical expenditures (2). Properly solving the problem of population aging and improving the health-related quality of life (HRQoL) of older adults have become important issues of global concern. HRQoL is a key component of healthy aging (3), and refers to an individual's subjective feelings and overall satisfaction with respect to their physical function, mental state, and social abilities (4, 5). The results of systematic reviews confirmed that HRQoL of older adults is closely related to sociodemographic factors, social well-being, health status and health behaviors (6, 7). Among them, factors such as sociodemographic characteristics and chronic disease conditions are difficult to change. In order to effectively improve HRQoL of older adults, it is necessary for health professionals to seek modifiable factors as new targets to implement interventions.

The rapid advances in information and communications technology (ICT) contribute to the increasing innovation, and upgrading of health service mode and the emergence of digital health offers a new idea for improving the HRQoL of older adults. Especially during the COVID-19 pandemic, the vulnerable older adults are advised to stay at home and try to avoid unnecessary trips by the public health authority (8). Most of the supply to meet their needs for health services has to shift to online (9). Digital health enables low-cost, high-quality and prompt health care services for senior citizens and plays an important role in maintaining their physical and mental health (10). Digital health literacy, also known as electronic health literacy or eHealth literacy, reflects the ability to make use of the digital health services effectively, which is defined as an individual's ability to search, understand and evaluate the health information on digital media, actively engage in the exchange and interactions of health information, and use the acquired information for health management and health problem-solving (11, 12). An increasing body of evidence suggests that the digital health literacy-related interventions can significantly improve the health of older adults and promote healthy aging (10, 13). However, there is limited empirical research exploring the relationship between digital health literacy and HRQoL, merely with inconsistent conclusions. According to the longitudinal and cross-sectional studies of Iranian older adults, digital health literacy and HRQoL were significantly correlated (14, 15). However, the survey on American older adults showed no significant correlation between digital health literacy and HRQoL (16). The latest systematic review also underlined that the impact of digital health literacy on the HRQoL of older adults is unclear and there is still a lack of study into the underlying mechanism of effect (17).

The Integrative Model of eHealth Use (IMeHU) suggests that people with better digital health literacy have higher motivation and ability to use the Internet to obtain health information, more active online health behaviors, easier to master more health knowledge and form positive health beliefs and health behaviors (18). The results of the systematic review also proved that the use of digital health tools can stimulate positive health behaviors in older adults and promote the development of health-promoting lifestyle (19), suggesting that health-promoting lifestyle may be a potential mediating factor. Health-promoting lifestyle refers to actions that individuals take the initiative to pursue, which could benefit their health, including health responsibility, nutrition, physical activity, interpersonal relations, stress management, and spiritual growth (20). A previous study on Chinese college students found that health-promoting lifestyle played an important mediating role between health literacy and HRQoL (21). Digital health literacy is an extension of health literacy in the field of digital health (22). The mediating effect of health-promoting lifestyle between digital health literacy and HRQoL in older adults may also be established, but it remains to be confirmed by empirical research.

As the country with the largest older adults population in the world (23), China has 191 million people over the age of 65 (24), where the aging situation is extremely severe. In the last decade, Chinese government has been committed to actively promoting the adoption of ICT into the healthcare domain (25, 26), as well as strengthening the smart senior care industry (27). Taking Chinese community-dwelling older adults as an example, the current study discusses the effective ways to improve HRQoL of older adults from the unique perspective of digital health literacy, which can provide new ideas and methods for developing health promotion programs to enhance HRQoL in the future. Therefore, the objective of this study was to explore the relationship between digital health literacy and HRQoL of older adults and factors that mediate the association, and we developed the following priori hypotheses (Figure 1): (1) Digital health literacy will be positively correlated with HRQoL; (2) Health-promoting lifestyle will mediate the relationship between digital health literacy and HRQoL.

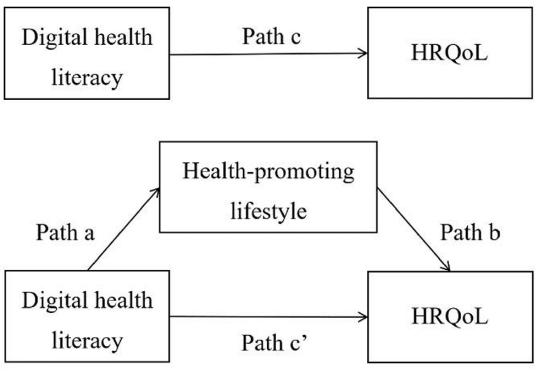


FIGURE 1
The hypothesised model.

2. Methods

2.1. Participants

This cross-sectional study was carried out in the main urban areas of Chongqing, China from September 2020 to April 2021. The sample size was estimated using the formula for epidemiology study in estimating the mean of continuous outcome: $n = \left(\frac{Z_{1-\alpha/2} \times \sigma}{\delta}\right)^2$ (28). According to a previous study, the standard deviation of HRQoL in Chinese older adults was 18.29 (29). Thus, we set σ as 18.29 in this study. Using $\alpha = 0.05$, $Z_{1-\alpha/2} = 1.96$, $\delta = 2.00$, the calculated sample size was 321. Multistage stratified sampling method was used for sample selection. Firstly, according to the statistics of Chongqing Statistics Bureau in 2019 (30), we categorized 9 administrative districts in main urban areas of Chongqing into three levels according to gross domestic product (GDP) *per capita*, and 1 administrative district was randomly selected from each category. Then 2 ~ 5 communities were selected from each of the selected administrative districts, and a total of 10 communities were used as sample sites for the study. Lastly, older adults who met the inclusion criteria were recruited from the selected communities for a questionnaire survey. The inclusion criteria were permanent residents in main urban areas of Chongqing and aged 65 years or older. The exclusion criteria were mental illness diagnosis, a definite diagnosis of severe physical illness, and declining to participate.

Research group members with standardized training served as investigators, explaining the purpose of the research to participants, and distributing paper questionnaires after obtaining written and oral informed consent. Questionnaires were filled out by participants themselves. Those who had difficulty in filling in the forms themselves were assisted by an investigator to read the questions one by one and record their answers. Once each participant completed the questionnaire, the investigators immediately checked on-site and asked the participant to complete the questionnaire if there were any omissions. In the end, A total of 600 questionnaires were distributed and 572 valid questionnaires were obtained, with an effective recovery rate of 95.33%. Our research was ethically approved by the Ethics Committee of Army Medical University/Third Military Medical University (approval number 2020–012-02). And survey administration was conducted according to the Declaration of Helsinki.

2.2. Measures

The questionnaire contained questions regarding sociodemographic characteristics, digital health literacy, health-promoting lifestyle, and HRQoL.

2.2.1. Assessment of sociodemographic characteristics

A self-designed sociodemographic information questionnaire was used to collect data on participants' gender, age (65–69, 70–74, 75–79 and ≥ 80 years), education level (primary school or below, junior high school, senior high school, college or above), marital status (with spouse or without spouse), and monthly household income per capital (<1,000, 1,000–2,999, 3,000–4,999, ≥5,000).

2.2.2. Digital health literacy assessment scale for community-dwelling older adults (DHLAS)

Digital Health Literacy Assessment Scale for community-dwelling older adults was developed by our research group in the previous research (see Supplementary material for complete scale) (31). It was the first original digital health literacy assessment tool targeted for Chinese older adults, based on the digital health background and digital devices usage characteristics of older adults in China, and proven to be with good internal consistency (0.941), spilt-half reliability (0.889), test–retest reliability (0.941), content validity (0.967), criterion validity (0.938) and construct validity. The scale included 3 dimensions of digital health information acquisition and evaluation ability (9 items), digital health information interaction ability (3 items), and digital health information application ability (3 items), with a total of 15 items. Answers were based on a 5-point Likert scale ranging from 1 ("strongly disagree") to 5 ("strongly agree"). The total score was 15–75 points. Higher scores indicate a higher level of digital health literacy. Cronbach's α coefficient for the total scale in this study was 0.959.

2.2.3. Health promoting lifestyle profile-II, revise (HPLP-IIR)

Health Promoting Lifestyle Profile (HPLP) was developed by Walker et al. (32) to measure individual health promotion behaviors. This study employed the Chinese revised version by Cao et al. (33), with a total of 40 items, including 6 dimensions of physical activity (8 items), health responsibility (11 items), stress management (5 items), nutrition (6 items), interpersonal relations (5 items) and spiritual growth (5 items). The scale used a 4-point Likert scale ranging from 1 ("never") to 4 ("always"). The total score was 40–160 points. Higher scores indicate a healthier lifestyle. The instrument has been validated for use in Chinese older adults, the reliability of which has been reported with a Cronbach's α coefficient 0.82 for total scale (34). In this study, Cronbach's α coefficient was 0.926.

2.2.4. 12-item short form health survey (SF-12)

12-item short form health survey (SF-12), the abbreviated version of the 36-item short form health survey (SF-36), was developed by the health Institute of New England Medical Center to assess HRQoL (35). The scale is consisted of 12 items, including 8 dimensions, namely general health (GH), physical functioning (PF), role physical (RP), bodily pain (BP), role emotional (RE), vitality (VT), mental health (MH) and social functioning (SF). The first four dimensions were combined into the physical component summary (PCS), while the last four dimensions were combined into the mental component summary (MCS). PCS and MCS were scored with a mean of 50 and a SD of 10, ranging from 0 to 100 in the general population (35, 36), reflecting individual's physical and mental health status, respectively. According to the score criteria, the total score was transformed into standard scores, with higher score indicating better HRQoL. Chinese version SF-12 has been verified to have good reliability and validity when applying to the health status evaluation of Chinese community-dwelling older adults, with Cronbach's α coefficient of 0.910 (37). The Cronbach's α coefficient in this study was 0.884.

2.3. Data analysis

Data was analysed with SPSS 23.0. Continuous variables conforming to normal distribution (such as digital health literacy, health-promoting lifestyle, and HRQoL, etc.) were described by means ± standard deviation (SD), and categorical variables (such as gender, education level, etc.) were described by *N* (%). Independent sample t test and one-way analysis of variance (ANOVA) were used to compare the differences of HRQoL among community-dwelling older adults with different sociodemographic characteristics. Pearson correlation analysis was used to explore the correlation between digital health literacy, health-promoting lifestyle and HRQoL of older adults.

The hypothesized mediation model (Figure 1) was examined via the PROCESS macro in SPSS (38), which is widely used to test the mediating effects in current studies (9, 39). We used the digital health literacy as the prediction variable, health-promoting lifestyle as the mediator variable, and HRQoL as the outcome variable. Meanwhile, sociodemographic factors, including gender, age, education level, marital status, and monthly household income *per capita*, were used as covariates in the analyses to overcome the potential confounding effects. The coefficient c' was the direct effect of digital health literacy on HRQoL. Digital health literacy might also indirectly influence HRQoL through health-promoting lifestyle, the effects of which were captured by the produce of coefficients a and b (a × b). Coefficient c was the total effect of digital health literacy on HRQoL, namely c' + a × b. Point estimates were based on 5,000 bootstrap samples, and 95% confidence intervals (CI) were constructed. An indirect effect was considered significant if the CI did not contain zero. All statistical tests were two-tailed and statistical significance for all analysis was set at 0.05.

3. Results

3.1. Sociodemographic characteristics and HRQoL status of samples

This study included 572 community-dwelling older adults with a mean age of 70.93 (SD 5.51) years, ranging from 65 to 88 years. More than half of participants only had junior high school education or below (388/572, 67.83%). Among all participants, the mean score of HRQoL was 97.97 (SD 11.45), in which the mean score of PCS was 44.70 (SD 9.45), and the MCS was 53.26 (SD 6.81). The results of univariate analysis indicated that there were statistically significant differences in HRQoL among older adults with different gender, age, education level, marital status, and monthly household income *per capita* ($p < 0.05$). Female, 70 years old and above, without spouse, primary school education or below, monthly household income *per capita* below 1,000 yuan, are the characteristics older adults with which have a lower level of HRQoL compared with other groups. For further details, see Table 1.

TABLE 1 The status of HRQoL by different sociodemographic characteristics (*N* =572).

Characteristics	*n* (%)	HRQoL			
		Mean±SD	*t* or *F*	*p* value	*Post hoc*
Gender			2.232	0.026	
Male	273 (47.73%)	99.08 ± 11.28			
Female	299 (52.27%)	96.95 ± 11.53			
Age (years)			10.853	<0.001	
65-69[a]	283 (49.48%)	100.46 ± 10.04			a > b, c, d
70-74[b]	144 (25.17%)	96.44 ± 11.70			
75-79[c]	92 (16.08%)	95.81 ± 12.09			
≥80[d]	53 (9.27%)	92.57 ± 13.53			
Education level			12.214	<0.001	
Primary school or below[a]	202 (35.31%)	94.36 ± 12.38			a < b, c, d
Junior high school[b]	186 (32.52%)	98.84 ± 10.56			
Senior high school[c]	114 (19.93%)	101.27 ± 10.75			
College and above[d]	70 (12.24%)	100.68 ± 9.18			
Marital status			2.959	0.003	
With spouse	444 (77.62%)	98.80 ± 10.87			
Without spouse	128 (22.38%)	95.09 ± 12.92			
Monthly household income *per capita* (RMB)			12.359	<0.001	
<1000[a]	42 (7.34%)	90.50 ± 11.78			a < b, c, d
1,000-2999[b]	216 (37.76%)	96.66 ± 12.15			b < d
3,000-4999[c]	242 (42.31%)	99.03 ± 10.67			c < d
≥5000[d]	72 (12.59%)	102.68 ± 8.72			

The lowercase letters a,b,c and d represent different groups of the characteristics of different age, education level and monthly household income *per capita*.

TABLE 2 Correlations (r) between digital health literacy, health-promoting lifestyle, and HRQoL (N =572).

Variables	Mean±SD	1	2	3
1.Digital health literacy	37.10 ± 18.65	1	–	–
2.Health-promoting lifestyle	109.53 ± 16.64	0.706***	1	–
3.HRQoL	97.97 ± 11.45	0.416***	0.507***	1

***$p < 0.001$.

TABLE 3 Multivariate linear regression analysis for the association among digital health literacy, health-promoting lifestyle, and HRQoL (N =572).

Variables	Model 1 (HRQoL)			Model 2 (Health-promoting lifestyle)			Model 3 (HRQoL)		
	B (SE)	t	*p* value	B (SE)	t	*p* value	B (SE)	t	*p* value
Gender	−1.613 (0.905)	−1.782	0.075	5.411 (0.997)	5.428	<0.001	−3.364 (0.869)	−3.874	<0.001
Age	−0.279 (0.086)	−3.259	0.001	0.038 (0.094)	0.401	0.689	−0.291 (0.080)	−3.637	<0.001
Education level	−0.309 (0.549)	−0.563	0.574	1.768 (0.605)	2.926	0.004	−0.882 (0.517)	−1.704	0.089
Marital status	−0.681 (1.117)	−0.610	0.542	−2.464 (1.230)	−2.004	0.046	0.117 (1.048)	0.112	0.911
Monthly household income *per capita*	1.295 (0.669)	1.935	0.054	2.180 (0.737)	2.958	0.003	0.589 (0.631)	0.934	0.351
Digital health literacy	0.210 (0.029)	7.280	<0.001	0.541 (0.032)	17.006	<0.001	0.035 (0.033)	1.061	0.289
Health-promoting lifestyle							0.324 (0.036)	9.057	<0.001
R^2	0.202			0.542			0.303		
F	23.811 ($p < 0.001$)			111.455 ($p < 0.001$)			35.056 ($p < 0.001$)		

TABLE 4 Mediation analyses of health-promoting lifestyle in the association between digital health literacy and HRQoL.

	Effect	95% Bootstrap CI	Bootstrap SE
Total effect (c)	0.210	(0.152, 0.269)	0.030
Direct effect (c')	0.035	(−0.028, 0.099)	0.032
Indirect effect (a × b)	0.175	(0.135, 0.214)	0.021

3.2. Correlations between digital health literacy, health-promoting lifestyle, and HRQoL

Pearson's r correlation analysis indicated that digital health literacy and health-promoting lifestyle were significantly positively associated with HRQoL ($r = 0.416$, $p < 0.001$; $r = 0.507$, $p < 0.001$). Meanwhile, digital health literacy was also significantly positively associated with health-promoting lifestyle ($r = 0.706$, $p < 0.001$) (Table 2). The significant correlation between the three variables suggested that the relationship between the variables could be further analysed and explained by establishing a model for regression analysis.

3.3. Mediation test for health-promoting lifestyle

Tables 3, 4 and Figure 2 presented the mediation analysis result based on the PROCESS macro. After controlling sociodemographic factors, the total effect of digital health literacy on HRQoL was significant (c = 0.210, $p < 0.001$). Then putting the mediation variable of health-promoting lifestyle into the model, the direct effect was statistically non-significant (c' = 0.035, $p > 0.05$). In addition, digital health literacy had a significant predictive effect on health-promoting lifestyle (a = 0.541, $p < 0.001$), and the predictive effect of health-promoting lifestyle on HRQoL was also significant (b = 0.324, $p < 0.001$). We further generated 5,000 bootstrapping samples from the original dataset by random sampling to assess the size of the indirect effect. The results indicated that this indirect effect (a × b) was 0.175, with a 95% CI from 0.135 to 0.214. The bootstrap 95% CI did not conclude zero, revealing that the mediating effect was statistically significant. Thus, health-promoting lifestyle mediated the association between digital health literacy and HRQoL, and the model accounted for 30.3% of the total variance of HRQoL.

4. Discussion

In the context of aging and digitalization, this study taking Chinese community-dwelling older adults as example, explored and confirmed the impact of digital health literacy on HRQoL of older adults and the mediating effect of health-promoting lifestyle in the relationship. It has important reference value for future theoretical and practical research on improving HRQoL for older adults.

Our findings revealed a significant difference in the HRQoL score of older adults by gender, age, education level, marital status, and monthly household income *per capita*, which was consistent with the results of previous studies (40–42). These identified non-modifiable factors can be used to determine which individuals are at risk of poor HRQoL, and to identify the vulnerable population that health professionals need to target. In health education, we should pay high attention to population who are female, aged 70 and older, have no partner, only received primary education or below, with a monthly household income per capita less than 1,000 yuan and deliver more health interventions to improve their HRQoL.

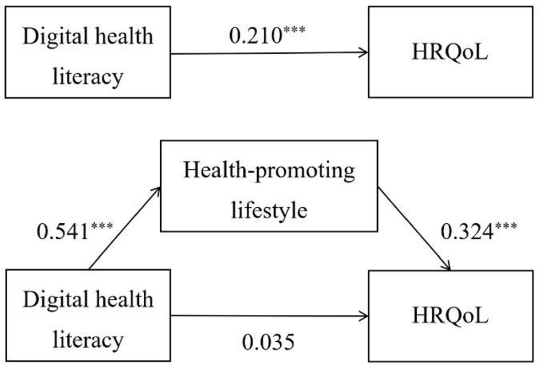


FIGURE 2
Health-promoting lifestyle mediated the association of digital health literacy and HRQoL. ***$p < 0.001$.

This study found that digital health literacy was positively correlated with HRQoL of community-dwelling older adults, which confirmed Hypothesis 1. The possible explanation is that in the context of the digital health era, higher digital health literacy means more varied health information resources and more efficient digital health services. In the daily life, more health information resources will help older adults change their wrong health awareness and health lifestyle, to build more positive health behaviors and maintain better health (43). When seeking health services, the older adults who are skilled in using digital health services will be able to manage their health in a more efficient manner and communicate with health personnels in real time so that they can be provided with more comprehensive and customized health services to help with disease treatment and management (44). During the COVID-19 pandemic, conventional offline diagnosis and treatment are restricted and the impact of digital health literacy on HRQoL has been further expanded. The older adults who lack of digital health literacy are unable to make effective use of online health information platforms, telemedicine service and other digital health services, thus it becomes extremely inconvenient for them to get daily health consultations, purchase drugs and so on (45). At the same time, faced with massive and complicated information about the pandemic, it is hard to identify the real information from the wrong one and older adults are highly susceptible to negative emotions like fear and anxiety which have a great impact on their health, both physically and mentally (46). Therefore, older adults as the vulnerable group in the Internet age are affected far more than other groups in HRQoL because of lacking digital health literacy. Health professionals should give sufficient attention to them.

This study also found that health-promoting lifestyle fully mediated the association between digital health literacy and HRQoL of community-dwelling older adults, which preliminarily elucidated the mechanism of association between digital health literacy and HRQoL, and confirmed Hypothesis 2. The mediating effect was mainly divided into two stages, namely, (1) digital health literacy had a positive effect on health-promoting lifestyle, and (2) health-promoting lifestyle had a positive effect on HRQoL. Both stages have been confirmed in previous studies as ample literature support for this study (14, 47–50). Meanwhile, it is worth emphasizing that this study adopted DHLAS based on the current context of the Internet in China and the characteristics of digital devices usage among older adults to assess digital health literacy, which is different from former universal scale survey and is a further expansion of previous research conclusions. The mediating effect of health-promoting lifestyle between digital health literacy and HRQoL can be explained by Andersen's Behavioral Model of Health Services Use (51). This model emphasizes that individual characteristics is an antecedent variable influencing health behaviors and health outcomes. It can either directly affect health outcomes or indirectly affect health outcomes by influencing health behaviors (52). Enabling resources in the dimension of individual characteristics refers to the availability of health service resources and the ability of individuals to access health services (53). Digital health literacy can be seen as one of the key competencies. It can be inferred based on this model that older adults with higher digital health literacy are more confident in using digital health services and more active in accessing effective health resources through digital media, thereby improving their awareness of health management and adoption of science-based health management behaviors, developing more positive health-promoting lifestyle that in return improve HRQoL.

This study has important theoretical and practical implications for improving HRQoL of community-dwelling older adults. First, this study evaluates the digital health literacy of older adults with an original designed tool based on the characteristics of older adults digital health behaviours to fill the gap in the literature, expounding the relationship between digital health literacy and HRQoL of older adults, and enrich the conclusions of previous studies. Second, this study explores and confirms the important mediating effect of health-promoting lifestyle between digital health literacy and HRQoL of older adults with a new perspective. Third, this study may provide new ideas for the interventions to improve HRQoL for older adults. The findings suggest that in the future health professionals may intervene in HRQoL of older adults from the perspectives of digital health literacy and health-promoting lifestyle. On the one hand, communities should carry out normalized digital health literacy training. By building community exchange and mutual assistance platforms combined with family guidance, the digital health literacy of older adults can be jointly promoted to help them obtain and apply health information more efficiently, and promote the transformation of health behaviors. On the other hand, health professionals should strengthen daily health education to guide older adults to adopt a healthy lifestyle such as doing physical exercises and keeping a balanced diet, so as to enhance HRQoL.

This study has certain limitations. First, our research is cross-sectional, which makes it impossible to clarify the causal relationship and direction of effect among digital health literacy, health-promoting lifestyle and HRQoL. Longitudinal or intervention studies could be conducted in the future to further confirm the longitudinal association or causality between them. Second, this study was only conducted in Chongqing, China. Considering that individual digital health literacy level and HRQoL status are closely related to local economic development level, we should pay attention to the extrapolation of the research results. In future studies, the sample size should be further expanded and a large-scale cross-regional survey should be conducted to make the research results more representative. Third, this study used self-report measures, which may have some information bias.

5. Conclusion

This study focuses on the impact of digital health literacy on HRQoL of community-dwelling older adults and explores the mediating effect of health-promoting lifestyle in a creative way by constructing and confirming the mediation model. To some extent, this enriches the perspectives of digital health literacy study and offers an updated idea for improving HRQoL of community-dwelling older adults. Relevant regulatory authorities, communities, and families are prompted to endeavor to raise the digital health literacy of older adults, broaden access to health information and build up their ability to apply it in the future, assist with the development of health-promoting lifestyle, and help them fully enjoy the convenience of digital health to improve HRQoL and promote healthy aging.

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 ethical committees of Army Medical University/Third Military Medical University. The patients/participants provided their written informed consent to participate in this study.

Author contributions

YuL obtained funding for the study. SL, YaL, and YuL conceived and designed the study. DW, XH, and WR coordinated the study. SL, YaL, DW, XH, and WR collected the data. SL, DK analysed and interpreted the data. SL and YaL drafted the manuscript. YuL and DK revised the manuscript. All authors contributed to the article and approved the submitted version.

Funding

The research was supported by the National Social Science Fund of China (Grant No. 19XRK001).

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.

Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpubh.2023.1200722/full#supplementary-material

References

1. World Health Organization. *Decade of healthy aging 2020–2030*. (2021). Available at: https://www.who.int/docs/default-source/decade-of-healthy-ageing/full-decade-proposal/decade-proposal-fulldraft-en.pdf (Accessed February 26, 2021).

2. Picco L, Achilla E, Abdin E, Chong SA, Vaingankar JA, Mccrone P, et al. Economic burden of multimorbidity among older adults: impact on healthcare and societal costs. *BMC Health Serv Res* (2016) 16:173. doi: 10.1186/s12913-016-1421-7

3. Buehler R, Simpkins C, Yang F. Effects of vibration training on quality of life in older adults: a preliminary systematic review and meta-analysis. *Qual Life Res* (2022) 31:3109–22. doi: 10.1007/s11136-022-03135-w

4. Ferrans CE, Zerwic JJ, Wilbur JE, Larson JL. Conceptual model of health-related quality of life. *J Nurs Scholarsh* (2005) 37:336–42. doi: 10.1111/j.1547-5069.2005.00058.x

5. Wang H, Beyer M, Gensichen J, Gerlach FM. Health-related quality of life among general practice patients with differing chronic diseases in Germany: cross sectional survey. *BMC Public Health* (2008) 8:246. doi: 10.1186/1471-2458-8-246

6. Chen Y, Hicks A, While AE. Quality of life of older people in China: a systematic review. *Rev Clin Gerontol* (2013) 23:88–100. doi: 10.1017/S0959259812000184

7. Poursadeqiyan M, Arefi MF, Pouya AB, Jafari M. Quality of life in health Iranian elderly population approach in health promotion: a systematic review. *J Educ Health Promot* (2021) 10:449. doi: 10.4103/jehp.jehp_1546_20

8. Yang G, Lin X, Fang A, Zhu H. Eating habits and lifestyles during the initial stage of the COVID-19 lockdown in China: a cross-sectional study. *Nutrients* (2021) 13:970. doi: 10.3390/nu13030970

9. Green G, Tesler R, Sharon C. Perceived efficiency outcomes, sources and awareness of online health information among the elderly during COVID-19. *Int J Environ Res Public Health* (2021) 18:8121. doi: 10.3390/ijerph18158121

10. Buyl R, Beogo I, Fobelets M, Deletroz C, Van Landuyt P, Dequanter S, et al. E-health interventions for healthy aging: a systematic review. *Syst Rev* (2020) 9:9. doi: 10.1186/s13643-020-01385-8

11. Bittlingmayer UH, Dadaczynski K, Sahrai D, van den Broucke S, Okan O. Digital health literacy—conceptual contextualization, measurement, and promotion. *Bundesgesundheitsblatt Gesundheitsforschung Gesundheitsschutz* (2020) 63:176–84. doi: 10.1007/s00103-019-03087-6

12. Norman CD, Skinner HA. Ehealth literacy: essential skills for consumer health in a networked world. *J Med Internet Res* (2006) 8:e9. doi: 10.2196/jmir.8.2.e9

13. Bevilacqua R, Strano S, Di Rosa M, Giammarchi C, Cerna KK, Mueller C, et al. Ehealth literacy: from theory to clinical application for digital health improvement. Results from the access training experience. *Int J Environ Res Public Health* (2021) 18:11800. doi: 10.3390/ijerph182211800

14. Filabadi ZR, Estebsari F, Milani AS, Feizi S, Nasiri M. Relationship between electronic health literacy, quality of life, and self-efficacy in Tehran, Iran: a community-based study. *J Educ Health Promot* (2020) 9:175. doi: 10.4103/jehp.jehp_63_20

15. Lin C, Ganji M, Griffiths MD, Bravell ME, Broström A, Pakpour AH. Mediated effects of insomnia, psychological distress and medication adherence in the association of ehealth literacy and cardiac events among Iranian older patients with heart failure: a longitudinal study. *Eur J Cardiovasc Nurs* (2020) 19:155–64. doi: 10.1177/1474515119873648

16. Arcury TA, Sandberg JC, Melius KP, Quandt SA, Leng X, Latulipe C, et al. Older adult internet use and ehealth literacy. *J Appl Gerontol* (2020) 39:141–50. doi: 10.1177/0733464818807468

17. Xie L, Zhang S, Xin M, Zhu M, Lu W, Mo PK. Electronic health literacy and health-related outcomes among older adults: a systematic review. *Prev Med* (2022) 157:106997. doi: 10.1016/j.ypmed.2022.106997

18. Bodie GD, Dutta MJ. Understanding health literacy for strategic health marketing: ehealth literacy, health disparities, and the digital divide. *Health Mark Q* (2008) 25:175–203. doi: 10.1080/07359680802126301

19. Kampmeijer R, Pavlova M, Tambor M, Golinowska S, Groot W. The use of e-health and m-health tools in health promotion and primary prevention among older adults: a systematic literature review. *BMC Health Serv Res* (2016) 16:290. doi: 10.1186/s12913-016-1522-3

20. Walker SN, Sechrist KR, Pender NJ. The health-promoting lifestyle profile: development and psychometric characteristics. *Nurs Res* (1987) 36:76–81. doi: 10.1097/00006199-198703000-00002

21. Hua L, Zhou XY, Huang XH. Path analysis of health literacy, health related behavior and quality of life among college students in Hangzhou. *Chin J School Health* (2018) 39:1469–71. doi: 10.16835/j.cnki.1000-9817.2018.10.009

22. Hanik B, Stellefson M. E-health literacy competencies among undergraduate health education students: a preliminary study. *Int Electron J Health Educ* (2011) 14:46–58.

23. United Nations, Department of Economic and Social Affairs, Population Division. *World population ageing 2019 (st/esa/ser.A/444)*. (2020). Available at: https://www.un.org/en/development/desa/population/publications/pdf/ageing/WorldPopulationAgeing2019-Report.pdf (Accessed December 15, 2021).

24. The National Bureau of Statistics of the People's Republic of China. *The seventh national population census bulletin of the people's Republic of China*. (2021). Available at: http://www.stats.gov.cn/ztjc/zdtjgz/zgrkpc/dqcrkpc/ggl/202105/t20210519_1817698.html (Accessed October 27, 2021).

25. Hong YA, Zhou Z. A profile of ehealth behaviors in China: results from a national survey show a low of usage and significant digital divide. *Front Public Health* (2018) 6:274. doi: 10.3389/fpubh.2018.00274

26. Zhao J, Zhang Z, Guo H, Li Y, Xue W, Ren L, et al. E-health in China: challenges, initial directions, and experience. *Telemed J E Health* (2010) 16:344–9. doi: 10.1089/tmj.2009.0076

27. Ministry of Industry and Information Technology, Ministry of Civil Affairs, National Health Commission of the People's Republic of China. *Action plan for the development of smart health and elderly care industry (2021–2025)*. (2021). Available at: http://www.nhc.gov.cn/lljks/zcwj2/202110/597c48d327744dc1976cf9b6972e5a4f.shtml (Accessed December 17, 2021).

28. Hajian-Tilaki K. Sample size estimation in epidemiologic studies. *Caspian J Intern Med* (2011) 2:289–98.

29. Feng X. *The relevant research among depression, psychological capital, and quality of life among community elderly*. Jinzhou: Jinzhou Medical University (2017).

30. Chongqing Statistics Bureau of the People's Republic of China. (2020). *2019 Chongqing statistical yearbook*. Chongqing. Available at: http://tjj.cq.gov.cn/zwgk_233/tjnj/202012/t20201214_8606164.html (Accessed June 4, 2022).

31. Liu SQ, Fu JJ, Kong DH, Zhong Z, Gu CY, Luo Y. Development and reliability and validation test of the digital health literacy assessment scale for the community-dwelling elderly. *Chin Nurs Res* (2021) 35:4169–74. doi: 10.12102/j.issn.1009-6493.2021.23.006

32. Walker SN, Sechrist KR, Pender NJ. *Health promotion model - instruments to measure health promoting lifestyle: Health-promoting lifestyle profile [HPLP II] (adult version)*. (1995) Available at: https://deepblue.lib.umich.edu/handle/2027.42/85349 (Accessed June 19, 2021).

33. Cao WJ, Guo Y, Ping WW, Zheng JZ. Development and psychometric tests of a Chinese version of the HPLP-II scales. *Chin J Dis Control Prev* (2016) 20:286–9. doi: 10.16462/j.cnki.zhjbkz.2016.03.018

34. Zhou W, Chen D, Hong Z, Fan H, Liu S, Zhang L. The relationship between health-promoting lifestyles and depression in the elderly: roles of aging perceptions and social support. *Qual Life Res* (2020) 30:721–8. doi: 10.1007/s11136-020-02674-4

35. Ware JE, Kosinski M, Keller SD. *SF-12: How to score the SF-12 physical and mental health summary scales*. Boston, MA: The health Institute, New England Medical Center (1995).

36. Jenkinson C, Layte R, Jenkinson D, Lawrence K, Petersen S, Paice C, et al. A shorter form health survey: can the SF-12 replicate results from the SF-36 in longitudinal studies? *J Public Health Med* (1997) 19:179–86. doi: 10.1093/oxfordjournals.pubmed.a024606

37. Shou J, Ren L, Wang H, Yan F, Cao X, Wang H, et al. Reliability and validity of 12-item short-form health survey (SF-12) for the health status of Chinese community elderly population in Xujiahui district of Shanghai. *Aging Clin Exp Res* (2016) 28:339–46. doi: 10.1007/s40520-015-0401-9

38. Hayes AF. *Introduction to mediation, moderation, and conditional process analysis: a regression-based approach (the third edition)*. New York: Guilford Press (2022).

39. Zhang C, Xiao S, Lin H, Shi L, Zheng X, Xue Y, et al. The association between sleep quality and psychological distress among older Chinese adults: a moderated mediation model. *BMC Geriatr* (2022) 22:35. doi: 10.1186/s12877-021-02711-y

40. Krawczyk-Suszek M, Kleinrok A. Health-related quality of life (HRQoL) of people over 65 years of age. *Int J Environ Res Public Health* (2022) 19:625. doi: 10.3390/ijerph19020625

41. Ma X, Mcghee SM. A cross-sectional study on socioeconomic status and health-related quality of life among elderly Chinese. *BMJ Open* (2013) 3:e2418. doi: 10.1136/bmjopen-2012-002418

42. Marzo RR, Khanal P, Ahmad A, Rathore FA, Chauhan S, Singh A, et al. Quality of life of the elderly during the COVID-19 pandemic in Asian countries: a cross-sectional study across six countries. *Life* (2022) 12:365. doi: 10.3390/life12030365

43. Chai X. How has the nationwide public health emergency of the COVID-19 pandemic affected older Chinese adults' health literacy, health behaviors and practices, and social connectedness? Qualitative evidence from urban China. *Front Public Health* (2021) 9:774675. doi: 10.3389/fpubh.2021.774675

44. van Middelaar T, Beishuizen CRL, Guillemont J, Barbera M, Richard E, Moll Van Charante EP. Engaging older people in an internet platform for cardiovascular risk self-management: a qualitative study among DUTCH HATICE participants. *BMJ Open* (2018) 8:e19683. doi: 10.1136/bmjopen-2017-019683

45. von Humboldt S, Low G, Leal I. Health service accessibility, mental health, and changes in behavior during the COVID-19 pandemic: a qualitative study of older adults. *Int J Environ Res Public Health* (2022) 19:4277. doi: 10.3390/ijerph19074277

46. Delgado CE, Silva EA, Castro E, Carbogim F, Puschel V, Cavalcante RB. COVID-19 infodemic and adult and elderly mental health: a scoping review. *Rev Esc Enferm USP* (2021) 55:e20210170. doi: 10.1590/1980-220X-REEUSP-2021-0170

47. Li S, Yin Y, Cui G, Xu H. The associations among health-promoting lifestyle, ehealth literacy, and cognitive health in older Chinese adults: a cross-sectional study. *Int J Environ Res Public Health* (2020) 17:2263. doi: 10.3390/ijerph17072263

48. Qin W, Blanchette JE, Murrock C. Exploring the relationship between lifestyle behaviors and health-related quality of life among older adults with diabetes. *Diabetes Educ* (2019) 45:96–104. doi: 10.1177/0145721718816630

49. Zhang S, Tao F, Ueda A, Wei C, Fang J. The influence of health-promoting lifestyles on the quality of life of retired workers in a medium-sized city of northeastern China. *Environ Health Prev Med* (2013) 18:458–65. doi: 10.1007/s12199-013-0342-x

50. Li SJ, Cui GH, Yin YT, Wang SY, Liu XY, Chen L. Health-promoting behaviors mediate the relationship between eHealth literacy and health-related quality of life among Chinese older adults: a cross-sectional study. *Qual Life Res* (2021) 30:2235–43. doi: 10.1007/s11136-021-02797-2

51. Andersen RM. National health surveys and the behavioral model of health services use. *Med Care* (2008) 46:647–53. doi: 10.1097/MLR.0b013e31817a835d

52. Andersen RM, Davidson PL, Baumeister SE. Improving access to care in America: individual and contextual indicators. In: *Changing the US health care system: Key issues in health services policy and management*. San Francisco: Jossey-Bass (2014). 3–31.

53. Travers JL, Hirschman KB, Naylor MD. Adapting Andersen's expanded behavioral model of health services use to include older adults receiving long-term services and supports. *BMC Geriatr* (2020) 20:58. doi: 10.1186/s12877-019-1405-7

frontiers | Frontiers in Public Health

TYPE Original Research
PUBLISHED 20 July 2023
DOI 10.3389/fpubh.2023.1169083

OPEN ACCESS

EDITED BY
Bijan Najafi,
Baylor College of Medicine, United States

REVIEWED BY
Juan Luis Sánchez González,
University of Salamanca, Spain
Huanghe Zhang,
Stevens Institute of Technology,
United States

*CORRESPONDENCE
Zhong Pei
✉ peizhong@mail.sysu.edu.cn
Zhimin Yang
✉ yangyo@vip.tom.com
Fuping Xu
✉ xufuping1983@gzucm.edu.cn

RECEIVED 18 February 2023
ACCEPTED 30 June 2023
PUBLISHED 20 July 2023

CITATION
Fan S, Ye J, Xu Q, Peng R, Hu B, Pei Z, Yang Z and Xu F (2023) Digital health technology combining wearable gait sensors and machine learning improve the accuracy in prediction of frailty.
Front. Public Health 11:1169083.
doi: 10.3389/fpubh.2023.1169083

Digital health technology combining wearable gait sensors and machine learning improve the accuracy in prediction of frailty

Shaoyi Fan[1], Jieshun Ye[2], Qing Xu[1], Runxin Peng[1], Bin Hu[3], Zhong Pei[4]*, Zhimin Yang[5]* and Fuping Xu[5]*

[1]The Second Clinical College of Guangzhou University of Chinese Medicine, Guangzhou, China, [2]School of Civil Engineering and Transportation, South China University of Technology, Guangzhou, China, [3]Division of Translational Neuroscience, Department of Clinical Neurosciences, Hotchkiss Brain Institute, Alberta Children's Hospital Research Institute, Cumming School of Medicine, University of Calgary, Calgary, AB, Canada, [4]Department of Neurology, First Affiliated Hospital of Sun Yat-Sen University, Guangzhou, China, [5]The Second Affiliated Hospital of Guangzhou University of Chinese Medicine, Guangdong Provincial Hospital of Chinese Medicine, Guangzhou, China

Background: Frailty is a dynamic and complex geriatric condition characterized by multi-domain declines in physiological, gait and cognitive function. This study examined whether digital health technology can facilitate frailty identification and improve the efficiency of diagnosis by optimizing analytical and machine learning approaches using select factors from comprehensive geriatric assessment and gait characteristics.

Methods: As part of an ongoing study on observational study of Aging, we prospectively recruited 214 individuals living independently in the community of Southern China. Clinical information and fragility were assessed using comprehensive geriatric assessment (CGA). Digital tool box consisted of wearable sensor-enabled 6-min walk test (6MWT) and five machine learning algorithms allowing feature selections and frailty classifications.

Results: It was found that a model combining CGA and gait parameters was successful in predicting frailty. The combination of these features in a machine learning model performed better than using either CGA or gait parameters alone, with an area under the curve of 0.93. The performance of the machine learning models improved by 4.3–11.4% after further feature selection using a smaller subset of 16 variables. SHapley Additive exPlanation (SHAP) dependence plot analysis revealed that the most important features for predicting frailty were large-step walking speed, average step size, age, total step walking distance, and Mini Mental State Examination score.

Conclusion: This study provides evidence that digital health technology can be used for predicting frailty and identifying the key gait parameters in targeted health assessments.

KEYWORDS

digital health technology, wearable sensor, machine learning, prediction model, frailty, gait

Introduction

As the population ages, frailty is becoming a major challenge for public healthcare. Frailty is a condition that affects many older people and is characterized by a decline in physical function, decreased resilience to stressors, and a higher risk of negative health outcomes such as falls, hospitalization, and death (1). Patients with frailty commonly show multifaceted clinical symptoms, phenotypic heterogeneity, and fluctuating manifestations that challenge the comprehensive appraisal of the condition (2, 3). Undiagnosed frailty is common in older people, since it typically has no explicit connection to a defined medical issue; therefore, frailty frequently remains untreated until later stages. Early detection of the risk of frailty is essential especially in the early stages, as such identification would facilitate the implementation of treatments to slow down declines and reduce adverse outcomes.

Currently, the prediction of frailty is performed using questionnaires and tests of physical activity, muscle strength or gait. The most widely used assessment is the fried performance (FP) test (4), which includes measures of weight loss, exhaustion, low physical activity, weakness, and slow walking speed. However, the FP test only evaluates the physical aspects of frailty, while frailty is acknowledged to be a multifaceted state that includes not only physical dimensions, but also social, cognitive, and psychological dimensions (5, 6). Gait-related mobility is a key physical ability that has been linked to frailty and is often used as a predictor of future health outcomes (7, 8).

During the aging process, the loss of function is intrinsic to all the physiological systems, including the Central and peripheral nervous systems, musculo-skeletal system, and cardiopulmonary system. The most dramatic and significant changes is the decline in limb muscle, which can lead to changes in gait parameters such as walking speed, cadence, and stride-length (9, 10). Gait speed, which is a quantifiable index of ambulatory ability and a major predictor of future health outcomes (11), is commonly used as an outcome in the research of frailty.

Advances in technologies associated with wearable devices has enabled the collection of more precise parameters regarding other spatial and temporal gait variables in addition to the commonly observed gait speed. These technologies are valid and practical, and they provide a promising, cost-effective digital method in standardizing the data collection and analysis of gait function with improved efficiency and accessibility both in the clinical setting and within seniors' living communities (12–14).

With improved multidisciplinary diagnostic approaches, some researchers have predicted frailty status based on CGA, but this approach has several limitations. For example, questions within the CGA frequently require advanced knowledge and thus might not accurately reflect the mental status of subjects. Concurrently, with the evolution of computer science and artificial intelligence, many researchers would like to predict frailty using ML approaches (Table 1) (15–23). Previous studies in this regard have commonly utilized easy-to-access epidemiological datasets or electronic health records to construct ML algorithms (24); the nature of these databases mean that these algorithms are potentially limited to the use of a single dimension. Furthermore, little research has analyzed Asian populations, which have very different socio-economic profiles as compared with Western populations (16).

Therefore, the objectives of this study were to (A) obtain the relevant gait parameters using wearable sensor and to analyze their association with deterioration of physical function and evolution into frailty, and to (B) develop an ML frailty risk prediction model suited for an Asian population, using a combination of both wearable sensor-based gait analysis and CGA.

Materials and methods

Study design, participants, and features

In total, we consecutively recruited 214 community-dwelling volunteers from the course of the anti-aging study, a prospective cohort study conducted to investigates the association of frailty with health. All subjects were recruited through advertisements in two ways. First, recruitment was conducted at four communities centers in Guangzhou (the capital of the Guangdong Province in the southeastern region of China). Second, with the assistance of the District Health Center and GPs clinics, recruitment invitations was handed out via online announcement to older individuals on Wechat platforms. Eligibility criteria for participants were: aged 60–95 years, having adequate auditory and visual acuity, and the ability to ambulate with or without any walking aids or assistance of others. Exclusion criteria included orthopedic or neurological complications or other relevant medical conditions that might restrict walking speed and natural movement. All subjects were required to complete CGA including but not limited to a standardized questionnaire that collected demographic information, medical and medication records, as well as multidimensional clinical assessment, including anthropometric evaluation, emotional evaluation, and neuropsychological evaluation.

The parameters of CGA included the patients' demographic data, including age, gender, education level, marital status, employment position and measurement data. The clinical measurement data involved multimorbidity (defined by the coexistence of >2 chronic conditions), polypharmacy (defined as currently using >5 drugs), depression disorder (25) (defined by scores ≥10 on the 9-item Patient Health Questionnaire, PHQ-9), anxiety disorder (26) (defined by scores ≥10 on the 7-item Generalized Anxiety Disorder, GAD-7), cognitive function (27, 28) (assessed by the Mini-Mental State Examination, MMSE and the Chinese versions of the Montreal Cognitive Assessment, MoCA-BC) and neuropsychiatric function (29, 30) (assessed by the Mild Behavioral Impairment Checklist, [MBI-C]). A detailed description of how these features were defined is also provided in Table 2.

Walking test

To obtain an objective and quantitative assessment of gait parameters, all participants were instructed to complete a 6-min walk test (6MWT) using a wearable sensor (Ambulosono Sensor System) (13, 31). The sensor was connected to the iOS Gait Reminder App, which can issue auditory instructions while continuously recording step size via an iOS gyroscope and accelerometers, after corrections for limb length, angular excursion, signal filtering, and drift.

TABLE 1 Previous researches regarding frailty risk prediction by machine learning.

Reference	Number of variables	Machine learning model	Data type	Outcome
Ambagtsheer et al. (15)	70	SVM, DT, and KNN	Administrative records	SVM (sensitivity of 97.8%, specificity of 89.1%), DT (sensitivity of 63.0%, specificity of 21.4%), and KNN (sensitivity of 63.0%, specificity of 71.7%)
Aponte-Hao et al. (16)	75	ENLR, SVM, KNN, NB, DT, RF, XGBoost, and ANN	Administrative records	In terms of AUROC, ENLR (0.82), SVM (0.80), KNN (0.66), NB (0.74); DT (0.77), RF (0.81), XGBoost (0.83), and ANN (0.78)
Le Pogam et al. (17)	18	LR, RF, and SVM	Electronic medical records	In terms of AUROC, best-subsets LR (0.71), RF (0.66), SVM (0.58)
Tarekegn et al. (18)	58	ANN, GP, SVM, RF, LR, and DT	Administrative records	ANN classifier generated the optimal prediction results for mortality: Accuracy within ANN (0.78),SVM (0.79), RF (0.78), LR (0.78), DT (0.75)
Koo et al. (19)	27	SVM, RF, and GB	Electronic medical records	SVM (Precision of 88.9%), RF (Precision of 92.3%), and GB (Precision of 88.0%)
Williamson et al. (20)	3,761	LR	Electronic medical records	Sensitivity of 36.1%, specificity of 62.9%, PPV of 17.3%, and NPV of 82.1%
Park et al. (21)	16	LR	Pendant Sensor data	AUROC of 0.80, sensitivity of 72.2%, specificity of 70.0%, and accuracy of 71.3%
Kraus et al. (22)	9	RF, KNN, RF	Insole Sensor data	In terms of AUROC, RF (0.92), KNN (0.80)
Minici et al. (23)	25	RF, NB, LR, SVC, MLPC	Wrist Sensor data	In terms of AUROC, RF (0.80), NB (0.87), LR (0.73), SVC (0.64), MLPC (0.71)

SVM, support vector machine; DT, decision tree; KNN, K-nearest neighbors; ENLR, elastic net logistic regression; NB, naive bayes; XGBoost, extreme gradient boosting; LR, logistic regression; BS-LR, best-subsets logistic regression; RF, random forest; ANN, artificial neural network; MLPC, multilayer perceptron classifier; KFACS, Korean Frailty and Aging Cohort Study.

TABLE 2 Features of cohort characteristics used for machine learning.

Demographics	Data type	Clinical measures	Data type	Walking test	Data type
Age	Numeric	Exhaustion	Binary	Total step walking distance	Numeric
Education level	Categorical	Sleep quality	Binary	Average walking speed	
Gender	Binary	Anxiety	Binary	Total cadence	
Marital status/partnerships	Categorical	Depression	Binary	Large step distance	
Employment position	Categorical	Cognition test	Numeric	Large step walking time	
Medical history		Energy expenditure	Binary	Large step walking speed	
Medical record	Binary	Anthropometry		Large step cadence	
Medications/supplements	Binary	Grip strength	Numeric	Average step size	
Unintentional weight loss	Binary	Body mass index (BMI)	Numeric	Average step time	

Participant were instructed to walk independently if possible, and were permitted to use walking aid (e.g., walker or cane) if needed.

Frailty assessment

The outcome measures used to categorize no-frailty and frailty was assessed utilizing the five components specified in the FP test (4), including: self-reported unintentional weight loss of 10 pounds or more within the last year; self-reported exhaustion; slowness stratified by gender and height; weakness via grip strength test using a hand dynamometer; and low physical activity based on the short version Minnesota Leisure Time Activity questionnaire (32). FP scores range from 0 to 5 points, with higher scores indicating more severe frailty. Based on the results, individuals with scores of 0 through 2 were categorized into the no-frailty group, and those with scores of 3 or more were included in the frailty group. This scale has exhibited high validity and has become a gold standard for classifying frailty in older adults (33).

Machine learning models

In this study, five widely accepted and extensively used supervised ML models were applied: random forests (RF); decision trees (DT); naïve Bayes; neural network (NN) and stochastic gradient descent (SGD).

DT is a powerful ML algorithm capable of performing classification tasks. Advantages of DT include simplicity, interpretability, ability to model nonlinear data and ability to handle outliers during training (34), but weaknesses of the simple decision tree are instability and a risk of over fitting. RF, a popular ensemble classification method, combines multiple learning algorithms to achieve better performance. RF models generally outperform those generated by DT in terms of accuracy. Naive Bayes is a supervised

probabilistic machine learning algorithm for probabilistic classification that relies on Bayes' theorem with an assumption of strong independence between the input features (35). Neural network is a mathematical computing model that imitates the construction of biological neural networks and that is commonly used in classification tasks with various applications (36).We also attempted to apply SGD (37), an algorithm for optimization problems arising in high-dimensional inference tasks.

Experimental setting

An overview of the ML approach used in this study is shown in Figure 1. After imputation of missing values by multiple interpolation, the values of input features were standardized to ensure that each feature had the same influence on the cost function in designing the ML models. In this study, the data were randomly divided, with 70% used for training and the remaining 30% used as test data. Within the 70% training set, the data was split into ten random folds for cross validation to guard against overfitting. The rigorous use of holdout method with random resampling and stratified k-fold cross-validation ensured the validity and generalizability of the findings, and helped to mitigate potential biases in the analysis. We used average values as they are robust to outlying predictions.

Feature selection

When not all features have significant class discrimination information, using feature selection methods can help to remove the irrelevant and redundant features. This method can reduce the computational time and improve classification performance. To determine the lowest number of demographic features, clinical features and sensor-derived gait sequence features required to best identify frailty, optimal feature selection using either the independent samples t-test or the chi-square test was applied, depending on each feature's types. Sixteen of the features showed a significant difference between the no-frailty and frailty groups, and thus they were used as independent variables for optimal feature selection.

Performance measures

The performance of the ML models was evaluated using AUC score, sensitivity, specificity, precision, F1-score and accuracy. We aimed to find the simplest model that achieves the highest accuracy. As the original training data were imbalanced (13.1% frailty), such data can result in biased estimates of training performance; hence, with the best performing model chosen by average AUC score, which can be understood as the probability that a randomly chosen no-frailty patient will have a score lower than a randomly chosen frailty patient. SHapley Additive exPlanation (SHAP) values were used to provide consistent and locally accurate attribution values for each feature within each prediction model (38).

Statistical analyses

All statistical analyses and calculations were performed using R software and Python (version 3.9.7; Python Software Foundation). The categorical variables were expressed as total numbers and percentages, with the chi-square test used for comparison between

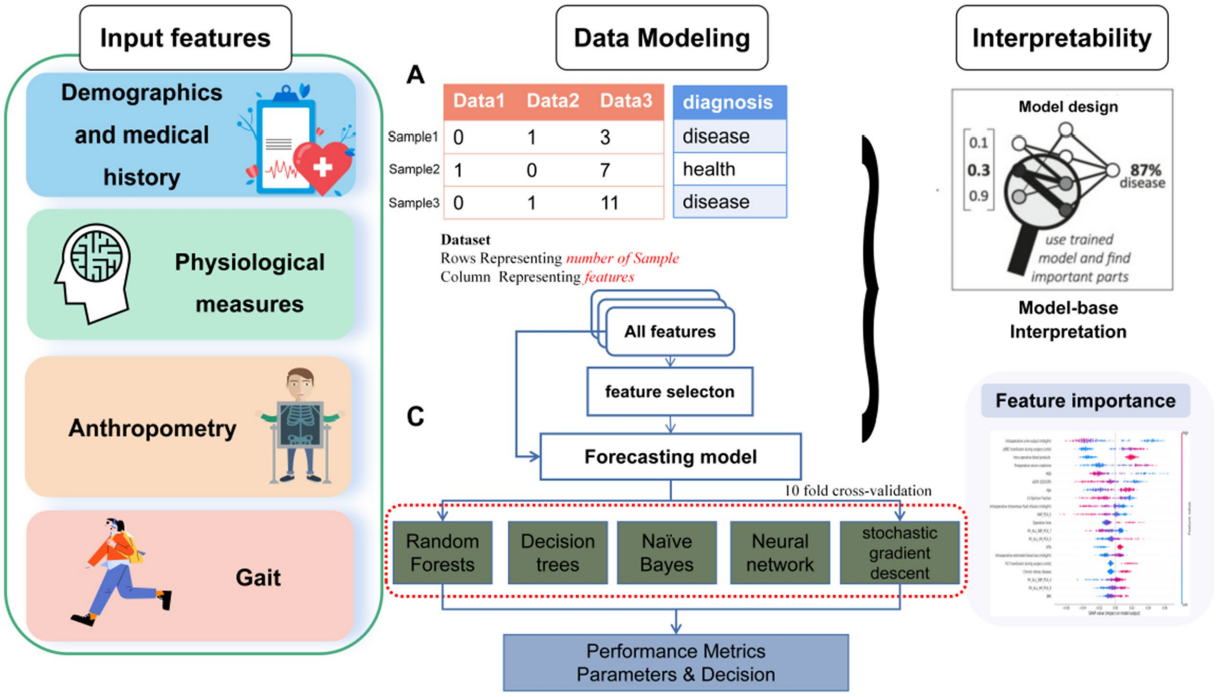


FIGURE 1
Overall data acquisition, feature extraction, feature selection, data classification analysis and machine learning flow for the classification of frailty.

groups. Normally continuous variables were expressed as $\bar{x} \pm s$, and the independent samples *t*-test for was used for comparisons between groups; non-normally continuous variables were expressed as median and IQR, with a Mann–Whitney U test used for comparisons between groups. The inspection level $\alpha = 0.05$, and we considered any difference statistically significant if $p < 0.05$.

Results

Demographic and clinical characteristics

Table 3 compares the detailed demographic and clinical characteristics of each group. A total of 214 subjects were included in the study, among which 28 (13.1%) subjects were classified into the frailty group. Compared with the no-frailty group, subjects in the frailty group were of older age (74.3 ± 8.4 vs. 68.1 ± 6.1 years) and had lower BMI (22.2 ± 2.7 vs. 23.5 ± 2.9). Moreover, the frailty group had a higher proportion of comorbid conditions (74.4% vs. 31.7%), polypharmacy (35.7% vs. 8.6%) and depression (32.1% vs. 14.0%) with significant difference. The results also showed that the scores on the Mini Mental State Examination (MMSE) and the Montreal Cognitive Assessment from subjects in the frailty group were significantly lower than those of subjects in the no-frailty group ($p < 0.01$). There were no significant differences in gender or education between two groups (Table 3).

Characteristics of the gait features in each study group

Table 4 shows gait parameters in relation to the presence of frailty. In comparison to subjects in the no-frailty group, those in the frailty group had slower gait speed (57.3 ± 17.6 vs. 70.1 ± 15.2 m/min), lower step walking distance (338.6 ± 96.7 vs. 420.5 ± 91.3 m), lower total cadence (113.5 ± 11.7 vs. 120.4 ± 15.2 step/min), shorter step size (0.508 ± 0.143 vs. 0.593 ± 0.107 m), and higher average step time (0.533 ± 0.059 vs. 0.502 ± 0.051 s).

Performance of machine learning approaches

We performed feature selection analyses among the various feature categories to investigate and identify crucial feature signatures for our models. The input data used were the gait features based on the outputs from wearable sensor and the demographic and clinical features derived from CGA. As illustrated in Table 5, the ML models achieved up to 63.5% accuracy, 88.2% specificity, 56.5% sensitivity, 98.4% precision and an F1-score of 65.0% using demographic and clinical features. When using the gait features, the ML models achieved up to 65.6% accuracy, 83.8% specificity, 65.3% sensitivity, 97.8% precision and F1-score of 65.6%. In comparison, the ML models that employed all features achieved the highest performance,

TABLE 3 Demographics and clinical characteristics of participants stratified by frailty status.

Variable	Frailty status			
	All (*n*=214)	No-frailty (*n*=186)	Frailty (*n*=28)	*p*-value
Age, mean (SD)	68.9 (6.7)	68.1 (6.1)	74.3 (8.4)	<0.001
Female	156 (72.9)	139 (74.7)	17 (60.7)	0.120
Education				0.212
Primary or lower	119 (55.6)	104 (55.9)	15 (53.6)	
Completed high school	69 (32.2)	57 (30.6)	12 (42.9)	
At least some college	26 (12.1)	25 (13.4)	1 (3.6)	
Marital status				0.782
Married	173 (80.8)	152 (81.7)	21 (75.0)	
Divorced	32 (15.0)	24 (14.5)	5 (17.9)	
Widowed	9 (4.2)	7 (3.8)	2 (7.1)	
Comorbid conditions >2	79 (36.9)	59 (31.7)	20 (71.4)	<0.001
Polypharmacy	26 (12.1)	16 (8.6)	10 (35.7)	<0.001
BMI, mean (SD)	23.3 (2.9)	23.5 (2.9)	22.2 (2.7)	0.026
Insomnia(PSQI>7)	121 (56.5)	104 (55.9)	17 (60.7)	0.633
Depression (PHQ-9 ≥ 10)	9 (8.4)	26 (14.0)	9 (32.1)	0.015
Anxiety (GAD-7 ≥ 10)	15 (7.0)	13 (7.0)	2 (7.1)	0.976
MBI-C, mean (SD)	5.1 (3.8)	5.0 (3.8)	5.9 (3.6)	0.208
MMSE, mean (SD)	26.2 (3.0)	26.6 (2.8)	23.7 (3.5)	<0.001
MoCA-B, mean (SD)	24.2 (3.4)	24.5 (3.2)	22.2 (3.6)	0.001

SD, standard deviation; BMI, body mass index; PSQI, Pittsburgh Sleep Quality Index; PHQ-9, Patient Health Questionnaie-9; GAD-7, General Anxiety Disorder Screener-7; MBI-C, Mild Behavioral Impairment Checklist; MMSE, Mini-mental State Examination; MoCA-B, Chinese versions of the Montreal Cognitive Assessment; Results presented as *n* (%) unless otherwise noted. Chi-square tests were used for categorical variables, whereas *t*-tests were used for continuous variables.

TABLE 4 Characteristics of the gait sequence features in each study group.

Variable	Unit	Frailty index status			
		All (n=214)	No-frailty (n=186)	Frailty (n=28)	p-value
Total step walking distance (m)	m	409.8 (95.9)	420.5 (91.3)	338.6 (96.7)	<0.001
Large step distance (m)	m	402.5 (103.4)	413.7 (99.0)	328.6 (103.1)	<0.001
Average gait speed (m/min)	m/min	68.5 (16.2)	70.1 (15.2)	57.3 (17.6)	<0.001
Large step walking speed	m/min	69.0 (15.7)	70.8 (14.6)	57.4 (17.6)	<0.001
Total cadence (step/min)	Step/min	119.5 (14.9)	120.4 (15.2)	113.5 (11.7)	0.023
Large step cadence	Steps/min	117.7 (15.4)	118.9 (15.4)	109.6 (13.1)	0.003
Average step size	m	0.582 (0.115)	0.593 (0.107)	0.508 (0.143)	<0.001
Average step time	s	0.506 (0.053)	0.502 (0.051)	0.533 (0.059)	0.004
Step size variance (Median)	n	0.007 [0.003–0.019]	0.006 [0.003–0.019]	0.010 [0.003–0.023]	0.184[†]
Step time variance (Median)	n	0.012 [0.009–0.021]	0.012 [0.008–0.020]	0.018 [0.011–0.036]	0.002[†]

[†]Tested using the Mann–Whitney U test.

TABLE 5 Performance summary of ML models for frailty classification using different features set.

Models	Accuracy	Specificity	Sensitivity	Precision	F1-score
Demographic and clinical features					
Random forests	60.56	88.21	54.42	98.35	65.01
Decision trees	63.50	71.37	56.53	90.17	64.30
Naive bayes	56.63	61.81	54.25	67.62	53.22
Neural network	52.53	65.23	51.75	84.59	53.82
Stochastic gradient descent	58.75	82.13	55.63	86.42	58.16
Gait sequence features					
Random forests	63.22	83.80	54.81	97.84	65.57
Decision trees	63.60	70.81	56.27	91.17	64.57
Naive bayes	60.47	60.06	55.14	76.23	59.64
Neural network	47.49	56.37	47.12	74.54	44.96
Stochastic gradient descent	53.75	78.35	52.77	91.00	58.62
All features					
Random forests	69.58	89.46	58.54	96.95	68.80
Decision trees	71.11	78.28	60.86	92.35	68.68
Naive bayes	67.98	66.74	61.30	75.38	63.06
Neural network	67.90	75.60	58.73	89.75	66.80
Stochastic gradient descent	58.42	78.22	53.30	92.54	62.69
Selected features					
Random forests	66.58	95.69	57.38	98.76	67.74
Decision trees	68.74	80.14	59.45	93.10	67.88
Naive bayes	65.35	73.88	57.31	86.33	64.29
Neural network	51.46	61.74	50.51	77.42	48.27
Stochastic gradient descent	59.00	78.71	55.70	89.50	61.43

with up to 71.1% accuracy, 89.5% specificity, 61.3% sensitivity, 97.0% precision, and an F1-score of 68.0%.

The receiver operating characteristic (ROC) curves of each ML model using different features are shown in Figure 2. All ML models achieved significant improvements in discrimination by using selected features as compared to the indiscriminate use of all features. In particular, RF exhibited an AUC gain of 4.3% when using selected features as compared to using all features, a gain of 6.2% when using selected features as compared to all demographic and clinical features, and a gain of 11.4% when using selected features as compared to using

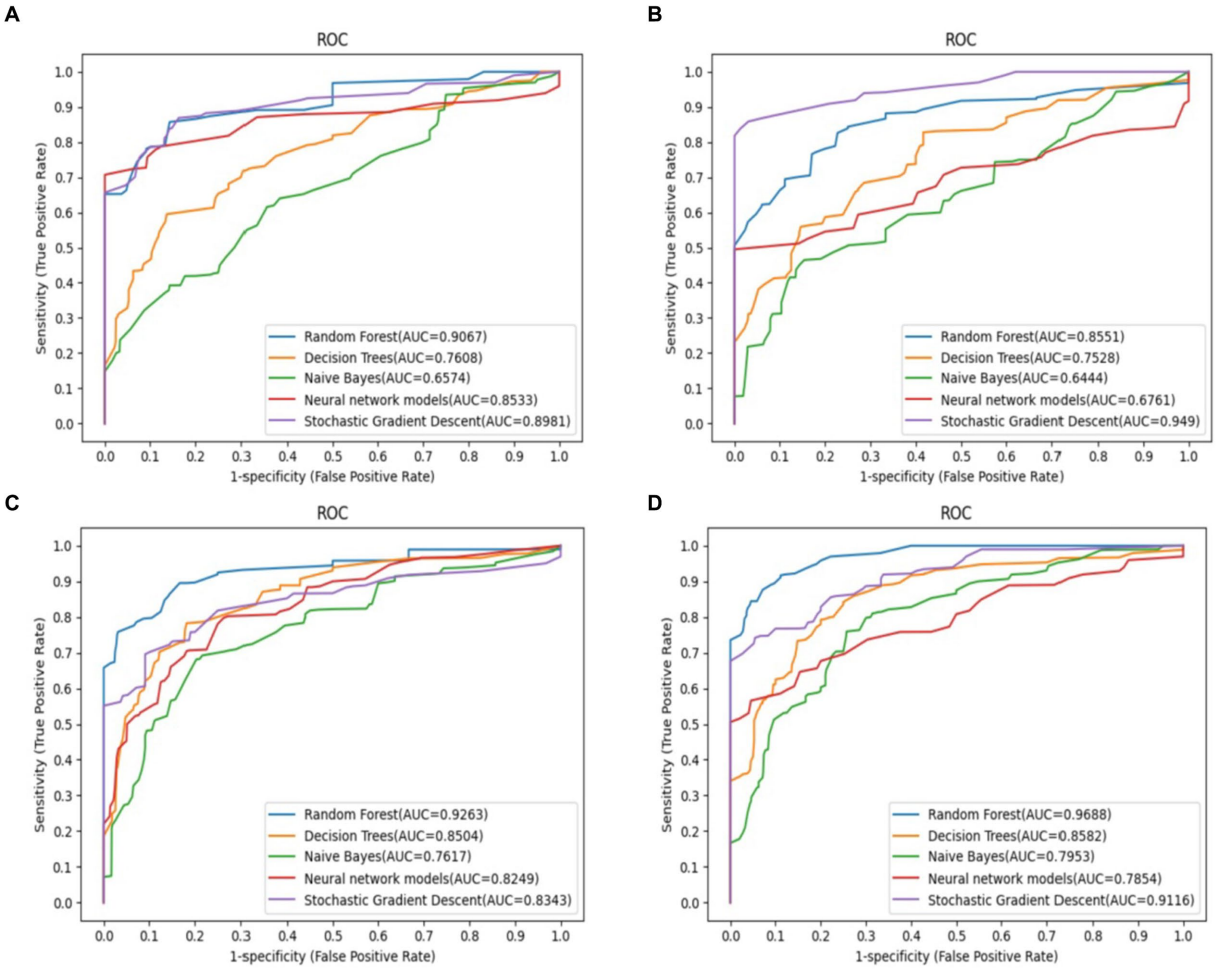


FIGURE 2
Predictive performance of different feature selection in predict the outcomes of frailty model. The RF model demonstrated the most favorable performance. **(A)** Demographic and clinical prediction (AUC=0.907), **(B)** gait sequence prediction (AUC=0.855), **(C)** all feature prediction (AUC=0.926), **(D)** selected feature prediction (AUC=0.969).

all gait sequence features. Since the RF model outperformed other ML models according to accuracy and AUC, it was selected for all downstream analyses.

Feature importance

Figure 3 shows the SHAP summary plot of RF using selected features, with the features contributing to the model in descending order of average absolute SHAP values. This plot depicts the relationships of values to SHAP values in the training dataset. According to the prediction model, the higher the SHAP value of a feature, the more likely frailty becomes. As observed in the plot, the five most important predictors in the prediction model were large step walking speed, average step size, age, total step walking distance, and MMSE score.

Discussion

Frailty is a common condition among older adults that is characterized by a decline in physical and cognitive function and an increased risk of adverse health outcomes. Identifying frailty on the early stage can help healthcare professionals implement hierarchical strategies to prevent or delay its onset and manage potential conditions. In this study, we adopted a set of analytical and machine-learning approaches to analyze the relationship between frailty and a combination of CGA and wearable sensor-derived gait parameters in community-dwelling older adults.

To achieve this, we used statistical methodologies to extract a subset of uncorrelated components associated with frailty predictors, which were then used to independently identify and visualize multiple dimensions associated with frailty. Our results indicate that machine learning methods are effective in predicting frailty and that using a combination of both CGA characteristics and wearable sensor data improved the performance of our model compared to using either features separately. This multifaceted combination of features provides a comprehensive perspective on frailty, allowing the model to capture the intricate relationship between various factors.

Our final model, which was processed using a random forest machine learning method, achieved an impressive area under the curve (AUC) score of 0.926, indicating a high level of accuracy compared with previous estimates, ranging from 0.58 up to 0.92 (15–23). In contrast to other traditional predictive formulas, such as

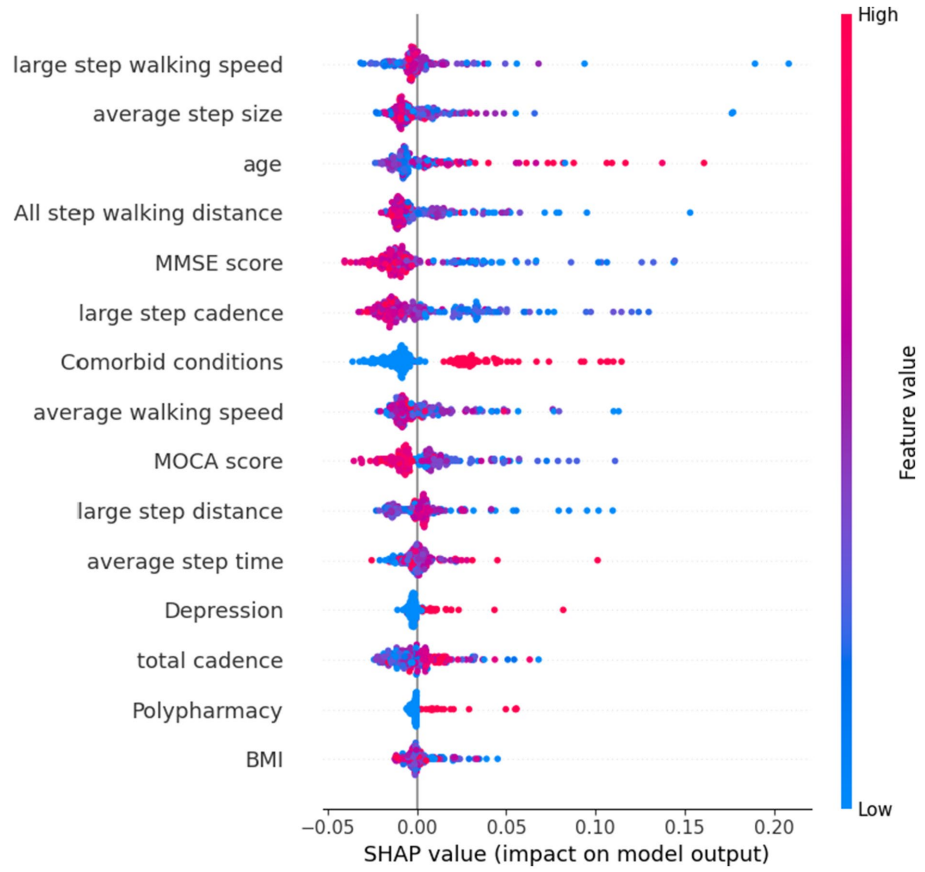


FIGURE 3
SHAP plot of top features influencing our model's prediction of frailty using all features.

the electronic medical records-based model, administrative records-based model, and sensor-based model, the classification results of our model outperformed other traditional models. This enhanced performance may be attributed to our study design and to the synergistic approach that combined CGA and wearable sensor data, accompanied by rigorous feature selection and optimization processes.

Furthermore, we also calculated the accuracy of each model when processing different complements of patient characteristics, in addition to overall model performance. We found that using a narrower set of carefully selected features achieved significant improvements in discrimination relative to models that included all available features. This reduced the dimensionality of our dataset and allowed our model to focus on the most relevant features for predicting frailty. In previous study, Williamson and colleagues (20) reported that frailty was predicted using a large number of features of electronic medical record database without feature selection as effectively, which can lead to overfitting and reduced generalization of the model.

This limitation of the number of features needed would be helpful in clinical settings due to difficulties in collecting consistent data from older patients, especially with functional data or data indicating cognitive and emotional status. Notably, the top five features found to be important in predicting frailty were step walking speed, average step size, age, total step walking distance, and MMSE score. These results are consistent with previous research that has identified gait and physical activity parameters measured by wearable sensors as being associated with physical frailty and has found that certain gait parameters, such as percentage time standing, percentage time walking, walking cadence, and longest walking bout, are effective digital biomarkers for identifying frailty (21, 39). Gait stability, as determined by double-limb support time, step time and stride time, and long short-term memory have also been found to produce the highest discriminative power in identifying frailty using the RF model (40). Accordingly, our findings suggest that healthcare professionals treating older patients should focus on these five features, as they may indicate the risk of future frailty.

In particular, the strength of the gait parameters in our analysis, accounting for 50% of the predictive power, demonstrates the importance of these motor characteristics as a measure of frailty. The 6MWT is a valid, reliable and sensitive measure of functional performance capacity that has been found to be useful in evaluating frailty in older adults (41). Using digital methods to perform the 6MWT, such as wearable sensors or GPS devices, an economical and convenient way to provide diagnostic and clinical information, can significantly improve the accuracy and reliability of the test results compared to manual methods (42, 43).

CGA has also been used to identify risks of adverse events such as cognitive impairment, mortality, functional decline, surgical complications, and chemotherapy toxicity among frailty patients (44, 45). This is the first study ever done to show the benefits of utilizing

a combination of CGA and wearable sensor data in predicting frailty. Our research adds to the existing knowledge by revealing the efficacy of employing an integrated approach, using both CGA and wearable sensor data in predicting frailty and a limited number of judiciously selected features in a machine learning model. It also highlights the importance of gait-related measures for frailty prediction. Previous studies have used various artificial intelligence (AI) models to analyze frailty and predict frailty risk in older adults using different types of data, including clinical records (15–18, 24, 46), physical function data (47, 48), and wearable sensor data (21, 22, 49). Additionally, the clinical implications of our method were summarized as follows:

A. The integration of both CGA and wearable sensors objectively measure gait parameters offers healthcare professionals comprehensive understand of frailty risk, enabling early intervention and better management of pre-clinical condition to prevent adverse health outcomes.

B. In terms of feature selection, our study identified the five most important indexs in the prediction model as large step walking speed, average step size, age, total step walking distance, and MMSE score. Clinicians can prioritize these factors when assessing frailty risk in older patients, allowing for a more effective and targeted approach that streamlines data collection and reduces the burden of frailty on patients and healthcare systems.

C. In terms of gait assessment, we depicted wearable sensors for auto digital gait data analysis such as the 6MWT that can provide more accurate and reliable results classification of frailty individuals compared to traditional manual methods, improving the overall quality of frailty evaluations.

D. In terms of the clinical setting, the application of ML techniques to analyze and predict frailty risk has proven beneficial in identifying at-risk individuals. These methods have shown promising results in identifying relevant features and interactions, particularly when numerous variables are involved, allowing for timely interventions and more personalized care plans.

Considering the implications of a future digital health approach, we aimed to capture pertinent gait components based on 6MWT that can be utilized to remotely predict the risk of frailty using wearable sensors. With this approach, patients would able to be long-term digital monitored without having to undergo an in-person clinic visit to assess their physical frailty. However, this study is subject to several limitations that need to be addressed. Since, the 6MWT is a long-distance walking test that places higher demands on the abilities, functional status, and reserves of older adults. Our recruitment threshold of walking behavior, a minimum test time of 6 min, was achievable for the vast majority of this population with or without any walking aids. However, the physical state of all senior persons cannot be accurately represented by our community-sourced volunteer recruiting. While the physical condition of older adults in the community is generally acceptable, the degree of frailty may exhibit more pronounced manifestation within older institutions, such as nursing homes.

Throughout the research process, some patients were unable to complete the full test due to their limited capacity for sustained long-distance walking. For safety reasons, these individuals had to be excluded from the study. While we would handle missing data appropriately, this may impact the experimental results and potentially weaken the test's effectiveness. Consequently, the restricted source of the samples supply diminishes the representativeness, universality, and generalizability of our study findings, thereby reducing their therapeutic usefulness. Although there are some intrinsic limitations to the test, the 6MWT can be potentially performed in the vast majority of geriatric population, thus key gait parameters can be served as an important tool for early frailty screening, diagnostic assessment, and early prevention in older adults (50).

Future study is warranted to validate and generalize these findings to other populations and settings, as well as to explore the potential of integrating additional data sources and advanced machine learning algorithms to further enhance the ability of ML to identify the risk of frailty. Ultimately, the insights gained from this study have the potential to significantly impact clinical practice, leading to improved identification and management of frailty in older adults, enhancing their quality of life and overall health outcomes.

Conclusion

Overall, our findings suggest that combining CGA and wearable sensor-derived gait parameters can improve the accuracy of frailty prediction models. The use of digital measures of gait, such as the 6MWT, plays a crucial role in enhancing the model's predictive power and should be considered by healthcare professionals when evaluating frailty risk in older patients. Due to the rapid rate at which wearable sensor-based data is being collected, high-performance data processing is becoming increasingly important. Further research is needed to determine the generalizability of these findings to other populations and settings.

Data availability statement

The datasets presented in this article are not readily available because the datasets used and/or analyzed during the current study could be obtained from the corresponding author with reasonable requests. Requests to access the datasets should be directed to FX, xufuping1983@gzucm.edu.cn.

Ethics statement

The studies involving human participants were reviewed and approved by Ethics Review Board of Guangdong Provincial Hospital of Chinese Medicine Ethics Committee (reference: B2017-168-01). The patients/participants provided their written informed consent to participate in this study.

Author contributions

SF, ZY, and FX conceived and designed the study. SF, RP, and QX recruited the participants, collected the data for the manuscript and provided substantial feedback. SF, JY, ZP, and BH analyzed and interpreted the data. SF, BH, and FX wrote the first draft of the

manuscript. All authors contributed to the article and approved the submitted version.

Funding

The study was supported by the National Natural Science Foundation of China, No. 81974560; Guangzhou Science and Technology Plan Project, No. 2023A03J0736; Yan Dexin Academic Lessons learned Studio, The Second Hospital of Chinese Medicine [2014] No. 89; Scientific and technological research project of Guangdong Provincial Hospital of Chinese Medicine, No. YN2019ZWB03; Guangdong Provincial Key Laboratory of Diagnosis and Treatment of Major Neurological Diseases, No. 2020B1212060017; Guangdong Provincial Clinical Research Center for Neurological Diseases, No. 2020B1111170002; Southern China International Joint Research Center for Early Intervention and Functional Rehabilitation of Neurological Diseases, No. 2015B050501003 and 2020A0505020004; Guangdong Provincial Engineering Center for Major Neurological Disease Treatment, Guangdong Provincial Translational Medicine Innovation Platform for Diagnosis and Treatment of Major Neurological Disease, Guangzhou Clinical Research and Translational Center for Major Neurological Diseases, No. 201604020010 and Guangdong Basic and Applied Basic Research Foundation, No. 2021B1515120062. Funders played no role in this study (the design, data collection, execution, analysis, interpretation of data and writing the manuscript).

Acknowledgments

We appreciate the cooperation of the staff of the Guangdong Provincial Hospital of Chinese Medicine.

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

References

1. Dent E, Martin FC, Bergman H, Woo J, Romero-Ortuno R, Walston JD. Management of frailty: opportunities, challenges, and future directions. *Lancet*. (2019) 394:1376–86. doi: 10.1016/S0140-6736(19)31785-4

2. Looman WM, Fabbricotti IN, Blom JW, Jansen APD, Lutomski JE, Metzelthin SF, et al. The frail older person does not exist: development of frailty profiles with latent class analysis. *BMC Geriatr*. (2018) 18:84. doi: 10.1186/s12877-018-0776-5

3. Stolz E, Mayerl H, Freidl W. Fluctuations in frailty among older adults. *Age Ageing*. (2019) 48:547–52. doi: 10.1093/ageing/afz040

4. Fried LP, Tangen CM, Walston J, Newman AB, Hirsch C, Gottdiener J, et al. Frailty in older adults: evidence for a phenotype. *J Gerontol A Biol Sci Med Sci*. (2001) 56:M146–57. doi: 10.1093/gerona/56.3.M146

5. Solfrizzi V, Scafato E, Lozupone M, Seripa D, Schilardi A, Custodero C, et al. Biopsychosocial frailty and the risk of incident dementia: the Italian longitudinal study on aging. *Alzheimers Dement*. (2019) 15:1019–28. doi: 10.1016/j.jalz.2019.04.013

6. Henry JD, Coundouris SP, Mead J, Thompson B, Hubbard RE, Grainger SA. Social frailty in late adulthood: social cognitive and psychological wellbeing correlates. *J Gerontol B Psychol Sci Soc Sci*. (2022) 78:87–96. doi: 10.1093/geronb/gbac157

7. Zhou H, Park C, Shahbazi M, York MK, Kunik ME, Naik AD, et al. Digital biomarkers of cognitive frailty: the value of detailed gait assessment beyond gait speed. *Gerontology*. (2022) 68:224–33. doi: 10.1159/000515939

8. Chu WM, Kristiani E, Wang YC, Lin YR, Lin SY, Chan WC, et al. A model for predicting fall risks of hospitalized elderly in Taiwan – a machine learning approach based on both electronic health records and comprehensive geriatric assessment. *Front Med*. (2022) 9:937216. doi: 10.3389/fmed.2022.937216

9. Pirker W, Katzenschlager R. Gait disorders in adults and the elderly: a clinical guide. *Wien Klin Wochenschr*. (2017) 129:81–95. doi: 10.1007/s00508-016-1096-4

10. Millan-Domingo F, Tarazona-Santabalbina FJ, Carretero A, Olaso-Gonzalez G, Viña J, Gomez-Cabrera MC. Real-life outcomes of a multicomponent exercise intervention in community-dwelling frail older adults and its association with nutritional-related factors. *Nutrients*. (2022) 14:5147. doi: 10.3390/nu14235147

11. Fritz S, Lusardi M. White paper: walking speed: the sixth vital sign. *J Geriatr Phys Ther*. (2001) 32:2–5. doi: 10.1519/00139143-200932020-00002

12. Hu B. Application of wearable technology in clinical walking and dual task testing. *J Transl Int Med*. (2019) 7:87–9. doi: 10.2478/jtim-2019-0019

13. Chomiak T, Watts A, Burt J, Camicioli R, Tan SN, McKeown MJ, et al. Differentiating cognitive or motor dimensions associated with the perception of fall-related self-efficacy in Parkinson's disease. *NPJ Parkinsons Dis*. (2018) 4:26. doi: 10.1038/s41531-018-0059-z

14. Hu B, Chomiak T. Wearable technological platform for multidomain diagnostic and exercise interventions in Parkinson's disease. *Int Rev Neurobiol*. (2019) 147:75–93. doi: 10.1016/bs.irn.2019.08.004

15. Ambagtsheer RC, Shafiabady N, Dent E, Seiboth C, Beilby J. The application of artificial intelligence (AI) techniques to identify frailty within a residential aged care administrative data set. *Int J Med Inform*. (2020) 136:104094. doi: 10.1016/j.ijmedinf.2020.104094

16. Aponte-Hao S, Wong ST, Thandi M, Ronksley P, McBrien K, Lee J, et al. Machine learning for identification of frailty in Canadian primary care practices. *Int J Popul Data Sci*. (2021) 6:1650. doi: 10.23889/ijpds.v6i1.1650

17. le Pogam MA, Seematter-Bagnoud L, Niemi T, Assouline D, Gross N, Trächsel B, et al. Development and validation of a knowledge-based score to predict Fried's frailty phenotype across multiple settings using one-year hospital discharge data: The electronic frailty score. *EClinicalMedicine*. (2022) 44:101260. doi: 10.1016/j.eclinm.2021.101260

18. Tarekegn A, Ricceri F, Costa G, Ferracin E, Giacobini M. Predictive modeling for frailty conditions in elderly people: machine learning approaches. *JMIR Med Inform*. (2020) 8:e16678. doi: 10.2196/16678

19. Koo D, Lee AR, Lee E, Kim IK. Development of a frailty detection model using machine learning with the Korean frailty and aging cohort study data. *Healthc Inform Res*. (2022) 28:231–9. doi: 10.4258/hir.2022.28.3.231

20. Tyler Williamson P, Aponte-Hao S, Mele B, Lethebe BC, Leduc C, Thandi M, et al. Developing and validating a primary care EMR-based frailty definition using machine learning. *Int J Popul Data Sci*. (2020) 5:1344. doi: 10.23889/ijpds.v5i1.1344

21. Park C, Mishra R, Golledge J, Najafi B. Digital biomarkers of physical frailty and frailty phenotypes using sensor-based physical activity and machine learning. *Sensors (Basel)*. (2021) 21:5289. doi: 10.3390/s21165289

22. Kraus M, Saller MM, Baumbach SF, Neuerburg C, Stumpf UC, Böcker W, et al. Prediction of physical frailty in orthogeriatric patients using sensor insole-based gait analysis and machine learning algorithms: cross-sectional study. *JMIR Med Inform*. (2022) 10:e32724. doi: 10.2196/32724

23. Minici D, Cola G, Giordano A, Antoci S, Girardi E, Bari MD, et al. Towards automated assessment of frailty status using a wrist-worn device. *IEEE J Biomed Health Inform*. (2022) 26:1013–22. doi: 10.1109/JBHI.2021.3100979

24. Wu Y, Jia M, Xiang C, Fang Y. Latent trajectories of frailty and risk prediction models among geriatric community dwellers: an interpretable machine learning perspective. *BMC Geriatr*. (2022) 22:900. doi: 10.1186/s12877-022-03576-5

25. Levis B, Benedetti A, Thombs BD. Accuracy of patient health questionnaire-9 (PHQ-9) for screening to detect major depression: individual participant data meta-analysis. *BMJ*. (2019) 365:l1476. doi: 10.1136/bmj.l1476

26. Löwe B, Decker O, Müller S, Brähler E, Schellberg D, Herzog W, et al. Validation and standardization of the Generalized Anxiety Disorder Screener (GAD-7) in the general population. *Med Care*. (2008) 46:266–74. doi: 10.1097/MLR.0b013e318160d093

27. Chen KL, Xu Y, Chu AQ, Ding D, Liang XN, Nasreddine ZS, et al. Validation of the Chinese version of montreal cognitive assessment basic for screening mild cognitive impairment. *J Am Geriatr Soc*. (2016) 64:e285–90. doi: 10.1111/jgs.14530

28. Zhuang L, Yang Y, Gao J. Cognitive assessment tools for mild cognitive impairment screening. *J Neurol*. (2021) 268:1615–22. doi: 10.1007/s00415-019-09506-7

29. Ismail Z, Agüera-Ortiz L, Brodaty H, Cieslak A, Cummings J, Fischer CE, et al. The Mild Behavioral Impairment Checklist (MBI-C): a rating scale for neuropsychiatric symptoms in pre-dementia populations. *J Alzheimers Dis*. (2017) 56:929–38. doi: 10.3233/JAD-160979

30. Hu S, Patten SB, Fick G, Smith EE, Ismail Z. Validation of the mild behavioral impairment checklist (MBI-C) in a clinic-based sample. *Alzheimers Dement*. (2019) 15:P365. doi: 10.1016/j.jalz.2019.06.872

31. Chomiak T, Sidhu AS, Watts A, Su L, Graham B, Wu J, et al. Development and Validation of Ambulosono: A Wearable Sensor for Bio-Feedback Rehabilitation Training. *Sensors (Basel)*. (2019) 19:686. doi: 10.3390/s19030686

32. Taylor HL, Jacobs DR Jr, Schucker B, Knudsen J, Leon AS, Debacker G. A questionnaire for the assessment of leisure time physical activities. *J Chronic Dis*. (1978) 31:741–55. doi: 10.1016/0021-9681(78)90058-9

33. Schwenk M, Mohler J, Wendel C, D"Huyvetter K, Fain M, Taylor-Piliae R, et al. Wearable sensor-based in-home assessment of gait, balance, and physical activity for discrimination of frailty status: baseline results of the Arizona frailty cohort study. *Gerontology*. (2015) 61:258–67. doi: 10.1159/000369095

34. Smith A, Anand H, Milosavljevic S, Rentschler KM, Pocivavsek A, Valafar H. Application of machine learning to sleep stage classification. *Proce Int Conf Comput Sci Comput Intell*. (2021) 2021:349–54. doi: 10.1109/csci54926.2021.00130

35. Muhammad LJ, Islam MM, Usman SS, Ayon SI. Predictive data mining models for novel coronavirus (COVID-19) infected patients' recovery. *SN Comput Sci*. (2020) 1:206. doi: 10.1007/s42979-020-00216-w

36. Kriegeskorte N, Golan T. Neural network models and deep learning. *Curr Biol*. (2019) 29:R231–6. doi: 10.1016/j.cub.2019.02.034

37. Nguyen B, Morell C, De Baets B. Scalable large-margin distance metric learning using stochastic gradient descent. *IEEE Trans Cybern*. (2020) 50:1072–83. doi: 10.1109/TCYB.2018.2881417

38. Lundberg SM, Erion G, Chen H, DeGrave A, Prutkin JM, Nair B, et al. From local explanations to global understanding with explainable AI for trees. *Nat Mach Intell*. (2020) 2:56–67. doi: 10.1038/s42256-019-0138-9

39. Park C, Mishra R, Sharafkhaneh A, Bryant MS, Nguyen C, Torres I, et al. Digital biomarker representing frailty phenotypes: the use of machine learning and sensor-based sit-to-stand test. *Sensors (Basel)*. (2021) 21:3258. doi: 10.3390/s21093258

40. Jung D, Kim J, Kim M, Won CW, Mun KR. Frailty assessment using temporal gait characteristics and a long short-term memory network. *IEEE J Biomed Health Inform*. (2021) 25:3649–58. doi: 10.1109/JBHI.2021.3067931

41. Bortone I, Sardone R, Lampignano L, Castellana F, Zupo R, Lozupone M, et al. How gait influences frailty models and health-related outcomes in clinical-based and population-based studies: a systematic review. *J Cachexia Sarcopenia Muscle*. (2021) 12:274–97. doi: 10.1002/jcsm.12667

42. Rubin DS, Ranjeva SL, Urbanek JK, Karas M, Madariaga MLL, Huisingh-Scheetz M. Smartphone-based gait cadence to identify older adults with decreased functional capacity. *Digit Biomark*. (2022) 6:61–70. doi: 10.1159/000525344

43. Mueller A, Hoefling HA, Muaremi A, Praestgaard J, Walsh LC, Bunte O, et al. Continuous digital monitoring of walking speed in frail elderly patients: noninterventional validation study and longitudinal clinical trial. *JMIR Mhealth Uhealth*. (2019) 7:e15191. doi: 10.2196/15191

44. Lee H, Lee E, Jang IY. Frailty and comprehensive geriatric assessment. *J Korean Med Sci*. (2020) 35:e16. doi: 10.3346/jkms.2020.35.e16

45. Ma L, Zhang L, Zhang Y, Li Y, Tang Z, Chan P. Cognitive frailty in China: results from China comprehensive geriatric assessment study. *Front Med*. (2017) 4:174. doi: 10.3389/fmed.2017.00174

46. Sajeev S, Champion S, Maeder A, Gordon S. Machine learning models for identifying pre-frailty in community dwelling older adults. *BMC Geriatr*. (2022) 22:794. doi: 10.1186/s12877-022-03475-9

47. Eskandari M, Parvaneh S, Ehsani H, Fain M, Toosizadeh N. Frailty identification using heart rate dynamics: a deep learning approach. *IEEE J Biomed Health Inform*. (2022) 26:3409–17. doi: 10.1109/JBHI.2022.3152538

48. Akbari G, Nikkhoo M, Wang L, Chen CPC, Han DS, Lin YH, et al. Frailty level classification of the community elderly using Microsoft Kinect-based skeleton pose: a machine learning approach. *Sensors (Basel)*. (2021) 21:4017. doi: 10.3390/s21124017

49. Abbas M, Somme D, Jeannes RB, (Eds.) Machine Learning-Based Physical Activity Tracking with a View to Frailty Analysis. 2020 42nd Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC) in conjunction with the 43rd Annual Conference of the Canadian Medical and Biological Engineering Society; (2020).

50. Yin MC, Yan YJ, Tong ZY, Xu CQ, Qiao JJ, Zhou XN, et al. Development and validation of a novel scoring system for severity of plantar fasciitis. *Orthop Surg*. (2020) 12:1882–9. doi: 10.1111/os.12827

frontiers | Frontiers in Public Health

TYPE Original Research
PUBLISHED 20 July 2023
DOI 10.3389/fpubh.2023.1118207

OPEN ACCESS

EDITED BY
Francesco De Micco,
Campus Bio-Medico University, Italy

REVIEWED BY
Pedro R. Palos Sanchez,
Sevilla University, Spain
Abdolvahab Samavi,
University of Hormozgan, Iran

*CORRESPONDENCE
Xinyu Guo
✉ gxy19831468213@163.com

RECEIVED 07 December 2022
ACCEPTED 05 June 2023
PUBLISHED 20 July 2023

CITATION
Wei Y and Guo X (2023) Impact of smart device use on objective and subjective health of older adults: findings from four provinces in China. *Front. Public Health* 11:1118207. doi: 10.3389/fpubh.2023.1118207

Impact of smart device use on objective and subjective health of older adults: findings from four provinces in China

Yan Wei and Xinyu Guo*

School of Statistics, Xi'an University of Finance and Economics, Xi'an, China

Background: The digital divide has grown because of the deepening digitalization of the Chinese society and the intersection between high-end technology and the age structure. Older adults show an increasing level of weakness in digital life integration. What digital development can bring to older adults is a pressing concern.

Objective: This study aims to investigate how smart device use affects older adults' health status and offers an empirical reference for improving their digital literacy and health.

Methods: The data in this study were collected from an offline survey conducted from December 2021 to April 2022, which obtained 1110 valid samples of older adults This study used a multivariate ordered logit model, mediating effect model, and heterogeneity test to analyze the impact of smart device use on the health status of older adults.

Results: Smart device use has a significant positive effect on the self-rated, physical, and psychological health of older adults, and this positive effect is more pronounced among older adults living in urban areas or with a higher age. The average net effect of smart devices on each health status of older adults is 0.161 for self-rated health, 0.155 for physical health, and 0.071 for psychological health. In-depth research found that older adults' attitudes toward smart devices played a mediating role in the influence of smart device use on self-rated and psychological health respectively.

Conclusions: The study found that smart device use had a positive effect on the health status of older adults and that the performance expectations and individualized needs of older adults exhibited an effective linkage between smart devices and health status. Smart device use could improve the overall health of older adults, especially the urban and low-age older adults. Promoting the understanding of the practicality of smart devices for older adults and the aging-oriented transformation of smart devices is an effective way to improve the health status of older adults. The findings provide theoretical support for the wide application of smart devices in older adults, and can effectively help eHealth practitioners implement accurate geriatric health support strategies.

KEYWORDS

smart device, older adults, self-rated health, physical health, psychological health, propensity score matching, mediating effect

1. Introduction

The intersection of high-end technology and the age structure widened the age-oriented digital divide. The large population has made the digital divide among older adults a major livelihood concern for governments in the digital age. Older adults lag behind younger people in their adoption, especially when it comes to internet use (1). Also, older adults have been classified as one of the most information-weak groups in some countries including Korea (2) and China. Exploring the impact of digital development on older adults will help integrate existing resources for senior care and significantly enhance the support for older adults' health and digital literacy.

The United Nations projects that the world's population could grow to around 8.5 billion by 2030 (3), up from the recent number of 8 billion. Average life expectancy also increases with population growth. It is predicted that the average longevity worldwide will be 77.2 years by 2050 (4). Population aging will increase because of increased life expectancy and declining birth rate. The Second World Assembly on Aging took place in Madrid in 2002, where it was proposed that "population aging is a universal force that has the power to shape the future as much as globalization." (5) As the world's most populous region, the overall speed and level of population aging in Asia have a huge impact on the quantity and quality of life of the global population. In China, the population of older adults aged 60 or above had reached 2.67 billion by the end of 2021(6), making China the country with the largest number of older adults in the world. Aging in China shows obvious characteristics of getting old before becoming rich and processing faster. China put forward a policy of actively coping with population aging in 2006, which was elevated to a national level in the 14th Five-Year Plan (2021–2025) in 2021.

Currently, the main problems that need to be resolved are how to better satisfy the needs of older adults, encourage their engagement, and help them share the benefits of social development considering China's rapid aging. This study focused on the impact of smart device use on the health status of older adults. The rationale behind choosing this research theme is that older adults exhibit growing digital fragility and obvious digital weakness as the digitalization of Chinese society deepens. Smart devices are among the most direct links between the internet and its users. Research on the impact of smart devices on the health status of older adults will help clarify the impact of digital life on the health of older adults, help explore the aging-oriented development of smart products, and effectively help solve the digital divide for older adults.

The possible innovations and contributions of this study are as follows: first, in the context that most of the current research is on a single health aspect, the study for the first time comprehensively considers the subjective and objective health of older adults and analyzes the impact on each health status by combining multidimensional perspectives of social interaction, economic level, and intergenerational support. Second, in the context of a deeply aging society and accelerating the construction of digital China, this paper further analyzes the intrinsic effect mechanism combined with actual life needs, and analyzes the essence in depth based on the analysis of the impact of smartphone use on health to provide empirical references for the improvement of health quality and digital literacy of older adults. Finally, the findings show that use smartphone in moderation can improve the overall health of older adults, and provide a feasible development direction for improving the digital literacy of older adults and achieving healthy aging.

This study is divided into four parts. First, the literature review section gives the theoretical origins of the concept of "eHealth" and reviews the literature on smart device use and health status of older adults. Second, materials and methods are included, which consist of data sources, variable definitions, and analysis strategies. Third, the impact of smart device use on the health status of older adults were analyzed, in which robustness tests and mediating effects tests were conducted, and heterogeneity tests based on older characteristics were analyzed. Finally, this paper discusses the analyses and summarizes the limitations.

2. Literature review

Palos-Sanchez's study (7) noted that telemedicine and eHealth have duly become important factors for the analysis, study, etc.,. "Health services and information provided by the Internet and related technologies." was used by Eysenbach (8) to define Electronic health or eHealth. It can be seen that eHealth not only refers to the development of medical information technology, but also means an Internet-based way, which is more conducive to promoting the development of modern health care (9). As one of the main accesses for older adults to the Internet, smart devices offer older adults a new way to access health information and improve their health conditions.

The relationship between smart devices and the health status of older adults is an important topic in digitalization and aging. Studies have been conducted to analyze the overall health of older adults in terms of smart devices, individual characteristics, and social status. The popularity of smart mobile devices such as smartphones and smartwatches has promoted the openness and expansion of mobile health applications, providing support for coping with structural changes and population aging (32). The popularity of mobile technology has led to the widespread development of digital health interventions (10), and the use of smart wearable devices can help older adults improve their health (11). In terms of social interaction, active participation in social activities contributes to healthy aging. The social networks of older adults have different influences on their health. The use of digital technologies such as the internet can effectively contribute to active aging, and studies have shown that older adults who use online payments have better physical and psychological health (12). Older adults who use the internet also have a larger social network in which their social participation plays a positive role (13), while living alone has a negative impact on their health and overall wellbeing (14). Education plays a role in the choice of social networks and the number of choices made by older adults (14). Moreover, some studies have shown that internet health information education for older adults can significantly improve their health literacy (15). The overall health of older adults has improved after using health self-tests and health training provided by smartphones (16).

The health of older adults can be divided into self-rated, physical, and psychological health. First, in terms of self-rated

TABLE 1 Summary of key literatures.

Item	Overall health	Self-rated health	Physical health	Psychological health
Smart device	Lead to widespread development of digital health interventions; online health training improves overall health; internet access positively affects health and life quality	Internet access improves self-rated health; internet use could improve self-rated health and mood	Help obtain health information and receive medical services; long-term internet use affects negatively	Positive effect increases over time; older adults addicted to smartphones being more likely to suffer from severe anxiety and depression.
Social interaction	Active participation contributes to active aging			Weaken psychological loneliness, relieve pressure and depression; Appropriate online socialization improves health
Education	Affect the choice of social networks and the number of choices	Education was an essential factor when predicting the impact of the internet		
Living arrangement	Living alone has a negative effect on health			Appropriate intergenerational technical and communication can positively affect older adults' feelings

health, some studies have shown that reported symptoms and disease factors, biological factors, and behavioral factors can lead to gender differences in the subjective health of older adults and that the health quality of the female population is lower than that of the male population when controlling for residential characteristics, basic physical health, socioeconomic status, and family support. Smartphone use among older adults has a significant positive effect, which increases with the improvement in education, income, and children's living conditions on their subjective health status determination (17). Some studies have found that internet access among older adults can improve self-rated health and has multiple positive effects on health and quality of life (18). A study by Nwoke et al. (19) pointed out that education was the least negligible factor when predicting the impact of the internet on the self-rated health of older adults, and the higher the education level, the better the psychological health status. Yang and He (20) found that internet use could significantly improve self-rated health and mood in adults aged 45 years or above.

Second, in terms of physical health, the development of the internet has helped older adults obtain health information. Moderate smartphone use and its support software are conducive to improving the health of older adults. Some studies have shown that internet use can effectively improve the physical health of older adults (21). The development of the internet has also facilitated access to health information, prevention of illnesses, and helped residents receive medical services more conveniently (20). Cohall et al. (22) believed that, through the internet, older adults could obtain more knowledge that benefits their physical health. However, Billari et al. (23) argued that long-term internet use could have a negative impact on physical health. Smartphones and their support software can also help older adults improve their health, with 12 smartphone applications being found to help older adults improve their health and quality of life while maintaining safe social distancing during the COVID-19 pandemic (24).

In terms of psychological health, intergenerational support and social interaction have a significant impact; moderate use of the internet and smartphones can also help older adults enhance socialization and alleviate loneliness. Appropriate online socialization can improve the psychological health of older adults. Studies have shown that once older adults establish a social network on the Internet, they are bound to weaken their psychological loneliness, relieve pressure and depression, and their psychological health benefits from it (25). The positive impact of the internet on the psychological health of older adults also increases over time (26). Sharing information through social media can consolidate family relations and alleviate the sense of social alienation and loneliness of older adults, improve self-efficacy and the sense of control, and ultimately enhance their life satisfaction (27). In terms of smartphone use, intergenerational technical support can significantly affect the feelings of older adults (28). Smartphones improve the emotional health of older adults more than VR technology (29); however, excessive smartphone use can also be harmful, with older adults who are addicted to smartphones being more likely to suffer from severe anxiety and depression symptoms (30).

Throughout the relevant studies, the overall health status of older adults was mostly analyzed from the aspects of individual characteristics, social interactions, and the use of internet and smart devices. We have summarized some of the key literature (Table 1). Some studies were conducted separately on self-rated, physical, and psychological health and concluded that older adults could effectively improve their health conditions by moderate contact and use of the internet and smart devices. At the same time, individual characteristics, social interaction, and intergenerational support had mostly significant effects on the health of older adults. Studies on the impact of smart device use on older adults' health status still have the following research spaces: first, most of the studies focus on a certain aspect of health status, and there is a lack of studies that analyze the impact of smart device use represented by smartphones on the comprehensive health status of older adults. Second, although some researchers have explored the impact of smart device use on the health status of older adults using both qualitative and quantitative methods, the underlying mechanism is relatively complex and the existence of self-selection bias remains to be further examined. Third, few studies have further explored whether other factors affect the relationship between smart device use and the health status of older adults. Therefore, this paper will examine the impact of smart device use on self-rated, physical, and psychological health to enrich the study on the impact of smart devices on health status of older adults and test the mediating effects

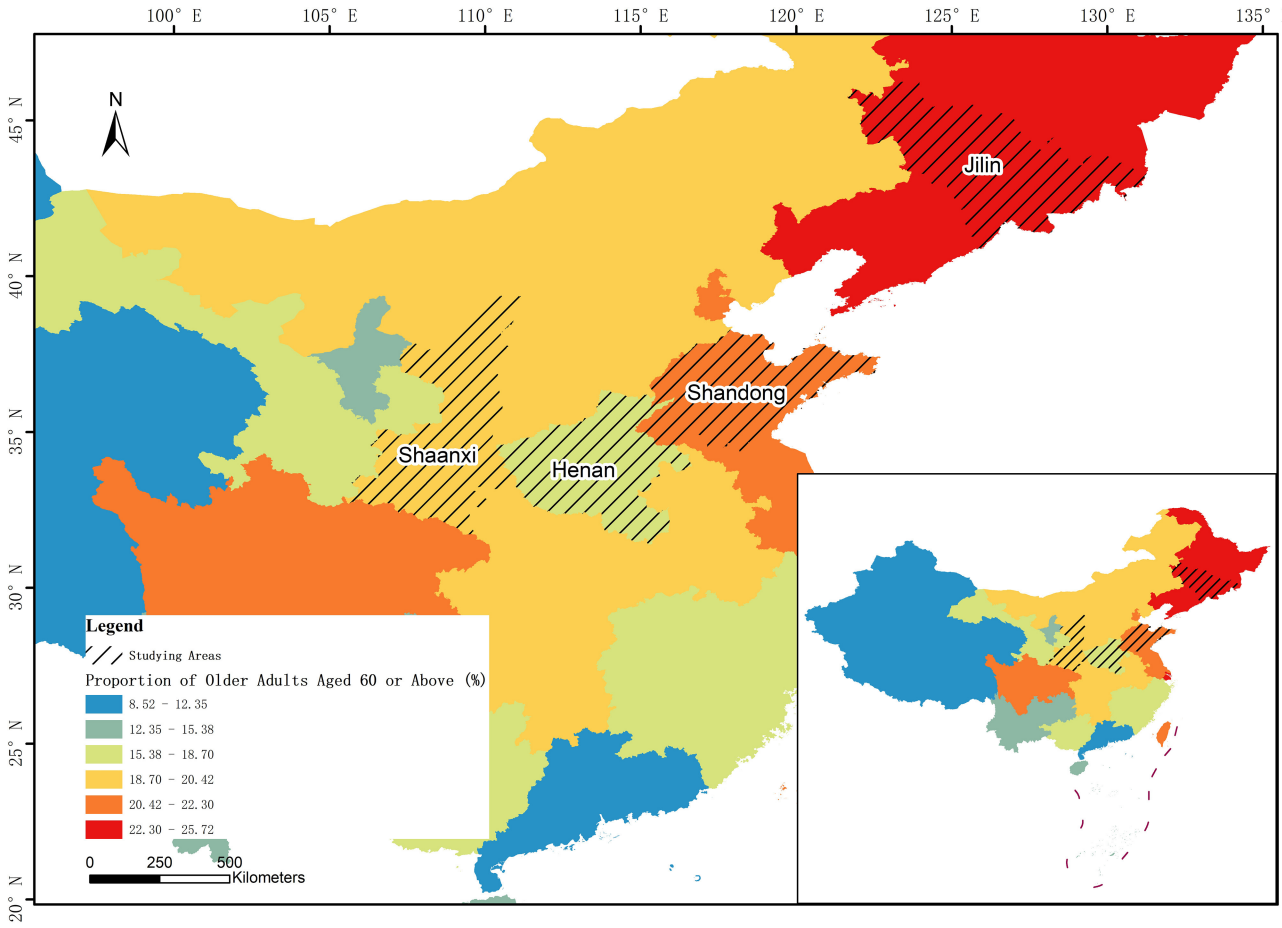


FIGURE 1
The distribution of survey locations.

of the performance expectations and individualized needs of older adults from smart devices. More conclusions were obtained from the group heterogeneity tests for comprehensive health according to age and residence.

3. Materials and methods

3.1. Aims and questions

This study aims to investigate how smart device use affects older adults' health status and offers an empirical reference for improving their digital literacy and health.

Specifically, this study wants to examine the following questions: whether the use of smart devices affects the health status of older adults? If so, are there any differences between older adults with different characteristics? If there are other factors that play a role in the mechanism between smart device use and the health of older adults?

3.2. Data

The data used in this study were obtained from a face-to-face offline survey of older adults in four provinces of China from December 2021 to April 2022.This project convened and trained investigators offline to obtain rigorous and authentic questionnaires through face-to-face interviews with older adults. Before the formal survey, a small-scale pre-survey was conducted to check the validity of the questionnaire. Investigators used the initial questionnaire to carry out a small-scale offline survey of the target older adults with different gender, age, residence and other characteristics. Then some questions and options were adjusted according to the survey results, which improved the rationality and rigor of the questionnaire. Based on the geographical distribution and aging degree in the results of Seventh National Population Census, four provinces were selected as survey locations: Jilin Province in the Northeast, Shandong Province in the East, Henan Province in the central, and Shaanxi Province in the West. According to factors such as the proportion of population in each province and the needed number of respondents, the number of respondents in each province is calculated, and then subdivided into municipalities within the provinces. The aging degree of Henan Province is lower than the average level of China (18.70%), while that of other three provinces is higher, which represents the different aging degrees in different regions of China. Figure 1 shows the distribution of survey locations; the colors of provinces with a higher aging degree are darker.

TABLE 2 Sample description.

Item	Content	Size	Proportion (%)
Gender	Male	522	47.02
	Female	588	52.97
Age	55–64	191	17.21
	65–74	424	38.20
	75 or above	495	44.59
Education level	Primary school or below	593	53.42
	Junior high school	302	27.21
	High school or technical secondary school	149	13.42
	Junior college or above	66	5.95
Marital status	Has spouse	793	71.44
	Without spouse	317	28.56
Average monthly income	0–1,999	659	59.37
	2,000–3,999	318	28.65
	4,000 or above	133	11.98

The survey, targeting people aged 55 and over, included both questionnaires and qualitative interviews. Questionnaires consist of individual and community questionnaires, and the former of which can be further divided into three parts: basic information about older adults and their family situation, smart device use in older adults, and basic information about their offspring. A total of 1,170 responses were obtained, including 1,110 valid responses used in this study. The sample statistics are shown in Table 2. It can be seen from the table that there were 522 male older adults, accounting for 47.02%, and 588 female older adults, accounting for 52.97%, indicating that the gender distribution of the survey respondents was relatively even. In terms of age, there were more older adults with a higher age. There are 191 older adults aged 55–64, accounting for only 17.21%, 424 older adults aged 65–74, accounting for 38.20%, and 495 older adults aged 75 and above, accounting for 44.59%, which was much in line with the aging trend of China's older adults. As for education level, the vast majority of older adults had a low education level, 593 older adults only had primary education or below, accounting for 53.42%, only 66 older adults have college education or above, accounting for 5.95%; In terms of marital status, 793 older adults had spouses, accounting for 71.44%, and 317 older adults were without spouses, accounting for a relatively low proportion of 28.56%; As for average monthly income, 59.37% of the older adults had a monthly income of <2,000 yuan, 28.65% of the older adults had 2,000–3,999 yuan, and only 11.98% of the older adults had more than 4,000 yuan, which mean that most of the older adults had a low monthly income.

Compared with the data of Seventh National Population Census and the 49th Statistical Report on China's Internet development released by the China Internet Network Information Center (CNNIC) (31) (Table 3), the characteristics of the survey respondents are relatively similar and the data have good representative traits.

3.3. Variables

Most existing studies on the health status of older adults have been conducted in terms of self-rated, physical, and psychological health. This study described the health status of older adults in terms of three dependent variables for a comprehensive analysis of the same sample. The dependent variables in this study were the health status of older adults, including their self-rated, physical, and psychological health (Table 4).

The first dependent variable was the self-rated health status of older adults. Specifically, the responses to the question "How is your current physical health?" was used to evaluate the self-rated health. The five categories that respondents used for their answers were combined into "Poor" (a combination of "Very poor" and "Poor"), "Average" and "Good" (a combination of "Very good" and "Good"), considering the small number of people who chose "Very poor" or "Very good."

The second dependent variable was the objective health degree of older adults. Physical health was measured using 12 indicators on the Activities of Daily Living (ADL) scale: eating, bathing, dressing, going to the toilet, walking, going up and down stairs, traveling by car, shopping, doing housework, washing, cooking, and talking on the phone. The value of each option was "1 = Fully able," "2 = Partially able," and "3 = Unable." The reliability (Cronabach's α = 0.928) and validity (KMO = 0.922) analysis of this scale showed good results. The total score of the 12 items was 12 for "Good" coded as 3, 13–24 for "Average" coded as 2, and 25–36 for "Poor" coded as 1.

The third dependent variable was the psychological health. This variable, was based on five indicators of the depression scale in the questionnaire: mood, life emptiness, loneliness, sleep status, and life attitude. Two of the questions were rated positively and three were rated negatively. The values assigned to each option were "1 = Strongly disagree," "2 = Disagree," "3 = Average," "4 = Agree," and "5 = Strongly agree." The positive scoring questions were turned, the reliability (Cronabach's α = 0.708) and validity (KMO = 0.661) analysis of this scale showed good results. Then the values of the five questions were combined. The total score of 16–25 for "Poor" coded as 1, 6–15 for "Average" coded as 2, and 5 for "Good" coded as 3.

The independent variable in this study was smart device use by respondents, represented by smartphones, as measured by the question "Do you use a smartphone" in the questionnaire with the options including "Yes" and "No."

Additionally, a list of factors considered important in affecting the health status of older adults was used as a control variable in this study. The personal characteristics of the older adults included gender (male, female), age (55–64, 65–74, 75 or above), resident area (rural, urban) (20), education (literacy) (17, 19), marital status (has spouse, without spouse) (12), and other variables reflected in the economic level (personal average monthly income) (12), social interactions (interpersonal expenditure) (25, 27), and

TABLE 3 Comparison of the survey with the results of Seventh National Population Census and the 49th statistics on China's Internet development (%).

Item	Content		Survey result	Seventh National Population Census
Health status	Good health		54.4	54.6
	General health		28.5	32.6
	Poor health		17.1	12.8
Education level	Primary school and below		53.5	58.6
	Junior high school		27.2	27.5
	High school or technical secondary school		13.4	9.92
	Junior college or above		6.00	3.98
Item	**Content**		**Survey result**	**CNNIC**
Internet Use	Internet penetration rate for older adults		47.1	43.2
	Commonly used applications of older Internet users	Instant messaging	95.7	90.6
		Web video	83.2	84.8
		Web news	62.4	77.9
		Online payments	54.6	70.6

TABLE 4 Variable definition and descriptive statistics.

Variable		Variable definition	Mean	SD
Dependent variable	Self-rated health	Poor = 1, Average = 2, Good = 3	2.377	0.760
	Physical health	Poor = 1, Average = 2, Good = 3	2.613	0.571
	Psychological health	Poor = 1, Average = 2, Good = 3	1.862	0.441
Independent variable	Smartphone use	No = 0, Yes = 1	0.570	0.495
Mediator	Performance expectations	Identification of getting valuable information from smart devices	2.294	0.768
	Individualized needs	Identification of smart devices meeting life needs	2.224	0.810
Control variable	Gender	Female = 0, Male = 1	0.470	0.497
	Age	55–64 = 1, 65–74 = 2, 75 or above = 3	2.274	0.737
	Residential area	Rural = 0, Urban = 1	0.445	0.497
	Education level	Primary school or below = 1, Junior high school = 2, High school or technical secondary school = 3, Junior college or above = 4	1.719	0.910
	Marital Status	Without spouse = 0, Has spouse = 1	0.714	0.452
	Average monthly income	0–1,999 = 1, 2,000–3,999 = 2, 4,000 or above = 3	1.526	0.700
	Interpersonal expenditures	0–999 = 1, 1,000–5,999 = 2, 6,000 or above = 3	1.969	0.676
	Living arrangement	With families = 1, Alone = 2, Others = 3	1.176	0.432

SD, Standard deviation.

intergenerational support (living arrangement) (14). It was tested that there was no muti-collinearity between the independent variable and the control variables.

According to existing studies, smartphone use by older adults could improve their quality of life (24), and the health of older adults with online social networks is better (25). In addition, health information obtained through the internet (22) or smartphones (16) helps older adults improve their health. Combined with Maslow's hierarchy of needs, cognitive (high-level), physiological, and social (low-level) needs are closer to the real needs of users in terms of social information and individual satisfaction. This study selected the performance expectations and individualized needs of older adults as mediators, considering the results of this survey that more than 50% of older adults use smartphones

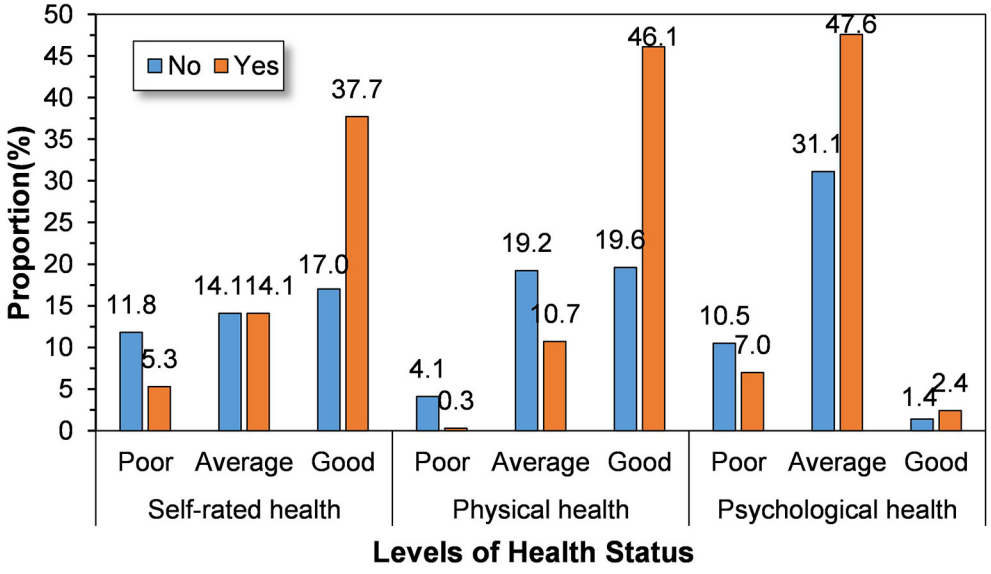


FIGURE 2
The health status of older adults under different smartphone use conditions.

to fulfill the following needs: receiving phone calls, chatting on WeChat, online payment, entertainment, and getting news and information. Performance expectations were expressed by "How much do you agree that you can get valuable information by using smart devices?" and individualized needs were expressed by "How much do you agree that using smart devices can meet your needs in life?" The values assigned to each option were "1 = Disagree," "2 = Average," and "3 = Agree."

3.4. Analytic strategy

This study first conducted a descriptive statistical analysis of the health status of older adults under different smartphone use conditions. Second, a multivariate ordered logit model was used to examine the impact of smart device use on the health status of older adults owing to the ordinal characteristics of its measurement, The reason for using the ordered multivariate ordered logit model here is that it can be used as a generalized form of logit model to analyze in the situation that the dependent variable is a multivariate ordered variable, and the dependent variables in this paper are all categorical variables and have more than two classifications, and also each classification is ordered. A propensity value matching model was used to analyze the net effect under control variables. Among the control variables, we also introduced interpersonal expenditure, average monthly income, and residential area of older adults in addition to the basic characteristics of older adults to comprehensively explore the impact of smart device use on the health status of older adults in a multi-dimensional way. Third, we analyzed the mediating effect of performance expectations and individualized needs between smart device use and the health status of older adults to further explore the mechanism. Finally, we examined age and residence heterogeneity in the impact of smart device use on the health status of older adults.

4. Results

4.1. Descriptive analyses of health status of older adults under different smartphone use conditions

Of the 1,110 respondents, 633 (57.0%) used smartphones, while 477 (43.0%) did not. As shown in Figure 2, the proportions of older adults using smartphones who reported good self-rated, physical, and psychological health were 37.7%, 46.1%, and 2.4%, respectively, while the corresponding proportions among those who did not use smartphones were 17.0%, 19.6%, and 1.4%, respectively. By comparing older adults' health under different smartphone use conditions, it was found that older adults who use smartphones account for a greater proportion of older adults displaying better health, which indicates that there is a positive correlation between smartphone use and the health condition of older adults.

4.2. Baseline regressions of the impact of smartphone use on the health status of older adults

In this study, six baseline regression models were built to analyze the impact of smartphone use on each health condition of older adults under control variables. Table 5 reports the impact of smartphone use on the health of older adults. Models (1) and (2) show the regression results for older adults' self-rated health. After adding the characteristics of economic level, social interaction, and intergenerational support of older adults, the estimated coefficients of smartphone use were still significant, and the interpretability of the model was enhanced. The significance

TABLE 5 Regression analyses of smartphone use on the health status of older adults ($N = 1,110$).

Variable	Self-rated health		Physical health		Psychological health	
	(1)	(2)	(3)	(4)	(5)	(6)
Smartphone use (no)	0.727***	0.624***	1.044***	0.952***	0.380**	0.317*
	(0.136)	(0.140)	(0.155)	(0.159)	(0.176)	(0.179)
Male (female)	0.023	−0.043	−0.173	−0.226	−0.073	−0.086
	(0.124)	(0.127)	(0.145)	(0.148)	(0.154)	(0.157)
Age (55–64)						
65–74	0.004	0.104	−0.773**	−0.737**	−0.025	0.047
	(0.193)	(0.197)	(0.303)	(0.307)	(0.236)	(0.239)
75 or above	−0.536***	−0.467**	−1.907***	−1.881***	0.015	0.078
	(0.199)	(0.202)	(0.299)	(0.302)	(0.248)	(0.250)
Urban (rural)	0.172	0.051	−0.063	−0.189	0.074	0.015
	(0.125)	(0.129)	(0.148)	(0.153)	(0.158)	(0.162)
Education level (primary school or below)						
Junior high school	0.376**	0.209	0.396**	0.249	0.368*	0.306
	(0.148)	(0.153)	(0.178)	(0.182)	(0.190)	(0.194)
High school or technical secondary school	0.541***	0.206	0.114	−0.183	0.413	0.278
	(0.202)	(0.214)	(0.233)	(0.247)	(0.257)	(0.268)
Junior college or above	1.176***	0.779**	0.743*	0.470	0.930**	0.719*
	(0.332)	(0.348)	(0.387)	(0.408)	(0.370)	(0.388)
Has spouse (without spouse)	0.271**	0.159	0.785***	0.734***	1.068***	0.887***
	(0.137)	(0.156)	(0.151)	(0.174)	(0.168)	(0.190)
Average monthly income (0–1999)						
2,000–3,999		0.826***		0.661***		0.267
		(0.163)		(0.194)		(0.200)
4,000 or above		0.759***		0.411		0.479
		(0.241)		(0.292)		(0.300)
Interpersonal expenditure (0–999)						
1,000–5,999		0.0677		0.457***		0.044
		(0.148)		(0.168)		(0.183)
6,000 or above		−0.068		0.261		0.090
		(0.187)		(0.219)		(0.235)
Living arrangement (alone)						
With families		0.262		0.186		0.444*
		(0.198)		(0.216)		(0.228)
Others		−0.055		0.604		−0.182
		(0.429)		(0.515)		(0.517)
LR chi^2	147.79	179.10	302.60	326.02	78.88	86.88
Pseudo R^2	0.067	0.082	0.176	0.190	0.058	0.063

*$p < 0.1$, **$p < 0.05$, ***$p < 0.01$.
The reference for each variable is shown in parentheses in column 1. The coefficients are in columns 2–7, where the standard errors are in parentheses.

of each control variable in Model (2) is consistent with that in Model (1), and the models show good stability. Models (3) and (4) are the regression results for older adults' physical health, and Models (5) and (6) are the regression results for older adults' psychological health, both of which can be interpreted similarly.

The results show that smartphone use has a significant positive effect on the self-rated and physical health of older adults at the 1% level, and a significant positive effect on psychological health at the 5% level. Besides, older adults with a higher age are less likely to have better self-rated and physical health. As aging progresses the physical functions of older adults deteriorate, but its impact on psychological health is not significant. In terms of education, all health indicators of older adults have been strengthened with the improvement in education level, which is in line with the findings of Liang et al. (17). Older adults with higher education levels have better physical and psychological health due to their investment in acquiring higher education, and thus receive more rewards, including a better living environment and more knowledge. A spouse has a significantly positive effect on the overall health of older adults, as the companionship of a spouse makes it easier to adapt to changes in their surroundings, thereby reducing the physical and mental shock from changes and improving their health.

Older adults with a higher average monthly income have significantly better self-rated and physical health. The improvement of economic level helps older adults obtain more abundant and convenient health support and better and more timely treatment in case of illness, but the impact of income on psychological health is not significant. Moderate interpersonal expenditure has a significant positive effect on the physical health of older adults. Appropriate social interaction activities not only enhance the social participation of older adults but also increase their daily exercise objectively, thus improving their physical health. Intergenerational support had a significant positive effect on psychological health. Older adults living with their families are more likely to receive emotional support and have better psychological health than those living alone.

4.3. Net effects of smartphone use on the health status of older adults

Some studies have shown that older adults who frequently surf the Internet or use smartphones tend to have better health (12, 15, 17). Using smartphones is a choice made by older adults based on their own thoughts, but it may be influenced by objective conditions such as age, gender, and residential area, resulting in the absence of randomized trial premises. The estimated coefficients may have errors owing to self-selection. Based on the reasons above, this study used the propensity score matching model for robustness tests and the net effects, in which three methods, namely, k-nearest neighbor matching, caliber matching, and kernel matching, were used to eliminate the bias caused by mixed factors. As shown in Table 6, the standard deviation of most variables is $<10\%$, and the differences in most variables between the control and treated groups are not significant after matching. This model largely eliminated self-selection bias, and the sample passed the balance test.

According to the results of the propensity score matching analysis (Table 7), the positive contribution of smartphone use to the development of better health among older adults was fully illustrated. The impact of smartphone use on self-rated, physical, and psychological health of older adults obtained from the three matching methods were consistent, and most of them passed the significance test, except the one regarding psychological health. Under control variables, smartphone use led to a significant increase in self-rated health by 0.158–0.178, physical health by 0.118–0.193, and psychological health by 0.063–0.073, compared with older adults who did not use smartphones. This indicates that smartphone use by older adults has a positive effect on all health statuses, and the positive net effects on self-rated and physical health are higher than that of psychological health. At the same time, the significant net effects of the different matching methods are close to each other, which verifies the robustness of the results of the regression analyses.

4.4. Mechanism analyses of the impact of smartphone use on the health status of older adults

As one of the main accesses for older adults to the Internet and interpersonal communication, smartphones play a key role in interactions between older adults and the outside world. In addition to daily needs, such as making phone calls and chatting online by smartphones, older adults also use some applications or search independently to obtain important events or information useful to themselves. Therefore, this study analyzed the mediation mechanism between smartphone use and the health of older adults with mediators, including performance expectations and individualized needs.

As shown in the second column of Tables 8, 9, the effect of smartphone use on performance expectations or individualized needs was significant. The results in Table 5 showed that smartphone use had a significant impact on each health status of older adults. Based on this finding, the mediators were added to the baseline regression equation for each health, and the results were shown in column 3–5 of Tables 8, 9, respectively.

The results showed that the performance expectation had a significant effect on the self-rated health and psychological health of older adults when it was used as a mediator, but did not show a significant effect on physical health. Further, the impact of smartphone use on self-rated health decreased, and the impact on psychological health was no longer significant after adding this mediator, indicating that the performance expectation played a major mediating role between smartphone use and self-rated health, and the major mediating role between smartphone use and psychological health was even more pronounced than the direct effect between them. Next, the distribution-of-product method was used to test the existence of the mediation effect. The results of the test were consistent with the previous results, the mediating effect of the performance expectation between smartphone use and self-rated health was 0.162, between smartphone use and psychological health was 0.202.

When the individualized need was used as the mediator, the results were similar to that of the performance expectation. The individualized need also played a major mediating role between smartphone use and self-rated health, and between smartphone use

TABLE 6 Sample balance tests.

Variable		Control group	Treated group	Standard deviation (%)	Deviation reduction (%)	T-value	P-value
Gender	U	0.411	0.515	21.0	61.0	3.46	0.001
	M	0.550	0.509	8.2		−1.40	0.163
Age	U	2.625	2.010	−93.5	83.5	−15.11	0.000
	M	2.183	2.081	−15.4		−2.53	0.012
Residential area	U	0.361	0.509	30.2	68.0	4.96	0.000
	M	0.538	0.491	−9.7		−1.63	0.103
Education level	U	1.392	1.965	67.6	79.2	10.93	0.000
	M	2.003	1.883	−14.1		−2.09	0.037
Marital status	U	0.589	0.809	49.3	96.2	8.26	0.000
	M	0.787	0.795	1.9		0.35	0.726
Average monthly income	U	1.260	1.727	72.4	93.4	11.65	0.000
	M	1.678	1.651	−4.2		−0.65	0.514
Interpersonal expenditure	U	1.799	2.098	45.3	99.2	7.48	0.000
	M	2.058	2.061	0.4		0.07	0.948
Living arrangement	U	1.235	1.131	−23.8	91.7	−3.99	0.000
	M	1.149	1.140	−2.0		−0.37	0.708

$^{*}p < 0.1$, $^{**}p < 0.05$, $^{***}p < 0.01$.
The value in columns 3 and 4 is the mean of the control and treated group, respectively.

TABLE 7 Net effect analysis of smartphone use on the health status of older adults.

Analysis method		Control group	Treated group	Difference	SE	T-value
Self-rated health	Unmatched	2.122	2.569	0.447	0.044	10.14
	K-nearest neighbor matching	2.399	2.557	0.158	0.097	1.63
	Caliper matching	2.379	2.557	0.178	0.073	2.45
	Kernel matching	2.379	2.541	0.162	0.072	2.25
Physical health	Unmatched	2.361	2.803	0.442	0.032	13.82
	K-nearest neighbor matching	2.677	2.795	0.118	0.076	1.56
	Caliper matching	2.641	2.795	0.154	0.057	2.72
	Kernel matching	2.594	2.788	0.193	0.056	3.46
Psychological health	Unmatched	1.786	1.919	0.133	0.026	5.04
	K-nearest neighbor matching	1.847	1.910	0.063	0.055	1.14
	Caliper matching	1.898	1.910	0.012	0.043	0.28
	Kernel matching	1.830	1.903	0.073	0.043	1.71

SE, Standard error.
The value in columns 3 and 4 is the mean of the control and treated group, respectively.

and psychological health, which all passed the test of distribution-of-product method. The mediating effect of the individualized need between smartphone use and self-rated health was 0.220, between smartphone use and psychological health was 0.215.

The analysis results showed that the higher the satisfaction of older adults' individualized needs, the better their health status. On the one hand, older adults will not suffer from the psychological burden of embracing life, so they can spend extra time contacting more advanced intelligent technology, broaden their horizons, and make themselves happy. Thus, they can improve their self-regulatory abilities and health levels. On the other hand, they can maintain an active state, and be socially involved based on a more prosperous life, and better alleviate their sense of loneliness. Second, older adults can enhance their health literacy

TABLE 8 Mediating role of performance expectations in the relationship between smartphone use and the health status of older adults ($N = 1,110$).

Variable	Performance expectations	Self-rated health	Physical health	Psychological health
Smartphone use	0.752***	0.559***	0.913***	0.234
	(0.137)	(0.142)	(0.162)	(0.182)
Performance expectations		0.216***	0.141	0.269***
		(0.082)	(0.094)	(0.101)
Control variable	Yes	Yes	Yes	Yes
Pseudo R^2	0.053	0.085	0.190	0.068
Test				
CI		[0.039,0.310]	[-0.032,0.262]	[0.050,0.385]
Indirect effect		0.162	–	0.202

*$p < 0.1$, **$p < 0.05$, ***$p < 0.01$.
The coefficients are in columns 2–5, where the standard errors are in parentheses.
The control variables included gender, age, residential area, education level, marital status, average monthly income, interpersonal expenditure, living arrangement.

TABLE 9 Mediating role of individualized needs in the relationship between smartphone use and the health status of older adults ($N = 1,110$).

Variable	Individualized needs	Self-rated health	Physical health	Psychological health
Smartphone use	1.077***	0.534***	0.896***	0.231
	0.138	(0.144)	(0.164)	(0.184)
Individualized needs		0.204**	0.137	0.200*
		(0.080)	(0.092)	(0.100)
Control variable	Yes	Yes	Yes	Yes
Pseudo R^2	0.078	0.085	0.190	0.066
Test				
CI		[0.049, 0.408]	[−0.046, 0.354]	[0.004, 0.445]
Indirect effect		0.220	-	0.215

*$p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.
The coefficients are in columns 2–5, where the standard errors are in parentheses.
The control variables included gender, age, residential area, education level, marital status, average monthly income, interpersonal expenditure, living arrangement.

by acquiring valuable, useful information. They can improve their adaptability to the outside world and overall health, while enriching their inner thoughts by acquiring valuable information regarding enhancement of their cognitive realm.

4.5. Heterogeneity analyses of the impact of smartphone use on the health status of older adults of different age and residence

These results indicate that smartphone use can improve the overall health of older adults, but the impact of smartphone use on their health status may vary depending on the characteristics of older adults. The heterogeneity analysis of each health status of older adults demonstrated differences in the impact of use among different groups of older adults (Tables 10, 11).

As can be seen from the age subsample regression results, first, smartphone use had a significant positive effect on the physical health of older adults of all ages. And there were significant differences in the effects of older adults among all age groups. The smartphone use showed a positive effect on self-rated and psychological health only of the older adults aged 75 or above. Second, in terms of the size of the regression coefficients, the impact of smartphone use on older people of different ages did not change regularly with age in addition to psychological health; that is, active older adults aged 65–74 years are relatively less affected, followed by the older adults aged 55–64, older adults aged 75 or above are the most positively affected. Regarding psychological health, the impact grows with age, and older adults aged 55–64 years are negatively affected. Older adults of younger age are more likely to be more receptive to smart devices such as smartphones and less likely to have difficulty using them, as they are more similar to the smart age in their middle and younger years. Older adults with a higher age have relatively less access to information in modern society, and the marginal impact of outside information on them through smartphones can be greater than that of other channels. It is important to note that older adults aged 55–64 should be aware of digital addiction due to overuse and prevent the consequent negative psychological health effects (30).

TABLE 10 Impact of smartphone use on the health status of older adults at different ages.

Variable	Self-rated health			Physical health			Psychological health		
	55–64	65–74	75 or above	55–64	65–74	75 or above	55–64	65–74	75 or above
Smartphone use	0.754 (0.550)	0.241 (0.218)	0.948*** (0.198)	1.851** (0.783)	0.630** (0.260)	1.116*** (0.210)	−0.248 (0.736)	0.133 (0.278)	0.558** (0.254)
Control variable	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	191	424	495	191	424	495	191	424	495
Pseudo R^2	0.032	0.045	0.072	0.135	0.074	0.091	0.061	0.083	0.057
Empirical p-value									
55–64 vs. 65-74	0.122			0.098*			0.285		
55–64 vs. 75 or above	0.302			0.085*			0.050*		
65–74 vs. 75 or above	0.001**			0.055*			0.115		

*$p < 0.1$, **$p < 0.05$, ***$p < 0.01$.
The coefficients are in columns 2–10, where the standard errors are in parentheses.
The empirical p-value obtained from bootstrap sampling (1,000 times) was used to test the significance of the between-group difference in coefficients.
The control variables included gender, age, residential area, education level, marital status, average monthly income, interpersonal expenditure, living arrangement.

TABLE 11 Impact of smartphone use on the health status of older adults with different residences.

Variable	Self-rated health		Physical health		Psychological health	
	Urban	Rural	Urban	Rural	Urban	Rural
Smartphone use	0.826*** (0.210)	0.392** (0.188)	1.111*** (0.229)	0.750*** (0.223)	0.398 (0.263)	0.182 (0.247)
Control variable	Yes	Yes	Yes	Yes	Yes	Yes
Observations	494	616	494	616	494	616
Pseudo R^2	0.061	0.090	0.148	0.226	0.058	0.075
Empirical p-value	0.053*		0.128		0.294	

*$p < 0.1$, **$p < 0.05$, ***$p < 0.01$.
The coefficients are in columns 2–7, where the standard errors are in parentheses.
The empirical p-value obtained from bootstrap sampling (1,000 times) was used to test the significance of the between-group difference in coefficients.
The control variables included gender, age, residential area, education level, marital status, average monthly income, interpersonal expenditure, living arrangement.

In terms of the regression results for the residential subsample, first, smartphone use showed a significant effect on self-rated and physical health in both urban and rural older adults but not on their psychological health. It is notable that there is a significant difference in the effect on self-rated health between urban and rural older adults. Second, the size of the regression coefficients in urban older adults was larger than that in rural older adults for each health status. From the results of the previous analyses, urban older adults have a higher proportion of smartphone use and more access to new technologies such as smart devices. Urban older adults are more fluent and less psychologically frustrated when using smartphones and are better able to obtain benefits and convenience from the process based on the advanced development of urban areas. Further digitalization in rural areas is needed to promote the digital literacy of rural older adults, which in turn improves their health literacy.

Above all, according to the findings we can see that, smartphones do have a significant impact on the health status of older adults on the whole. From the regression results and propensity score matching results we know that, smartphones have a significant positive impact on self-rated health, physical health and psychological health of older adults. At the same time, different age, residences, education level, marital status and other characteristics also have an obvious impact on the health status of older adults. For older adults of different age and residences, the impact of smartphone use on health differs significantly. As for the impact of other factors, the individualized needs of older adults play a significant mediating effect in the impact of smartphone use on various health, and performance expectations play a significant mediating effect in the impact of smartphone use on self-rated health and psychological health.

5. Discussion

The above findings suggest that smartphones have an enhancing impact on the self-rated, physical, and psychological health of older adults, especially on their physical health. At the same time, older adults' performance expectations play a significant partial mediating role between smartphone use and self-rated and psychological health. This finding further deepens the conclusion obtained from existing studies that health training through smartphones can improve the health of older adults (16). Further, we also found that older adults' individualized needs have a significant partial mediating effect between smartphone use and each health status. Older adults

in this era are more focused on the usefulness and tangible value of objects, so they may be more concerned about what smart devices, such as smartphones, can bring to life. Therefore, access to knowledgeable information and satisfaction with life needs are the best outcomes that older adults expect to obtain through worthwhile economic exchange. Use of smartphones is convenient while also playing a key role in the health status of older adults.

However, this study found that smartphone use has a greater effect on the health of urban older adults compared to rural older adults, contrary to the findings of regional heterogeneity in Internet use (20). On the one hand, the marginal effect of smartphones and internet on rural older adults today is slightly weaker than it used to be, with the gradual optimization of rural construction. On the other hand, urban areas still have superior environments and living conditions compared to rural areas, where urban older adults are more likely to obtain the actual effect of digital support services in real life. The actual digital impact that rural older adults can receive is relatively weak, as digital construction in rural areas still needs to be improved. In terms of controlling factors, the effect of social engagement found by Zhang and Li (13) was limited in this study. A possible reason for this is that the interpersonal expenditure investigated in this study is the total spending of the household rather than that of the individual older person. It is influenced by the social interaction of their offspring, and therefore cannot accurately reflect the social support of the older person separately.

The above findings reflect the importance of smart device popularization in promoting the health of older adults and the construction of a healthy China. The digital integration dilemma of older Chinese people is becoming increasingly prominent with the development of the smart age. China needs to continuously promote the digital integration of older adults to enhance their overall life, including their health status. In recent years, China has introduced several policy documents to address the difficulties of older adults in accessing and using smart technologies and to expand the use scenarios in which smart devices can meet the needs of older adults. Based on the findings of this study, we should continue to promote access and smart device use among older adults. First, we should provide public service guidance for older adults to improve their digital skills, increase publicity in smart device use for older adults, and improve their awareness of the usefulness of smart devices in daily life and social interactions. Second, investment in the construction of digital infrastructure in rural areas should be expanded to improve the access and use of smart devices for rural older adults. Third, age-oriented requirements should be incorporated into the formulation of technical standards for smart devices to enhance the willingness of older adults to use them with the convenience of operation. Fourth, collaborative research between digital health professionals and typical older adults needs to be promoted to conduct in-depth study on the impact of smart devices on older adults' health. Thus, we can help improve older adults' digital literacy and help them integrate into the necessary digital life under the normalization of epidemic prevention.

6. Limitations

This study does have some limitations. First, the study takes smartphones as the representative of smart devices, which is rather representative but still not enough, and more studies on smart device use, such as smart watches or smart homes, can be subsequently added. Second, the data in this study were cross-sectional rather than long-term. It is less possible to obtain comparative differences before and after using the same sample; therefore, causal inferences cannot be made. Third, the level is not detailed enough when sampling, resulting in the uneven distribution of urban and rural areas of the respondents, which may make it difficult to detect the difference in impact between urban and rural older adults Further research can track changes in the same group of older adults before and after the use of smart devices to enrich the relevant research results. Combined with the findings and the limitations of the survey scope, the scope of the survey can be expanded to the whole country which can based on the existing nationwide survey, so that the impact of smart device use in China can be analyzed in more ways.

7. Conclusion

This paper reports the findings of a quantitative analysis to investigate the association between smart device use and health status of older adults in China. This analysis is the first study combined three dimensions of health to examine the effect of smart device use on health status and takes the real-life effect into account. The results of regression analysis showed that smartphone use could play an important role in improving the self-rated, physical and mental health of older adults, and subsequent propensity matching analysis also verified this finding. The age, education level, marital status, economic level and intergenerational support of older adults could significantly affect the physical health of older adults, among which the education level, marital status and economic level played an important role in the overall health of older adults. The results of the mediation effect test showed that the influence of smartphones on the health of older adults in real life would be affected by the perceived practicality of older adults, which also reflected the multi-faceted practical impact of the application effect in real scenarios. The results of heterogeneity analysis showed that, compared with older adults with a young age, older adults with a higher age were more likely to be affected by the positive effect of smartphones, while the former may experience digital addiction, which also provided a further direction for the improvement of smartphones for aging. As for people in different residence, the positive impact is stronger among urban older adults, with a more pronounced gap between urban and rural older adults in terms of self-rated health.

Data availability statement

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

Author contributions

YW developed the main ideas of the study, gathered the data, and proofread the article. XG performed the model construction and estimation, wrote and edited the manuscript. Both authors have read and agreed to the published version of the manuscript.

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

All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

References

1. Masterson-Creber RM, Hickley KT, Mauer MS, Reading M, Hiraldo G, Hickey KT, et al. Review and analysis of existing mobile phone apps to support heart failure symptom monitoring and self-care management using the mobile application rating scale (MARS). *JMIR MHealth UHealth.* (2016) 4:e74. doi: 10.2196/mhealth.5882

2. Jun W, A. study on the current status and improvement of the digital divide among older people in Korea. *Int J Environ Res Public Health.* (2020) 17:3917. doi: 10.3390/ijerph17113917

3. The United Nations. World population to reach 8 billion on 15 November 2022. (2022). Available online at: https://www.un.org/en/desa/world-population-reach-8-billion-15-november-2022 (accessed November 20, 2022).

4. United Nations Department of Economic and Social Affairs, Population Division. World Population Prospects 2022: Summary of Results. (2022). Available online at: https://www.un.org/development/desa/pd/sites/www.un.org.development.desa.pd/files/wpp2022_summary_of_results.pdf (accessed November 29, 2022).

5. The United Nations. Report of the Second World Assembly on Ageing. (2002). Available online at: https://www.un.org/development/desa/ageing/madrid-plan-of-action-and-its-implementation/second-world-assembly-on-ageing-2002.html (accessed November 20, 2022).

6. National Bureau of Statistics of the People's Republic of China. Statistical Bulletin of National Economic and Social Development of China 2021. (2022). Available online at: http://www.stats.gov.cn/xxgk/sjfb/zxfb2020/202202/t20220228_1827971.html (accessed November 29, 2022).

7. Palos-Sanchez P, Saura J, Rios Martin M, Aguayo-Camacho M. Toward a better understanding of the intention to use mhealth apps: exploratory study. *JMIR Mhealth Uhealth*. (2021) 9:9. doi: 10.2196/27021

8. Eysenbach G. Towards ethical guidelines for e-health: JMIR Theme Issue on eHealth Ethics. *J Med Internet Res.* (2000) 2:e7. doi: 10.2196/jmir.2.1.e7

9. Chan J. Exploring digital health care: eHealth, mHealth, and librarian opportunities. *J Med Libr Assoc.* (2021) 109:376–81. doi: 10.5195/jmla.2021.1180

10. Gulliford M, Alageel S. Digital health intervention at older ages. *Lancet Digit Health.* (2019) 1:e382–3. doi: 10.1016/S2589-7500(19)30194-3

11. Redfern J. Can older adults benefit from smart devices, wearables, and other digital health options to enhance cardiac rehabilitation? *Clin Geriatr Med.* (2019) 35:489–97. doi: 10.1016/j.cger.2019.07.004

12. Liu L, Wu F, Tong H, Hao C, Xie T. The digital divide and active aging in China. *Int J Environ Res Public Health.* (2021) 18:12675. doi: 10.3390/ijerph182312675

13. Zhang Q, Li Z. The impact of internet use on the social networks of the elderly in China-The mediating effect of social participation. *Int J Environ Res Public Health.* (2022) 19:9576. doi: 10.3390/ijerph19159576

14. Rondán-Cataluña FJ, Ramírez-Correa PE, Arenas-Gaitán J, Ramírez-Santana M, Grandón EE, Alfaro-Pérez J. Social network communications in chilean older adults. *Int J Environ Res Public Health.* (2020) 17:6078. doi: 10.3390/ijerph17176078

15. Chang SJ, Yang E, Lee KE Ryu H. Internet health information education for older adults: a pilot study. *Geriatr Nurs.* (2021) 42:533–39. doi: 10.1016/j.gerinurse.2020.10.002

16. Vizeshfar F, Ghelbash Z. Effect of a self-care training program using smartphones on general health, nutrition status, and sleep quality in the elderly. *Psychogeriatrics.* (2021) 21:910–9. doi: 10.1111/psyg.12766

17. Liang X, Xiong F, Xie F. The effect of smartphones on the self-rated health levels of the elderly. *BMC Public Health.* (2022) 22:508. doi: 10.1186/s12889-022-12952-0

18. Confortin SC, Giehl MW, Antes DL, Schneider IJ, d'Orsi E. Positive self-rated health in the elderly: a population-based study in the South of Brazil. *Cad Saude Publica.* (2015) 31:1049–60. doi: 10.1590/0102-311X00132014

19. Nwoke MB, Chukwuorji JC, Ebere MO. Number of dependents, community support, and mental health in later life: does gender make a difference? *Int J Aging Hum Dev.* (2016) 83:63–87. doi: 10.1177/0091415016641691

20. Yang KW, He H. The impact of internet usage on health of residents: a study from the China labor-force dynamic survey. *Nankai Econ Studies.* (2016) 03:182–203 doi: 10.14116/j.nkes.2020.03.010

21. Wang J, Liang C, Li K. Impact of internet use on elderly health: empirical study based on Chinese general social survey (CGSS) Data. *Healthcare.* (2020) 8:482. doi: 10.3390/healthcare8040482

22. Cohall AT, Nye A, Moon-Howard J, Kukafka R, Dye B, Vaughan RD, et al. Computer use, internet access, and online health searching among Harlem adults. *Am J Health Promot.* (2011) 25:325–33. doi: 10.4278/ajhp.090325-QUAN-121

23. Billari FC, Giuntella O, Stella L. Broadband internet, digital temptations, and sleep. *J Econ Behav Organ.* (2018) 153:58–76. doi: 10.1016/j.jebo.2018.07.001

24. Ha SK, Lee HS, Park HY. Twelve smartphone applications for health management of older adults during the COVID-19 pandemic. *Int J Environ Res Public Health.* (2021) 18:10235. doi: 10.3390/ijerph181910235

25. Chopik WJ. The benefits of social technology use among older adults are mediated by reduced loneliness. *Cyberpsychol Behav Soc Netw.* (2016) 19:551–6. doi: 10.1089/cyber.2016.0151

26. King DB, Cappeliez P, Canham SL, O'Rourke N. Functions of reminiscence in later life: predicting change in the physical and mental health of older adults over time. *Aging Ment Health.* (2019) 23:246–54. doi: 10.1080/13607863.2017.1396581

27. Leist AK. Social media use of older adults: a mini-review. *Gerontology.* (2013) 59:378–84. doi: 10.1159/000346818

28. He JP, Huang XX, The smartphone use and eudaimonic wellbeing of urban elderly: based on intergenerational support and TAM. *J Int Commun.* (2020) 42:49–73. doi: 10.13495/j.cnki.cjjc.20200409.003

29. Liu Q, Wang Y, Yao MZ, Tang Q, Yang Y. The effects of viewing an uplifting 360-degree video on emotional wellbeing among elderly adults and college students under immersive virtual reality and smartphone conditions. *Cyberpsychol Behav Soc Netw.* (2020) 23:157–64. doi: 10.1089/cyber.2019.0273

30. Guo N, Luk TT, Ho SY, Lee JJ, Shen C, Oliffe J, et al. Problematic smartphone use and mental health in Chinese adults: a population-based study. *Int J Environ Res Public Health.* (2020) 17:844. doi: 10.3390/ijerph17030844

31. China Internet Network Information Center. The 49th Statistical Report on China's Internet Development. (2022). Available online at: https://www.cnnic.cn/NMediaFile/old_attach/P020220721404263787858.pdf (accessed November 19, 2022).

32. Helbostad JL, Vereijken B, Becker C, Todd C, Taraldsen K, Pijnappels M, et al. Mobile health applications to promote active and healthy ageing. *Sensors.* (2017) 17:622. doi: 10.3390/s17030622

frontiers | Frontiers in Public Health

TYPE Original Research
PUBLISHED 25 September 2023
DOI 10.3389/fpubh.2023.1126900

OPEN ACCESS

EDITED BY
Zhenmei Zhang,
Michigan State University, United States

REVIEWED BY
Ke Shen,
Fudan University, China
Shazia Rehman, Central South University, China
Wenjuan Zhang,
Renmin University of China, China

*CORRESPONDENCE
Weihong Zeng
✉ zengwh@mail.xjtu.edu.cn

RECEIVED 18 December 2022
ACCEPTED 01 September 2023
PUBLISHED 25 September 2023

CITATION
Park S, Zeng W, Zhao P and Tong Y (2023) Information communication technology accessibility and mental health for older adults during the coronavirus disease in South Korea. *Front. Public Health* 11:1126900. doi: 10.3389/fpubh.2023.1126900

Information communication technology accessibility and mental health for older adults during the coronavirus disease in South Korea

Sujin Park[1,2], Weihong Zeng[1]*, Pianpian Zhao[1] and Yanke Tong[1]

[1]Jinhe Center for Economic Research, Xi'an Jiaotong University, Xi'an, China, [2]Technology Management, Economics and Policy Program, College of Engineering, Seoul National University, Seoul, Republic of Korea

Introduction: As society ages and the digital economy continues to develop, accessibility to information and communication technology (ICT) has emerged as a critical factor influencing the mental health of older adults. Particularly, in the aftermath of the COVID-19 pandemic, the need for non-face-to-face communication has significantly increased older adults' reliance on ICT for accessibility. This transition from a self-motivated engagement to a more socially passive mode of interaction highlights the importance of creating a digitally inclusive aging society.

Methods: This empirical study used pooled cross-sectional data from the Digital Gap Survey conducted in South Korea in 2018 and 2020. It aimed to analyze the association between ICT accessibility and the mental health of older adults during the COVID-19 pandemic.

Results: A significant positive relationship was found between ICT and mental health among older adults in South Korea. However, this positive association weakened during the COVID-19 period. Furthermore, the analysis revealed heterogeneity among older adults by age, sex, and place of residence, with older females in their 70s living in rural areas experiencing the greatest weakening.

Discussion: These results highlight the need for tailored interventions and support mechanisms for specific demographic groups of older adults. We recommend that the South Korean government implement various policies to facilitate the post-COVID-19 digital landscape. These include initiatives such as ICT-related education programs, development of user-friendly e-government systems, and creation of social media platforms designed to accommodate the needs and preferences of older adults.

KEYWORDS

mental health, older adults, ICT accessibility, COVID-19, South Korea

1. Introduction

South Korea has one of the fastest internet networks in the world, is known as an IT powerhouse, and has internet and smartphone penetration rates of 97.6 and 92.7%, respectively (1, 2). Even older adults aged 60 years and above have a smartphone penetration rate of 80.3% (3), which is one of the highest in the world. Given the high internet and smartphone penetration rates, studies have been conducted in South Korea since the early 2000s, and the relationship between older adults' information and communication technology (ICT) usage and their satisfaction with life, mental health, and overall quality of life (QOL) has been a subject of continuous discussion (4–7).

In general, older adults do not adapt well to social changes, and face social and psychological isolation. ICT use by older adults has been shown to reduce depression and feelings of loneliness, and increase their self-confidence (8). These findings have prompted governments to recommend and implement policies to facilitate older adults' access to ICT, such as free training programs, to improve their internet and smartphone proficiency. Thus, efforts have been made to make ICT a part of older adults' leisure activities. However, previous studies have shown that while ICT use can reduce social isolation, its use to pursue new encounters may increase emotional isolation (8). Furthermore, for older adults residing with their families, the utilization of ICT has demonstrated the potential to impede communication with their family members (9), and for older adults who are already socially affluent and highly educated, social connectivity through ICT may be deemed insignificant (10).

With the emergence of COVID-19 at the end of 2019, ICT has exerted a more direct influence on daily lives, making its access and usage by older adults an even more significant social issue. In the context of the pandemic, older adults' access to ICT has transcended mere leisure activities, such as personal enjoyment or social interactions, which were observed in the past. Instead, it plays a crucial role in ensuring their survival. The pandemic has introduced a significant shift in the perception and necessity of older adults' access to ICT. Owing to concerns regarding the spread of the infection, the government has largely transitioned most services from in-person to ICT-driven remote services, and personal social activities have been regulated to promote non-face-to-face interactions. As a result, access to and usage of ICT are no longer solely individual choices, but have become socially driven and essential aspects of daily life. In South Korea, many government services including vaccination appointments and government subsidy applications have moved to contactless channels using ICT, resulting in a significant increase in the use of e-government services. According to the Korea National Information Society Agency's (NIA) 2022 report on the use of e-government services, approximately 90% of South Koreans use e-government services, with the people aged 60 years and above showing a remarkable 12.2% increase in 2021 compared to 2020 (11).

Despite this growth in older adults' access to ICT in the post-pandemic period, it has been argued that encouraging them to adopt ICT in response to the pandemic could widen the information divide, disrupt their daily lives, and negatively influence their mental health (12–15). Compared to younger generations, older individuals have lower levels of internet usage, motivation to use, and technological proficiency, resulting in a potential widening of the digital divide, leading to social exclusion and inequality (16–18). Additionally, the widespread adoption of ICT in government services, medical facilities, and delivery apps has caused confusion among older adults, making it difficult for them to cope with new technologies (19). During the pandemic, older adults who were vulnerable to physical impairment and infections were unable to visit medical institutions unless appointments were made through ICT. For those unfamiliar with ICT, accessing public services and making online appointments was difficult (19). Furthermore, for older adults who experience virtual social interactions through ICT, the digital stress and burden suggest that virtual contact may not significantly contribute to their mental well-being (20). Consequently, there has been a shift in perspective regarding access to and utilization of ICT by older adults from the previous encouragement of ICT usage. Some studies have suggested that ICT use in remote social interactions may have a positive and beneficial influence on cognitive abilities and reduce feelings of loneliness and isolation among older adults (21–23). However, contrasting viewpoints argue that ICT-facilitated social interactions in a "contact-free society" may have adverse effects on mental well-being, further widening the digital divide (20, 24, 25).

In an ICT-driven "new normal" society initiated by the pandemic, the integration of various aspects of daily life with ICT will continue. However, this trend can lead to digital inequalities and social exclusion among certain populations, raising concerns about its potential negative influences on mental health. It is essential to continuously study and implement policies to identify suitable alternatives that meet the needs of digitally marginalized communities. Considering these social issues, we conducted a study on the association between older adults' ICT accessibility and mental health during COVID-19, and proposed policy implications to address these challenges and promote inclusivity.

2. Literature review

2.1. Mental health of the older adults and associated factors

Mental health encompasses emotional, psychological, and social well-being, and is closely related to life satisfaction, subjective well-being (SWB), and QOL. Previous studies have demonstrated significant associations between mental health and life satisfaction among older adults (26–29). Furthermore, they have shown links between mental and physical health (30) and argued that mental health is a fundamental resource for society's overall well-being (27). Consequently, mental health in older adults has received considerable attention in the fields of social and health economics.

According to a previous study, the mental health of older adults is associated with several key factors including individual characteristics, health, family dynamics, and social interactions (31–40). Empirical evidence suggests significant variations in the mental health of older adults based on factors such as sex, age, educational attainment, occupation, income level, and residential location (31–34). Additionally, mental health can differ according to physical health (35–37), quality of family relationships (38–40), engagement in social activities, availability of social support, and receipt of pension benefits (41–43).

In recent years, alongside the aforementioned factors, the widespread availability of the internet and increased ownership of smartphones and tablet PCs have established ICT as a critical determinant influencing the mental health, overall well-being, and life satisfaction of older adults.

The study of ICT use among older adults is an ongoing endeavor that has yielded various perspectives. Previous studies have shown that the use of the internet, smartphones, and ICT can increase self-efficacy (44), reduce depressive symptoms (45), and positively influence sense of control (46). Consequently, ICT acts as a medium through which socially isolated and physically frail older adults can engage in alternative activities, alleviate depressive symptoms, and influence overall life satisfaction (8, 44–50). Additionally, previous studies have shown that older adults' use of ICT and access to digital resources enable them to monitor their physical health more effectively, highlighting the potential of ICT to strengthen mental health and promote physical well-being (51, 52).

However, negative perspectives also exist regarding older adults' use of ICT. These views suggest that ICT access and utilization may hinder face-to-face communication and family interactions, potentially exacerbating social isolation, loneliness, and depression among older adults (9, 10, 53). Considering these previous studies, it can be concluded that ICT access and utilization among older adults may be beneficial primarily for those who do not cohabit with their families or have limited in-person social interactions owing to physical health issues.

2.2. The change of the ICT accessibility due to COVID-19 for older adults

The emergence of coronavirus disease (COVID-19) in 2019 has led to significant social changes. During the post-pandemic period, the concept of a contactless society, often referred to as a non-face-to-face society, gained prominence, leading to the continuous expansion of the scope of ICT. Although COVID-19 has played a role in promoting digitization, there are concerns about exacerbating digital inequalities. In an increasingly digitalized society, people with limited ICT skills are more likely to experience exclusion and marginalization. Digital exclusion and division are particularly pronounced among older adults. Compared to younger age groups, older adults are more likely not to use the internet, and have fewer skills in using digital devices to connect with others (15). Consequently, the accessibility of ICT for older adults belonging to the information-marginalized group has become a topic of great interest in many countries.

During the COVID-19 pandemic, studies on older adults' ICT use can be divided into two main perspectives. From the perspective of encouraging the use of ICT among older adults during COVID-19, it is argued that ICT plays a crucial role in enabling interactions with distant family members and friends in a contactless society, as well as enhancing older adults' leisure activities, allowing them to maintain a mentally active life in isolated environments (23). This is positively associated with subjective health, well-being, and mental health (54–56). Furthermore, using ICT to perform personal tasks independently can positively influence older adults' self-esteem and dignity (57).

However, it should be noted that virtual communication facilitated by ICT may amplify feelings of isolation (20), and increased subjective pleasure and improved well-being during the pandemic were found to be effective only when ICT was used for leisure purposes (56). Therefore, the use of ICT for tasks such as work management and accessing public services may not have a positive association with mental health. This is because of older adults' negative perceptions of technology and the digital divide. Previous studies have shown that despite the introduction of ICT in various social sectors during the pandemic, older adults experience reluctance and difficulties in social participation through ICT due to concerns about cybercrime, negative technological experiences, and the complexity of technology (19, 57). Furthermore, there are individual differences in ICT skills among older adults willing to use ICT (23), which can lead to digital and information inequalities, exacerbating social inequalities (24, 25, 58).

Considering the comprehensive review of previous studies, it is important to note the ongoing debate and contrasting results regarding ICT accessibility in older adults during the pandemic. Some studies suggest the potential benefits of ICT use for the mental health of older adults, while others emphasize the potential negative associations and the existence of digital inequalities. With the accelerated transition toward an ICT-based digital society, it is crucial to investigate the association between ICT and the well-being of older adults, and further explore how ICT can contribute to their lives. Developing policies that foster older adults' well-being through ICT has become imperative in light of this transition. This study aimed to investigate the association between ICT accessibility and the mental health of older adults during the COVID-19 pandemic.

3. Data source and variable selection

3.1. Data source

Samples were selected based on cross-sectional databases from the Digital Gap Survey conducted by the National Information Society Agency (NIA) in 2018 and 2020. The survey's primary objective was to gather essential data to address the digital divide in South Korea and formulate practical policy recommendations for the future. The survey covered various aspects, including the level of digital information access and demographic and sociological factors. Data were collected annually from September to December.

The survey included a diverse sample of participants, including 7,000 South Korean citizens, 2,200 agricultural and fishing workers, 2,200 individuals with disabilities, 2,200 low-income families, 700 North Korean defectors, and 700 married immigrants, for a total annual survey sample of 15,000 people. For this study, a subset of 30,000 original data entries was used, after excluding 2,800 North Korean defectors and married immigrants. Finally, the study analyzed a sample size of 9,301 after excluding 17,899 responses due to incomplete or erroneous data and individuals under 60 years of age, following the WHO's definition of older adults.

3.2. Empirical strategy and variable selection

In addition to the primary variables of ICT accessibility and COVID-19, several control variables were associated with the mental health of older adults. According to previous studies, these variables include demographic, health-related, family-related, and social factors. Demographic factors include individual characteristics such as age, sex, education, occupation, monthly income, living environment, and living area. Health-related factors refer to physical aspects that affect the general health of older adults (30, 59, 60). Social factors include sociological aspects relevant to older adults such as

social capital (61) and pensions, whereas family-related factors may include the presence of household members.

To identify factors that were significantly associated with the mental health of older adults in South Korea, a multiple regression equation was expressed as follows:

$$\text{Mental Health} = \beta_0 + \beta_1 \text{ICT} + \beta_2 \text{COVID\_19} + \beta_3 \text{ICT} * \text{COVID\_19} + \beta_4 \text{Dem} + \beta_5 \text{Fam} + \beta_6 \text{Health} + \beta_7 \text{Social} + \mu$$

Mental Health: as a measure of mental health, we used questions 21–7 from the 2018 and 2020 NIA Digital Gap Surveys. Question 21 assessed mental health and subjective satisfaction in various areas of daily life, including economic conditions, leisure and culture, social activities, interpersonal relationships, family relationships, work, education, and government. Therefore, it was appropriate to measure the respondents' mental health. The response scale is a 4-point rating scale ranging from 1 (very dissatisfied) to 4 (very satisfied). Higher scores indicated better mental health as reported by the respondents.

ICT: ICT accessibility represents the potential of older adults to utilize ICT. ICT accessibility for older adults was measured using six items from the NIA's Digital Gap Surveys conducted in 2018 and 2020 (Questions 1, 2, and 3). Question 1 consists of two items inquiring about ownership of Desktop and Laptop (1. Do you currently have a desktop or laptop available to you? 1–1 Desktop, 1–2 Laptop). Question 2 comprises three items asking about ownership of Cell Phone, Smart Pad, and Smart Device (2. Please answer whether you have a device available to you, 2–1 Cellphone, 2–2 Smart Pad, 2–3 Smart Device). Lastly, Question 3 is composed of a single item querying whether internet connectivity is available at home (3. Is the internet (including wireless Internet) currently available at your home through computers/laptops, smartphones/smart pads, TVs, and game device?). To simplify the analysis, a scoring system was devised: a score of 1 was assigned if the older adults possessed devices (for Questions 1 and 2) or had internet connectivity (for Question 3), and 0 if they did not. (Note: Question 2–1 for the cell phone ownership part, the responses were divided into 1) smartphone, 2) feature phone, and 3) unpossessed. Both 1) smart phone and 2) feature phone were considered to be possessed and were considered as 1.) Total ICT accessibility scores ranged from 0 to 6 with the score of 1, 2 and 3 are the cutoffs of 25, 50 and 75% quarter, respectively. Participants whose ICT accessibility score is in the top 25% of the distribution are defined as the group with high ICT accessibility which we define as ICT accessibility = 1, and the remaining are categorized as the group with low ICT accessibility which we define as ICT accessibility = 0 (62, 63).

COVID-19: COVID-19 is a binary dummy variable COVID-19 emerged toward the end of 2019 and gained widespread global attention through news and media starting in January 2020. Accordingly, "0" was provided for data from 2018, and "1" for data from 2020. The interaction variable between ICT and COVID-19 is denoted as *ICT*Covid_19*.

Dem: Dem represents several demographic and sociological characteristics of older adults. These variables include respondents' age, sex, education level, occupation, type of residence, residential area, and monthly income. Sex is a binary variable, with "0" for female and "1" for male. The final education level was divided into four categories: 1) below elementary school, 2) middle school, 3) high school, and 4) college or higher. Occupation was categorized as 1) employed, 2) agricultural and fishing workers, 3) unemployed, and 4) other. Residence type was classified into four categories: 1) detached house, 2) apartment, 3) town/multiplex house (villa), and 4) other. Residential area is a binary variable, with "0" for rural areas and "1" for urban areas. The monthly income variable is divided into seven categories: 1) KRW 500,000 or less, 2) KRW 500,000-990,000, 3) KRW 1 million – 1.49 million, 4) KRW 1.5 million – 1.99 million, 5) KRW 2–2.49 million, 6) KRW 2.5–2.99 million, and 7) KRW 3 million or more. Demographic and sociological characteristics were used as the control variables.

Fam: Fam represents the living arrangements of older adults. It was categorized as follows: 1) living alone, 2) living with a spouse, 3) living with a spouse and children, 4) living with a spouse, children, and parents, and 5) living with others. The "living with others" category includes cases where older adults reside with relatives such as grandparents, grandchildren, aunts, uncles, and others, excluding spouses, children, and parents.

Health: health represents people with disabilities registered by the government. Health is a binary dummy variable, with "0" for respondents who are not registered as disabled by the government, and "1" for those with disabilities officially recognized by the government.

Social: social represents the social characteristics of older adults, including social support and guarantee of living. Social support is an independent variable that reflects the respondents' level of support from online and offline sources. Question 17 assessed the social support. However, there was variation in the number of questions comprising this item across the two survey years. In 2018, the items consisted of 20 questions, whereas in 2020, they consisted of 10 questions. For the convenience of analysis, a weighted approach was employed for the 2018 data, where a 50% weight was assigned to the total score. The response scale for this question was based on a 4-point rating scale, resulting in a score distribution ranging from 10 to 40. Higher scores indicate a greater perceived level of social support received by the respondents. The variable guarantee of living is another independent variable in this study, representing low-income families who receive government support. This variable was analyzed using personal information provided by respondents in the questionnaire. Guarantee of living is a binary dummy variable with "0" for respondents not included in the low-income group, and "1" for respondents in the low-income group, who are supported by the government.

4. Statistical analysis

4.1. Descriptive analysis

Table 1 presents the definitions and descriptive characteristics of the study variables. The total number of observations is 9,301.

The mean score for mental health is 2.45 (S.D = 0.76), indicating a moderate level. In the case of ICT accessibility, it has been found that most older adults have low levels of accessibility (58.21%). For COVID-19, 2018 was indicated as "Non" (47.93%) and 2020 as "Outbreak" (52.07%).

The respondents had a mean age of 67.58 (S.D = 5.75). The sample included a higher proportion of male respondents (55.09%), and the most prevalent level of education was high school graduation (37.62%), while the number of individuals with education beyond the

10.3389/fpubh.2023.1126900

TABLE 1 Definitions and descriptive analysis of variables (N = 9,301).

Variable	Definition	Mean(S.D)/Number(%)
Dependent variable		
Mental Health	Subjective mental health satisfaction, a four-point Likert scale	2.45 (0.76)
Independent variable		
ICT Accessibility	ICT accessibility = 0	5,414 (58.21%)
	ICT accessibility = 1	3,887 (41.79%)
COVID-19 outbreak Dummy	0) Non	4,458 (47.93%)
	1) Outbreak	4,843 (52.07%)
Demographic and sociological factors		
Age	Respondents' age	67.58 (5.75)
Sex	0) Female	4,177 (44.91%)
	1) Male	5,124 (55.09%)
Education	1) Below Elementary school	2,487 (26.74%)
	2) Middle school	2,930 (31.50%)
	3) High school	3,499 (37.62%)
	4) College or more	385 (4.14%)
Occupation	1) Employed	4,179 (44.93%)
	2) Agricultural and fishery workers	3,172 (34.10%)
	3) Unemployed	1,948 (20.94%)
	4) Other	2 (0.02%)
Type of residence	1) Detached house	4,938 (53.09%)
	2) Apartment	3,401 (36.57%)
	3) Town/Multiplex House (Villa)	940 (10.11%)
	4) Other	22 (0.24%)
Residential areas	0) Rural area	2,040 (21.93%)
	1) Urban area	7,261 (78.07%)
Monthly income (KRW)	1) Less than 500,000	317 (3.41%)
	2) 500,000–990,000	1,641 (17.64%)
	3) 1 million - 1.49 million	1,525 (16.40%)
	4) 1.5 million - 1.99 million	1,283 (13.79%)
	5) 2 million - 2.49 million	1,223 (13.15%)
	6) 2.5 million - 2.99 million,	874 (9.40%)
	7) More than 3 million	2,438 (26.21%)
Family		
Living arrangement	1) Living alone	1,777 (19.11%)
	2) Living with spouse	5,245 (56.39%)
	3) Living with spouse and children	1,754 (18.86%)
	4) Living with spouse, children, and parents	53 (0.57%)
	5) Other	472 (5.07%)
Health		
Disabled	0) Non-disabled	7,499 (80.63%)
	1) Disabled	1,802 (19.37%)
Social		
Social support	Respondents' social support online and offline	25.72 (5.35)
Guarantee of living	0) Non-recipients	8,082 (86.89%)
	1) Recipients	1,219 (13.11%)

college level was the lowest (4.14%). In terms of occupation, the largest category was employed (44.93%). Regarding residential type, majority of older adults lived in detached houses (53.09%) or apartments (36.57%), with a higher concentration in urban areas (78.07%) than in rural areas (21.93%). In terms of monthly income, the largest group consisted of older adults with a monthly income of three million won or more (26.21%). (About 22,973.78 USD at an exchange rate of 1 USD = 1,305.84 KRW).

In terms of living arrangements, the largest category among older adults was couple households (56.39%). When considering disability and guarantee of living, the majority of older adults were non-disabled (80.63%) and did not receive government support (86.89%). The mean score for social support was 25.72 (S.D = 5.35).

5. Empirical analysis

5.1. Benchmark model

We examined the association between older adults' mental health and ICT accessibility during the COVID-19 pandemic using an interaction term for ICT accessibility and COVID-19. The results are presented in Table 2. Model (1) was used to identify factors associated with the mental health of older adults. Model (2) examined the association between ICT accessibility and mental health in older adults, while Model (3) examined the association between COVID-19 and mental health in older adults. Model (4) examined the association between ICT accessibility and mental health of older adults during COVID-19 using an interaction term for ICT accessibility and COVID-19.

The results of Model (1) are as follows: age, sex, education level, occupation, type of residence, residential area, living arrangement, disability, social support, and guarantee of living were associated with the mental health of older adults. Mental health decreased with increasing age ($\beta = -0.013$, $p = 0.000$), and male participants had higher mental health scores ($\beta = 0.047$, $p = 0.003$). In the case of education level, middle school graduates ($\beta = 0.066$, $p = 0.001$), high school graduates ($\beta = 0.095$, $p = 0.000$), and college graduates ($\beta = 0.102$, $p = 0.014$) had better mental health than elementary school graduates. In the case of occupation, unemployed people ($\beta = -0.083$, $p = 0.000$) had lower mental health than the employed. Regarding the type of residence, older adults living in environments other ($\beta = -0.379$, $p = 0.021$) than detached houses, apartments, or town/multiplex houses (villas) had poorer mental health. In terms of residential area, older adults residing in urban areas ($\beta = 0.039$, $p = 0.046$) had better mental health than those living in rural areas. In the case of living arrangements, the mental health of those living with a spouse ($\beta = 0.045$, $p = 0.039$), living with a spouse and children ($\beta = 0.071$, $p = 0.013$), and others ($\beta = 0.112$, $p = 0.003$) were higher than that of older adults living alone. For disability and guarantee of living, non-disabled ($\beta = -0.527$, $p = 0.000$) and non-recipients ($\beta = -0.240$, $p = 0.000$) had better mental health than those with disabilities or recipients of support. Higher levels of social support ($\beta = 0.041$, $p = 0.000$) were associated with better mental health among older adults.

Model (2) showed a positive association between ICT accessibility and mental health among older adults ($\beta = 0.108$, $p = 0.000$). This suggests that greater ICT accessibility among older adults is associated with improved mental health. The results of model (3) indicated that the mental health of older adults was better before the onset of COVID-19 ($\beta = -0.076$, $p = 0.000$). This suggests a negative association between COVID-19 and the mental health of older adults, indicating that the pandemic had a detrimental effect on mental health. The results of Model (4) showed that during the COVID-19 period, the positive association between ICT accessibility and mental health weakened compared to the pre-COVID-19 period. The interaction variable was statistically significant ($\beta = -0.074$, $p = 0.010$). The results showed that older people with high ICT penetration had significantly lower levels of mental health during the COVID-19 period compared to the pre-COVID-19 period (−0.119). After controlling for the influence of COVID-19, ICT showed a statistically significant positive association (0.081) with mental health. However, compared to the pre-COVID-19 period, the positive association between ICT and mental health has weakened. Our findings suggest that more frequent access to ICT among older adults since the onset of COVID-19 has not contributed to improvements in their mental health to the same extent as before the pandemic.

5.2. Heterogeneity analysis

Table 3 presents a heterogeneity analysis to examine the differences based on the individual characteristics of older adults. Age and sex are commonly considered when analyzing heterogeneity within an aging population. Additionally, the disparity in digital inequality and subjective well-being across different residential areas has long been a topic of discussion in South Korea. Therefore, the digital gaps between residential areas, particularly during the pandemic, have garnered attention (64–67). The older adults were classified according to age, sex, and residential area to explore potential variations in the findings.

Columns 1–2 in Table 3 depict differences between the sexes. The analysis showed that before COVID-19, ICT accessibility had a positive association with mental health for both older male ($\beta = 0.136$, $p = 0.000$) and female ($\beta = 0.183$, $p = 0.000$) adults. However, this positive association weakened for female adults during the COVID-19 period ($\beta = -0.117$, $p = 0.008$). Previous studies have shown that older female adults had higher depression levels than male adults during the COVID-19 pandemic, and older females with poor subjective health had higher levels of fear of COVID-19 than males (68, 69). Thus, it can be concluded that the accessibility of ICT during the pandemic increased concerns and fears of infection among older female adults, which contributed to a negative influence on mental health.

Columns 3–5 in Table 3 show the differences among age cohorts: individuals in their 60s, 70s, and 80s or above. Before the pandemic, ICT accessibility was positively associated with the mental health of older adults in their 60s ($\beta = 0.150$, $p = 0.000$) and 70s ($\beta = 0.145$, $p = 0.003$). However, for those aged 80 and above, the association was not statistically significant. COVID-19 was found to be significantly associated only with the mental health of older adults in their 60s ($\beta = -0.098$, $p = 0.000$). Those in their 60s reported better mental health before the COVID-19 pandemic. Given that the legal retirement age in South Korea is 65 years, mental health was predicted to be higher before COVID-19, because COVID-19 affected the daily work of older adults in their 60s. The interaction term between COVID-19 and ICT accessibility

TABLE 2 Factors associated with the mental health of older adults in South Korea.

Variables	(1)	(2)	(3)	(4)
ICT		0.108***	0.114***	0.155***
		(0.016)	(0.016)	(0.022)
COVID			−0.076***	−0.045*
			(0.015)	(0.020)
COVID*ICT				−0.074*
				(0.029)
AGE	−0.013***	−0.011***	−0.010***	−0.010***
	(0.001)	(0.001)	(0.001)	(0.001)
Sex (base = Female)				
Male	0.047**	0.043**	0.031*	0.033*
	(0.016)	(0.016)	(0.016)	(0.016)
Education (base = Below Elementary school)				
Middle school	0.066**	0.065**	0.070***	0.067***
	(0.020)	(0.020)	(0.020)	(0.020)
High school	0.095***	0.087***	0.103***	0.100***
	(0.022)	(0.022)	(0.022)	(0.022)
College or more	0.102*	0.082*	0.102*	0.098*
	(0.041)	(0.041)	(0.041)	(0.041)
Occupation (base = Employed)				
Agricultural and fishery workers	−0.036	−0.038	−0.021	−0.020
	(0.022)	(0.022)	(0.022)	(0.022)
Unemployed	−0.083***	−0.082***	−0.077***	−0.077***
	(0.022)	(0.022)	(0.022)	(0.022)
Other	−0.432	−0.427	−0.439	−0.428
	(0.587)	(0.577)	(0.575)	(0.575)
Type of residence (base = Detached house)				
Apartment	0.021	0.020	0.023	0.022
	(0.018)	(0.018)	(0.018)	(0.018)
Town/Multiplex House (Villa)	−0.018	−0.020	−0.012	−0.010
	(0.026)	(0.026)	(0.026)	(0.026)
Other	−0.379*	−0.383*	−0.395*	−0.395*
	(0.164)	(0.161)	(0.158)	(0.156)
Residential areas (base = Rural area)				
Urban area	0.039*	0.034	0.035	0.035
	(0.020)	(0.020)	(0.020)	(0.020)
Monthly income (base = Less than 500,000)				
500,000–990,000	−0.020	−0.026	−0.001	−0.007
	(0.044)	(0.044)	(0.044)	(0.044)
1–1.49 million	−0.051	−0.061	−0.030	−0.036
	(0.046)	(0.046)	(0.046)	(0.046)
1.5–1.99 million	−0.049	−0.062	−0.025	−0.033
	(0.048)	(0.048)	(0.048)	(0.048)
2–2.49 million	−0.019	−0.036	0.007	−0.001
	(0.050)	(0.050)	(0.050)	(0.050)
2.5–2.99 million	−0.014	−0.036	0.012	0.003
	(0.052)	(0.052)	(0.053)	(0.053)
More than 3 million	0.014	−0.012	0.042	0.036
	(0.050)	(0.050)	(0.051)	(0.051)
Living arrangement (base = Living alone)				
Living with spouse	0.045*	0.043*	0.032	0.032
	(0.022)	(0.022)	(0.022)	(0.022)
Living with spouse and children	0.071*	0.055	0.041	0.041
	(0.029)	(0.029)	(0.029)	(0.029)
Living with spouse, children, and parents	−0.020	−0.032	−0.043	−0.041
	(0.093)	(0.092)	(0.092)	(0.092)
Other	0.112**	0.093*	0.081*	0.082*
	(0.038)	(0.038)	(0.038)	(0.038)
Disabled (base = Non-disabled)				
Disabled	−0.527***	−0.528***	−0.509***	−0.510***
	(0.024)	(0.024)	(0.024)	(0.024)
Social Support	0.041***	0.039***	0.039***	0.039***
	(0.001)	(0.001)	(0.001)	(0.001)
Guarantee of living (base = Non-recipients)				
Recipients	−0.240***	−0.238***	−0.210***	−0.212***
	(0.028)	(0.028)	(0.028)	(0.028)
Constant	2.282***	2.193***	2.077***	2.080***
	(0.123)	(0.123)	(0.125)	(0.125)
Observations	9,301	9,301	9,301	9,301
R-squared	0.202	0.206	0.208	0.208
F	98.07	97.94	96.11	93.34
F-test for joint significance				
ICT-COVID*ICT				29.31***
COVID-COVID*ICT				16.15***

Robust standard errors in parentheses. ***$p < 0.001$, **$p < 0.01$, and *$p < 0.05$.

was statistically significant for those in their 70s ($\beta = -0.146$, $p = 0.028$). Adults over 70s may be less willing to use ICTs than those in their 60s and their skills in using ICTs may be lower than those in their 60s, making them more likely to rely on help from

TABLE 3 Difference in gender, age cohort, and residential areas.

Variables	Difference in gender		Difference in age cohort			Difference in residential areas	
	Male	Female	60s	70s	Over 80s	Urban area	Rural area
ICT	0.136***	0.183***	0.150***	0.145**	0.166	0.164***	0.122**
	(0.028)	(0.034)	(0.025)	(0.048)	(0.213)	(0.025)	(0.047)
COVID	−0.043	−0.038	−0.098***	−0.003	0.113	−0.064**	0.021
	(0.027)	(0.030)	(0.024)	(0.038)	(0.096)	(0.022)	(0.042)
COVID*ICT	−0.046	−0.117**	−0.017	−0.146*	−0.346	−0.030	−0.280***
	(0.039)	(0.044)	(0.034)	(0.067)	(0.240)	(0.032)	(0.063)
Observations	5,124	4,177	6,560	2,339	402	7,261	2,040
R-squared	0.228	0.193	0.234	0.158	0.134	0.224	0.184
F-test for joint significance							
ICT-COVID*ICT	14.84***	15.18***	29.94***	4.57**	1.58	33.74***	9.92***
COVID-COVID*ICT	5.85**	9.61***	18.44***	3.27*	1.27	10.66***	12.78***

Robust standard errors in parentheses. ***$p<0.001$, **$p<0.01$, and *$p<0.05$. The rest of the variables in the benchmark model are controlled.

family members when they do use them. Therefore, the passive use of ICT in a contactless society during the pandemic is expected to be negatively associated with mental health.

Columns 6–7 of Table 3 present the differences between different residential areas. Prior to the COVID-19 outbreak, the association between ICT accessibility and mental health of older adults was found to be statistically significant in both urban ($\beta=0.164$, $p=0.000$) and rural areas ($\beta=0.122$, $p=0.010$). The mental health of older adults living in urban areas was found to be better before COVID-19 ($\beta=-0.064$, $p=0.005$). Previous studies have shown that urban residents report more COVID-19-related mental health problems than rural residents (70). In South Korea, the response to COVID-19 has been more severe in urban than in rural areas. Considering these facts, a significant negative association between COVID-19 and the mental health of older adults residing in urban areas is anticipated. Regarding the interaction term, the positive association between ICT accessibility and mental health of older adults living in rural areas weakened during COVID-19, and was also statistically significant ($\beta=-0.280$, $p=0.000$). This result can be attributed to limited access to ICT and lower frequency of use among older adults living in rural areas. Consequently, despite the possibility that rural areas may have been subjected to less severe activity restrictions during the pandemic, older adults in these areas face greater challenges in using ICT resources. These challenges are expected to exacerbate, especially when engaging in activities such as applying for government subsidies or completing official government tasks that rely heavily on ICT platforms.

5.3. Robustness check

As a robustness test, we investigate the life satisfaction and the use of e-government among older adults. Life satisfaction, a component of psychological well-being, is strongly correlated with mental health (26–29) and can be used as a proxy variable for mental health (71). As for ICT accessibility, e-government refers to the ability of citizens, including persons with disabilities, to access basic services without having to visit a physical location. The use of e-government can measure the use of ICT to ensure that government resources are accessible to everyone (11). Therefore, e-government usage is used as a proxy indicator for ICT accessibility (72).

Life satisfaction was measured in 2018 and 2020 using the common question number 22, and E-gov was measured using common question number 10–4. Question 22 measured the respondent's subjective satisfaction with life and consisted of five items (1. My life is close to the ideal; 2. My life is very good; 3. I am content with my life; 4. I have acquired the important things I want in life so far; 5. If I lived my life again, I would not change anything.) The response scale is a 4-point rating scale ranging from 1 (very dissatisfied) to 4 (very satisfied), resulting in a score distribution ranging from 5 to 20. Higher scores indicated higher life satisfaction. However, there were differences in the response rating scales between 2018 and 2020. In 2018, the response scale was a 7-point rating scale, whereas in 2020, it was rated on a 4-point scale. For the convenience of analysis, the 2018 response scale was converted to a 4-point scale. (Note: The 2018 response scale was converted from a 7-point rating scale to a 4-point rating scale: (1) Strongly Disagree, (2) Disagree, Somewhat Disagree (3) Neither Agree nor Disagree, Somewhat Agree (4) Agree, Strongly Agree.)

Question 10–4 measured the extent to which respondents use public services, such as taxes, public services, and welfare information services, on a PC or mobile device. Responses were split between PC and mobile devices, and both were rated on a 4-point rating scale. For the convenience of analysis, PC and mobile responses were weighted at 50% each and combined. The score distribution ranged from 1(never) to 4 (always), with higher scores indicating that users were more likely to access public services via PC and mobile phones. (Note: Question 10–4 can only be answered by respondents who have used the internet in the last month, thus reducing the sample size.)

Column 1 of Table 4 shows the results of the analysis after replacing the dependent variable with life satisfaction in the benchmark model. The results show that ICT is positively associated with life satisfaction ($\beta=0.681$, $p=0.000$), life satisfaction was higher before COVID-19 ($\beta=-1.309$, $p=0.000$), and the interaction term between ICT and COVID-19 is statistically significant for life satisfaction ($\beta=-0.273$, $p=0.007$). Column 2 of Table 4 shows the results of the analysis after replacing the existing independent variable ICT with E-gov. The results show that similar to the benchmark

TABLE 4 Robustness check: factors associated with the mental health of older adults in South Korea.

Variables	(1)	(2)	(3)
	Life satisfaction	Mental health	Life satisfaction
ICT	0.681***		
	(0.075)		
E-gov		0.179***	0.906***
		(0.022)	(0.090)
1.COVID	−1.309***	−0.052	−0.942***
	(0.069)	(0.043)	(0.156)
1.COVID#c.ICT	−0.273***		
	(0.100)		
1.COVID#c. E-government		−0.054*	−0.382***
		(0.028)	(0.108)
Constant	8.290***	1.703***	7.691***
	(0.442)	(0.178)	(0.628)
Observations	9,301	6,023	6,028
R-squared/Pseudo R-squared	0.288	0.201	0.281
F-test for joint significance			
ICT-COVID*ICT	52.39***		
COVID-COVID*ICT	361.33***		
E-gov-COVID* E-gov		58.27***	86.16***
COVID-COVID*E-gov		25.09***	261.02***

Robust standard errors in parentheses. ***$p < 0.001$, **$p < 0.01$, and *$p < 0.05$. The rest of the variables in the benchmark model are controlled.

model, E-gov has a significant positive association with mental health ($\beta = 0.179$, $p = 0.000$), while COVID-19 is not significant; however, the interaction term between E-gov and COVID-19 is statistically significant ($\beta = -0.054$, $p = 0.050$). Column 3 of Table 4 shows the results of the analysis by replacing the dependent variable with life satisfaction and the independent variable with E-gov in the benchmark model. The results show that E-gov ($\beta = 0.906$, $p = 0.000$) and COVID-19 ($\beta = -0.942$, $p = 0.000$) were significantly associated with life satisfaction. The interaction term between E-gov and COVID-19 was also statistically significant ($\beta = -0.382$, $p = 0.000$). The robustness checks show that the interaction terms are statistically significant in all three models ($p < 0.05$). These results, along with those of the benchmark model, demonstrate that ICT accessibility is positively associated with mental health in older adults. However, during the COVID-19 period, the positive association between ICT accessibility and mental health has weakened.

6. Conclusions and discussions

This study examined the association between ICT accessibility and mental health in older adults during the pandemic. Multiple regression models were used and heterogeneity and robustness analyses were performed.

During the pandemic, ICT accessibility of older adults maintained a positive association as it did before the pandemic; however, this association weakened during the pandemic. We included the ICT × COVID-19 interaction variables in this study. The results confirmed that when controlling for ICT levels, the positive association between COVID-19 and the mental health of older adults decreased, as supported by the joint significance test. These results suggest that ICT accessibility during the COVID-19 pandemic has a comparatively smaller association with mental health than that before the pandemic, and may even contribute to a decline in mental health.

There are two reasons for this finding. First, when ICT is used for leisure activities or social interaction, it is positively associated with mental health (73–75). Previous studies have shown that ICT is positively associated with mental health when mediated by social support or activities. However, owing to the ubiquity of ICT during the pandemic, older adults without ICT training may feel uncomfortable. This creates a digital divide, in which ICT use becomes socially passive. Previous studies have argued that more frequent ICT use during the pandemic led to discomfort among older adults and created a digital divide (19, 57, 76). Furthermore, older adults use ICT primarily for social interaction, and struggle with internet shopping and financial transactions. Subjective well-being increased significantly when older adults used ICT for leisure purposes. These findings indicate that ICT plays an important role in improving mental health when actively used for social interactions and leisure, while its passive use in online work or shopping may be detrimental to mental health (56, 77, 78). The tasks of public institutions or vaccine applications through ICT during the COVID-19 pandemic have negatively influenced the mental health of older adults. Second, frequent ICT exposure during the pandemic increased anxiety about COVID-19, thereby affecting mental health. Studies have shown anxiety and depression among older adults due to COVID-19 (79–82) and found that anxiety was higher among older adults who received COVID-19 information through social media (83, 84). Thus, emotional contagion on social media can affect mental health.

In Model 1 of the benchmark regression analysis, age, sex, education, occupation, type of residence, residential area, living arrangement, disability, social support, and guarantee of living were associated with the mental health of older adults. These findings support previous studies, indicating that demographic factors in older adults are associated with mental health (31–34). In terms of age, mental health tended to decline as individuals grew older. This could be attributed to older adults experiencing physical vulnerabilities and cognitive decline compared to younger generations, which may amplify feelings of depression. Mental health is expected to deteriorate with age. Additionally, mental health was better among males than females. This finding is consistent with that of a previous study indicating that older females are generally more likely to experience mental health disorders than younger females (32). Furthermore, higher levels of education and employment were associated with better mental health. This could be attributed to individuals with higher education attaining better social positions, and highly educated individuals or those in professional occupations having better prospects for maintaining employment and engaging in social activities even in their later years, leading to better mental health outcomes. With regard to residential status, not residing in apartments, townhouses, or villas was associated with poor mental health. In South Korea, not residing in such a residential environment is often indicative of financial difficulties.

Therefore, it can be predicted that individuals residing in "other" types of residences might have the lowest mental health levels among the three categories, excluding apartments, townhouses, and villas. Residing in urban areas and living with family members were associated with better mental health. This could be attributed to urban areas having stronger healthcare systems than rural areas (34), and that living with family members may reduce feelings of loneliness and depressive symptoms among older adults. Furthermore, social support can decrease feelings of loneliness among older adults and enhance their self-confidence and self-esteem, leading to better mental health outcomes. Thus, higher levels of social support are likely associated with better mental health among older adults. This study highlights the importance of emotional factors, such as social support, in the mental health of an aging population (38–43). Finally, disability and guarantee of living were associated with mental health in older adults (85, 86). However, in contrast to a previous study (66), monthly income was not associated with mental health in older adults.

Heterogeneity analysis revealed that during COVID-19, the positive association between ICT accessibility and mental health was most significantly weakened among older female adults in their 70s residing in rural areas. Previous studies have shown that females generally have higher rates of depression and are more vulnerable to external environmental factors (67, 87); female adults in their 70s living in rural areas may have been affected by emotional contagion, such as concerns and fears of infection, while using ICTs during COVID-19. Furthermore, considering the digital divide between rural and urban areas in South Korea, older adults living in rural areas may have had difficulty shopping online or using public services via ICT during the COVID-19 pandemic.

This study proposes a few policy recommendations. First, the South Korean government should implement regular ICT education programs specifically tailored to older adults. These programs should focus on raising awareness about ICT and providing training on using ICT devices and platforms effectively. It is important to address any potential feelings of alienation or discomfort that older adults may have toward ICT, and emphasize the benefits and convenience it can bring to their lives. Given that older adults may have a slower adaptation rate to the digital society than younger age groups, periodic ICT education will greatly assist them in integrating into the digital society. Second, when providing e-government services to older adults, the government should ensure that the systems are user-friendly and easy to understand. Many of South Korea's subsidy systems and vaccination applications are implemented through e-government platforms that utilize ICT. However, if these systems are complex and difficult for older adults to navigate, they can negatively influence their mental health. Therefore, it is crucial to design and develop user-friendly systems that cater to older adults' needs and capabilities. Finally, promoting older adults' participation in social communities facilitated by ICT can improve their mental health. Online gaming companies and local governments operate senior portal sites in South Korea. However, public awareness of these platforms is relatively low. The government should support social media sites, platforms, and communities that specifically target older adults, and encourage their active engagement and participation in society through ICT. The proposed policies aim to address the specific challenges faced by older adults in accessing and utilizing ICT, ultimately promoting their mental health during the digital age.

7. Limitations and perspectives

One notable limitation of the present study is its reliance on pooled cross-sectional data, which allows the observation of associations between mental health and ICT among older adults during the COVID-19 pandemic, rather than establishing causal relationships. The absence of panel data restricted our ability to examine temporal dynamics and draw definitive conclusions regarding causality.

Furthermore, the measurement of ICT accessibility was limited to indicators such as ICT ownership and internet access among older adults. Specific purposes of ICT use, such as online shopping, leisure activities, and engagement with e-government services, have not been differentiated. Consequently, this study did not capture the nuanced aspects of ICT accessibility and usage over time, which limited our ability to analyze the specific pathways through which ICT accessibility influences mental health.

However, our study found a weakening positive association between older adults' access to ICT and mental health during the COVID-19 period. These findings suggest that in a post-pandemic society where ICT adoption is expected to accelerate, our results will contribute to the formulation of ICT-related policies for older adults.

To address these limitations, future studies should employ rigorous methodologies, including panel data analyses, to investigate the causal relationship between ICT accessibility and mental health outcomes in older adults. Additionally, it is essential to expand data collection efforts to encompass specific domains of ICT use, such as social interaction, e-government engagement, and online shopping. This will provide a more comprehensive understanding of the potential influence of ICT on mental health, and facilitate the development of targeted policy proposals tailored to the specific contexts of social interaction, e-government use, and online shopping among older adults.

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

SP conceived the idea and collected the original data. WZ participates the research design, empirical strategy, and gave comments on the draft and polished it. SP, PZ and YT worked in data cleaning and statistical analysis. SP and PZ drafted the manuscript and edited the paper. All authors contributed to the article and approved the submitted version.

Conflict of interest

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

Publisher's note

References

1. Statista. (2023). Internet usage in South Korea-statistics & facts. Available at: https://www.statista.com/topics/2230/internet-usage-in-south-korea/ (Accessed August 2, 2023).

2. Statista. (2021). Ownership rate of smartphones in South Korea from 2011 to 2021. Available at: https://www.statista.com/statistics/777726/south-korea-smartphone-ownership/ (Accessed January 10, 2023).

3. Yihwa Huang. (2020). 6070 smartphone penetration rate is the highest in the world…Mobile carrier to target seniors. Available at: https://news.mtn.co.kr/news-detail/2020092311113260206 (Accessed January 10, 2023).

4. Kang W, Kim MS, Ko JU. Effects of the smartphone information use and performance on life satisfaction among the elderly. *J Korea Gerontol Soc*. (2013) 33:199–214.

5. Kim M-Y. The effects of smartphone use on life satisfaction, depression, social activity and social support of older adults. *J Korea Acad-Indust Cooper Soc*. (2018) 19:264–77.

6. Kim M-Y, Jun H. The effects of smartphone use on life satisfaction in older adults: the mediating role of participation in social activities. *J Korea Gerontol Soc*. (2017) 72:343–70.

7. Shin YJ, Minjeong G. An explorative study on computer education for the elderly and their life satisfaction. *Andragogy Today: Interdiscipl J Adult Contin Educ*. (2021) 13:119–47. doi: 10.22955/ace.13.4.201011.119

8. Lee Y-J. The effect of information conditions on mental health among elderly. *J Digit Converg*. (2013) 11:17–29. doi: 10.14400/JDPM.2013.11.10.017

9. Kraut R, Patterson M, Lundmark V, Kiesler S, Mukopadhyay T, Scherlis W. Internet paradox: a social technology that reduces social involvement and psychological well-being. *Am Psychol*. (1998) 53:1017–31. doi: 10.1037/0003-066X.53.9.1017

10. Nie NH. Sociability, interpersonal relations, and the internet: reconciling conflicting findings. *Am Behav Sci*. (2001) 45:420–35. doi: 10.1177/00027640121957277

11. Byeon Hye Jeong. (2022). E-government service utilization rate surpasses 90% for the first time … 98% "usability satisfied". Available at: https://newsis.com/view/?id=NISX20221228_0002138832&Cid=10301&Pid=10300 (Accessed January 13, 2023).

12. Song jeongeun. (2023). If the digital gap widens, the elderly will be completely excluded from society. Available at: https://www.yna.co.kr/view/AKR20230115034000004?Input=1195m (Accessed January 12, 2023).

13. Davies AR, Honeyman M, Gann B. Addressing the digital inverse care law in the time of COVID-19: potential for digital technology to exacerbate or mitigate health inequalities. *J Med Internet Res*. (2021) 23:e21726. doi: 10.2196/21726

14. Murciano-Hueso A, Martín-García A-V, Cardoso AP. Technology and quality of life of older people in times of COVID: A qualitative study on their changed digital profile. *Int J Environ Res Public Health*. (2022) 19:10459. doi: 10.3390/ijerph191610459

15. Seifert A, Cotten SR, Xie B. A double burden of exclusion? Digital and social exclusion of older adults in times of COVID-19. *J Gerontol B*. (2021) 76:e99–e103. doi: 10.1093/geronb/gbaa098

16. Hargittai E, Piper AM, Morris MR. From internet access to internet skills: digital inequality among older adults. *Univ Access Inf Soc*. (2019) 18:881–90. doi: 10.1007/s10209-018-0617-5

17. Mariano J, Marques S, Ramos MR, de Vries H. Internet use by middle-aged and older adults: longitudinal relationships with functional ability, social support, and self-perceptions of aging. *Psychol Aging*. (2021) 36:983–95. doi: 10.1037/pag0000643

18. Cheong Yoon Mo. *A study on the effect of E-government service and ICT capital service on digital divide*. South Korea: Korea University (2020).

19. Song Y, Qian C, Pickard S. Age-related digital divide during the COVID-19 pandemic in China. *Int J Environ Res Public Health*. (2021) 18:11285. doi: 10.3390/ijerph182111285

20. Hu Y, Qian Y. COVID-19, inter-household contact and mental well-being among older adults in the US and the UK. *Front Soc*. (2021) 6:714626. doi: 10.3389/fsoc.2021.714626

21. Nedeljko M, Bogataj D, Perović BT, Kaučič BM. The use of information and communication technologies affects mental health and quality of life of older adults during the COVID-19 pandemic. *IFAC-Papers OnLine*. (2022) 55:940–5. doi: 10.1016/j.ifacol.2022.09.461

22. Romanopoulou ED, et al. Technology enhanced health and social Care for Vulnerable People during the COVID-19 outbreak. *Front Hum Neurosci*. (2021) 15:721065. doi: 10.3389/fnhum.2021.721065

23. Llorente-Barroso C, Kolotouchkina O, Mañas-Viniegra L. The enabling role of ICT to mitigate the negative effects of emotional and social loneliness of the elderly during COVID-19 pandemic. *Int J Environ Res Public Health*. (2021) 18:3923. doi: 10.3390/ijerph18083923

24. Mubarak F, Suomi R. Elderly forgotten? Digital exclusion in the information age and the rising Grey digital divide. *J Health Care Organiz Provis Financ*. (2022) 59:469580221096272. doi: 10.1177/00469580221096272

25. Cheshmehzangi A, Zou T, Zhaohui S. The digital divide impacts on mental health during the COVID-19 pandemic. *Brain Behav Immun*. (2022) 101:211–3. doi: 10.1016/j.bbi.2022.01.009

26. Puvill T, Lindenberg J, De Craen AJM, Slaets JPJ, Westendorp RGJ. Impact of physical and mental health on life satisfaction in old age: a population based observational study. *BMC Geriatr*. (2016) 16:194. doi: 10.1186/s12877-016-0365-4

27. Lombardo P, Jones W, Wang L, Shen X, Goldner EM. The fundamental association between mental health and life satisfaction: results from successive waves of a Canadian national survey. *BMC Public Health*. (2018) 18:342. doi: 10.1186/s12889-018-5235-x

28. Ghubach R, El-Rufaie O, Zoubeidi T, Sabri S, Yousif S, Moselhy HF. Subjective life satisfaction and mental disorders among older adults in UAE in general population. *Int J Geriatr Psychiatry*. (2010) 25:458–65. doi: 10.1002/gps.2360

29. van Leeuwen CM, Post MW, Westers P, van der Woude LH, de Groot S, Sluis T, et al. Relationships between activities, participation, personal factors, mental health, and life satisfaction in persons with spinal cord injury. *Arch Phys Med Rehabil*. (2012) 93:82–9. doi: 10.1016/j.apmr.2011.07.203

30. Cho J, Martin P, Margrett J, Macdonald M, Poon LW. The relationship between physical health and psychological well being among oldest old adults. *J Aging Res*. (2011) 3:605041. doi: 10.4061/2011/605041

31. Barrenetxea J, Pan A, Feng Q, Koh WP. Factors associated with depression across age groups of older adults: the Singapore Chinese health study. *Int J Geriatr Psychiatry*. (2021) 37:5666. doi: 10.1002/gps.5666

32. Kiely KM, Brady B, Byles J. Gender, mental health and ageing. *Maturitas*. (2019) 129:76–84. doi: 10.1016/j.maturitas.2019.09.0045666

33. Alcañiz M, Riera-Prunera MC, Solé-Auró A. "When I retire, I'll move out of the City": mental well-being of the elderly in rural vs. urban settings. *Int J Environ Res Public Health*. (2020) 17:2442. doi: 10.3390/ijerph17072442

34. Du W, Zhou J, Liu J, Yang X, Wang H, He M, et al. Social-demographic correlates of the mental health conditions among the Chinese older adults. *Sustainability*. (2019) 11:247114. doi: 10.3390/su11247114

35. Beekman AT. Major and minor depression in later life: a study of prevalence and risk factors. *J Affect Disord*. (1995) 36:65–75. doi: 10.1016/0165-0327(95)00061-5

36. Kadariya S, Gautam R, Aro AR. Physical activity, mental health, and wellbeing among older adults in south and Southeast Asia: a scoping review. *Bio Med Res Int*. (2019) 6752182:1–11. doi: 10.1155/2019/6752182

37. Song J-Y. The effect of disability and disability type on the depression of the elderly. *J Korea Acad-Indust Cooper Soc*. (2019) 20:362–9. doi: 10.5762/KAIS.2019.20.6.362

38. Seo yoen hee. *Whether or not living with the elderly and families with mental health impact on quality of life*. South Korea: Dongeui University (2011).

39. Guo M, Li S, Liu J, Sun F. Family relations, social connections, and mental health among Latino and Asian older adults. *Res Aging*. (2015) 37:123–47. doi: 10.1177/0164027514523298

40. Singh R., Pant K., Lohia P. (2017). Contact with family: a boost for mental health of institutionalized elderly. Ind J Health Wellbeing. 8: 902–905. Available at: https://www.researchgate.net/publication/320585927_Contact_with_family_A_boost_for_mental_health_of_institutionalized_elderly (Accessed March 5, 2022).

41. Hee-Seog K. *The effect farming on the mental health of the elderly women in rural area*. South Korea: Joongbu University (2019).

42. Miao J. *Neighborhood influences on mental health among Hong Kong elderly*. Macau: Demographic Transition and Health (2017).

43. Tae-Young P. What are the effects of expanding social pension on health? Evidence from the basic pension in South Korea. *J Econ Ageing*. (2020) 42:349–66. doi: 10.1016/j.jeoa.2020.100287

44. Erickson J, Johnson GM. Internet use and psychological wellness during late adulthood. *Can J Aging*. (2011) 30:198–209. doi: 10.1017/S0714980811000109

45. Heo J, Chun S, Lee S, Lee KH, Kim J. Internet use and well-being in older adults. *Cyberpsychol Behav Soc Netw*. (2015) 18:268–72. doi: 10.1089/cyber.2014.0549

46. Ahn J-H, Lim K-C, Lee Y-J, Kim K-S. Effects of computer/internet game play on depression and life satisfaction among the elderly. *Int J Contents*. (2011) 11:406–17. doi: 10.5392/JKCA.2011.11.7.406

47. Bauer R, et al. Internet use by older adults with bipolar disorder: international survey results. *Int J Bipolar Disorders*. (2018) 6:1–7. doi: 10.1186/s40345-018-0127-7

48. Choi HK, Lee SH. Trends and effectiveness of ICT interventions for the elderly to reduce loneliness: a systematic review. *Healthcare*. (2021) 9:293. doi: 10.3390/healthcare9030293

49. Wallinheimo AS, Evans SL. More frequent internet use during the COVID-19 pandemic associates with enhanced quality of life and lower depression scores in middle-aged and older adults. *Healthcare*. (2021) 9:393. doi: 10.3390/healthcare9040393

50. Jeong Kyu Hyoung. The effects of internet utilization on the life satisfaction of the elderly-the mediating effect of social activity. *Korean Assoc Soc Welfare Stud*. (2013) 44:359–85. doi: 10.16999/kasws.2013.44.2.359

51. Hui Jeong Kim. *Digital informatization level and health satisfaction among elderly people: correlation and analysis of the influencing factors*. South Korea: Seoul National University (2019).

52. Seifert A, Reinwand DA, Schlomann A. Designing and using digital mental health interventions for older adults: being aware of digital inequality. *Front Psych*. (2019) 9:568. doi: 10.3389/fpsyt.2019.00568

53. Xie L, et al. Does the internet use improve the mental health of Chinese older adults? *Front. Public Health*. (2021) 9:673368. doi: 10.3389/fpubh.2021.673368

54. Lee J, Jang SN. Have changes in internet use during the COVID-19 pandemic affected older adults' self-rated health? A cross-sectional study of young-old and old-old populations in Korea. *Geriatr Nurs*. (2022) 48:145–9. doi: 10.1016/j.gerinurse.2022.09.012

55. Ghazi SN, Anderberg P, Berglund JS, Berner J, Dallora AL. Psychological health and digital social participation of the older adults during the COVID-19 pandemic in Blekinge, Sweden-an exploratory study. *Int J Environ Res Public Health*. (2022) 19:3711. doi: 10.3390/ijerph19063711

56. Nimrod G. Changes in internet use when coping with stress: older adults during the COVID-19 pandemic. *Am J Geriatr Psychiatry*. (2020) 28:1020–4. doi: 10.1016/j.jagp.2020.07.010

57. Bakshi T, Bhattacharyya A. Socially distanced or socially connected? Wellbeing through ICT usage among the Indian older adults during COVID-19. *Millennial Asia*. (2021) 12:190–208. doi: 10.1177/0976399621989910

58. Rinderud Peter. (2021). Seniors and technology during Covid-19: The latest insights. Sweden: Stockholm Ericsson. Available at: https://www.ericsson.com/en/blog/2021/1/seniors-and-technology-during-covid (Accessed February 28, 2022).

59. Cho C. A study on factors influencing the mental health of rural older adults by the activities of daily living (ADL) and economic difficulties. *Korean J Gerontol Soc Welfare*. (2016) 15:331–53. doi: 10.21194/kjgsw.71.1.201603.331

60. Turner RJ, Noh S. Physical disability and depression: a longitudinal analysis. *J Health Soc Behav*. (1998) 29:23–37. doi: 10.2307/2137178

61. Jinhee S. A study on influence of subjective health recognition and social support on the older adults suicide ideation: using parameter effect of depression. *Korean J Gerontol Soc Welfare*. (2011) 54:361–85. doi: 10.21194/kjgsw.54.201112.361

62. Zhang Y, Harper S. The impact of son or daughter care on Chinese older adults' mental health. *Soc Sci Med*. (2022) 306:115104. doi: 10.1016/j.socscimed.2022.115104

63. Yanan Z, Sarah H. Son or daughter care in relation to self-reported health outcomes for older adults in China. *Front Public Health*. (2022) 9:793873. doi: 10.3389/fpubh.2021.793873

64. Koh H. A study on the digital divide and life satisfaction: focusing on generation, SES, and an urban-rural comparison. *J Korea Content Assoc*. (2017) 17:633–41. doi: 10.5392/JKCA.2017.17.05.633

65. Yoon Ja min. (2021). Jeollanam-do, all-out efforts to resolve the 'digital gap' between urban and rural areas. Available at: https://www.asiae.co.kr/article/2021042013214166099 (Accessed February 4, 2023).

66. Min Dong Ju. (2023). Digital buses to rural areas narrow digital gap. Available at: https://www.rwn.co.kr/news/articleView.html?idxno=60888 (Accessed February 4, 2023).

67. Su Hui Lee. *The location optimization of public Wi-fi for mitigating of regional Mobile divide*. South Korea: Chonnam National University (2014).

68. Jeon SW, Han C, Lee J, Lim J, Jeong HG, Park MH, et al. Perspectives on the happiness of community-dwelling elderly in Korea. *Psychiatry Investig*. (2016) 13:50–7. doi: 10.4306/pi.2016.13.1.50

69. Reppas-Rindlisbacher C, Mahar A, Siddhpuria S, Savage R, Hallet J, Rochon P. Gender differences in mental health symptoms among Canadian older adults during the COVID-19 pandemic: a cross-sectional survey. *Canadian Geriatr J*. (2022) 25:49–56. doi: 10.5770/cgj.25.532

70. Liu L, Xue P, Li SX, Zhang J, Zhou J, Zhang W. Urban-rural disparities in mental health problems related to COVID-19 in China. *Gen Hosp Psychiatry*. (2021) 69:119–20. doi: 10.1016/j.genhosppsych.2020.07.011

71. Gong R, Xia D, Hu Z, et al. The impact of neighborhood mental health on the mental health of older adults. *BMC Public Health*. (2023) 23:1352. doi: 10.1186/s12889-023-16263-w

72. OECD. *"E-government service maturity", in government at a glance 2009*. Paris: OECD Publishing (2009).

73. Kexin Y, Shinyi W, Chi I. Internet use and loneliness of older adults over time: the mediating effect of social contact. *J Gerontol B*. (2020) 76:541–50. doi: 10.1093/geronb/gbaa004

74. Kim YH. *Effect of smartphone usage on life satisfaction of older adults in rural area: Mediation effects of social participation*. South Korea: Hallym University (2020).

75. Kokubun K. Social capital mediates the association between the ICT usage and well-being of older people in Japan: implication for a new design paradigm. *Sustainability*. (2022) 14:1–20.

76. Martins Van Jaarsveld G. The effects of COVID-19 among the elderly population: a case for closing the digital divide. *Front Psych*. (2020) 11:577427. doi: 10.3389/fpsyt.2020.577427

77. Hyo-jung Kim. (2020). Even if live with my smartphone … only 17% of people in their 60s can shop online. Available at: https://www.chosun.com/site/data/html_dir/2020/03/06/2020030602846.html (Accessed January 10, 2023).

78. LEE DONG WHA. (2020). 7 out of 10 elderly people with smartphones … financial affairs, shopping, and simple payments are still difficult. Available at: http://www.100news.kr/8525 (Accessed January 10, 2023).

79. De Pue S, Gillebert C, Dierckx E, et al. The impact of the COVID-19 pandemic on wellbeing and cognitive functioning of older adults. *Sci Rep*. (2021) 11:4636. doi: 10.1038/s41598-021-84127-7

80. McKinlay AR, Fancourt D, Burton A. A qualitative study about the mental health and wellbeing of older adults in the UK during the COVID-19 pandemic. *BMC Geriatr*. (2021) 21:439. doi: 10.1186/s12877-021-02367-8

81. Khademi F, Moayedi S, Golitaleb M, Karbalaie N. The COVID-19 pandemic and death anxiety in the older adults. *Int J Ment Health Nurs*. (2021) 30:346–9. doi: 10.1111/inm.12824

82. Namkung EH. Social and economic experiences and health changes for older persons during the COVID-19 pandemic. *Health Welfare Policy Forum*. (2021) 300:72–85. doi: 10.23062/2021.10.7

83. Wong FHC, Liu T, Leung DKY, Zhang AY, Au WSH, Kwok WW, et al. Consuming information related to COVID-19 on social media among older adults and its association with anxiety, social Trust in Information, and COVID-safe Behaviors: cross-sectional telephone survey. *J Med Internet Res*. (2021) 23:e26570. doi: 10.2196/26570

84. Ni MY, Yang L, Leung CMC, Li N, Yao XI, Wang Y, et al. Mental health, risk factors, and social media use during the COVID-19 epidemic and cordon sanitaire among the community and health professionals in Wuhan, China: cross-sectional survey. *JMIR Ment Health*. (2020) 7:e19009. doi: 10.2196/19009

85. Reich JW, Zautra AJ, Guarnaccia CA. Effects of disability and bereavement on the mental health and recovery of older adults. *Psychol Aging*. (1989) 4:57–65. doi: 10.1037/0882-7974.4.1.57

86. Myoung Shim Kim. *The relationship between basic livelihood security benefits and depression among low income families: Using the Korean welfare panel study*. South Korea: Yonsei University (2021).

87. Jungwha-Moon . An exploratory study on COVID-19 phobia and influencing factors. *Inst Soc Sci Chungnam Natl Univ*. (2021) 32:285–07. doi: 10.16881/jss.2021.01.32.1.285

frontiers | Frontiers in Public Health

TYPE Original Research
PUBLISHED 31 January 2024
DOI 10.3389/fpubh.2024.1284180

OPEN ACCESS

EDITED BY
Abdolvahab Samavi,
University of Hormozgan, Iran

REVIEWED BY
Magdalena Agnieszka Wrzesinska,
Medical University of Lodz, Poland
Sarah Dys,
Portland State University, United States

*CORRESPONDENCE
Wenqiang Yin
✉ yinwq1969@126.com
Dongmei Huang
✉ hdongm@126.com

RECEIVED 28 August 2023
ACCEPTED 15 January 2024
PUBLISHED 31 January 2024

CITATION
Li Q, Yang C, Zhao Z, Yang C, Chen Z, Huang D and Yin W (2024) The relationship between Internet use and loneliness of middle-aged and older adult people: the moderating effect of residence. *Front. Public Health* 12:1284180. doi: 10.3389/fpubh.2024.1284180

The relationship between Internet use and loneliness of middle-aged and older adult people: the moderating effect of residence

Qiusha Li[1], Chunxiao Yang[1], Zixuan Zhao[1], Chenxiao Yang[2], Zhongming Chen[2], Dongmei Huang[2]* and Wenqiang Yin[2]*

[1]School of Public Health, Shandong Second Medical University, Weifang, Shandong, China, [2]School of Management, Shandong Second Medical University, Weifang, Shandong, China

Objectives: The proportion of middle-aged and older adult people exposed to the Internet continues to grow. Internet use may have an impact on the mental health of the older adult, especially loneliness. This study analyzed the relationship between Internet use and presence of loneliness.

Methods: A total of 550 person aged 45 years and above were randomly selected from a province in eastern China at the end of 2022. The outcome variable was presence of loneliness, as measured by self-report. Descriptive analysis, chi-square test and binary logistic analysis were used to analyze the data.

Results: 58.3% of respondents use the Internet. Internet use could reduce the possible of reported loneliness in middle-aged and older adult people (*OR* = 0.652, 95%*CI:* 0.465, 0.940), and residence played a moderating role in the relationship between them. Middle-aged and older adults who used the Internet for 1–3 h (*OR* = 0.464, 95%*CI*: 0.275, 0.784) and 3–5 h (*OR* = 0.484, 95%*CI*: 0.247, 0.946) were less likely to felt lonely than those who used the Internet for less than 1 h per day. In addition, middle-aged and older adult people using the Internet to contact relatives and friends (*OR* = 0.488, 95%*CI*:0.292, 0.818), read the news (*OR* = 0.485, 95%*CI*:0.277, 0.848), assets management (*OR* = 0.297, 95%*CI*:0.109, 0.818) were less likely to report loneliness, while those who made online payment (*OR* = 3.101, 95%*CI*:1.413, 6.807) were more likely to report loneliness.

Conclusion: There is a significant negative correlation between Internet use and presence of loneliness, but different Internet duration and content have different effects on loneliness in middle-aged and older adult people. We should pay attention to the impact of Internet use on loneliness in middle-aged and older adult people.

KEYWORDS

Internet use, loneliness, middle-aged, older adult, digital divide

Introduction

As China's economy grows and medical services improve, people's life expectancy increases, and China is entering an aging society at the fastest rate (1–3). China has become the country with the largest older adult population in the world, accounting for about a quarter of the world's older adult population (4). The World Health Organization regards 45 years old and 60 years old as the age criteria for middle-aged and older adult people, respectively (5). According to China's seventh census, there will be more than 600 million people aged 45 and above in China in 2020, accounting for about 42.6% of the total population (6). With the rapid development of Internet technology, the proportion of the middle-aged and older adult population in the Internet community continues to grow. Studies have shown that the proportion of people aged 45 to 59 who have access to the Internet in China has reached 50.0% (7). This part of the "quasi-older adult" will be an important part of the future older adult population in China. The proportion of Internet users aged 60 and above has also climbed from 6.7% in March 2020 to 11.3% in 2022. Especially during the COVID-19 pandemic, when the Internet has brought many conveniences to life and Internet usage has risen sharply (3, 8, 9). At the same time, the mental health of middle-aged and older adult people may be affected by Internet use (10). Loneliness is an important indicator of the mental health of the older adult, which refers to the negative experience when there is a difference between the expected social relationship and the established social relationship (11). Studies have found that the older adult are vulnerable to loneliness due to the loss of social roles, the reduction of economic resources and the increase of injury (12). Loneliness may lead to an increased risk of depression, cognitive impairment, reduced life satisfaction, and severe loneliness is even associated with a higher risk of death (13–17).

The impact of the Internet on middle-aged and older adult people, especially on loneliness, has attracted more and more attention. However, the academic community has not yet reached a unified conclusion on the relationship between Internet use and loneliness of middle-aged and older adult people. Some scholars believe that by using the Internet, the older adult can break the restrictions of geographical space and enhance their connection with the outside world. Especially for the middle and young older adult, the use of the Internet can improve social participation and have a positive impact on mental health (18–20). Shillair found that the use of the Internet can maintain and enrich the social relations of the older adult, reduce the impact of loneliness, and improve life satisfaction (21). Lam, Wang and others found that the use of the Internet can reduce the anxiety, depression and other negative emotions of the older adult (22, 23). Cotten also found that older people who are reluctant to socialize also benefit from Internet use (24). Some scholars hold different views that Internet use will occupy the social time of the older adult in real life. And unhealthy Internet behavior reduces the opportunities for face-to-face communication, which is not conducive to emotional expression and the maintenance of social relations, thus increasing inner loneliness (25–28). Other scholars have also pointed out that people are affected differently by the content and duration of Internet use (29). In terms of online time, most of the existing studies focus on teenagers or college students (30, 31), and there are few studies on the relationship between online time and loneliness in middle-aged and older adult groups. Although some studies have explored the association between Internet use and loneliness and reported different results (18, 27, 28), there is limited evidence on the relationship between Internet use duration and content and loneliness. In this paper, examining the roles of Internet use duration and content may help understand the conflicting findings in the literature.

In addition, the digital divide between urban and rural areas in China is huge, and there may be obvious differences between urban and rural residents (2). At present, although the Internet is promoted nationwide, there are more non-Internet users in rural areas (32). A study on China shows that with the acceleration of China's urbanization process, the rural youth population continues to flow to the city, and the number of rural empty nesters is increasing. Compared with cities, the mental health problems of the older adult in rural areas are more prominent (33). Previous studies have shown that during the pandemic, when middle-aged and older adult people have certain restrictions on their activities, they can actively connect with others through the use of the Internet to reduce loneliness. However, the differences in Internet use between urban and rural areas may have different effects on the loneliness of middle-aged and older adult people in urban and rural areas (34). In this study, we will explore the following questions: What is the relationship between Internet use and presence of loneliness among middle-aged and older adults during the COVID-19 pandemic? Specifically, what are the effects of Internet use duration and content on loneliness among middle-aged and older adult people? Considering the existence of urban–rural differences, is the relationship between Internet use and loneliness of middle-aged and older adult people influenced by place of residence?

Methods

Study design and sampling

This study is a cross-sectional survey conducted in Shandong Province in December 2022. The respondents were middle-aged and older adult people aged 45 and above. Shandong Province is an economically developed region in the east of China. It is the second most populous province in China. In this study, we used the method of stratified random sampling to collect data. In order to ensure that the survey samples are representative of Shandong Province. Firstly, we selected three prefecture-level cities in Shandong Province according to the level of economic development, which are economically developed cities, economically medium cities and economically underdeveloped cities. Secondly, according to the same principle, three counties (cities, districts) were extracted from each prefecture-level city, and three natural villages (communities) were extracted from each county. Finally, we randomly selected 20 middle-aged and older adult people aged 45 and above in each natural village (community). To protect the privacy of the survey subjects, we follow the principle of informed consent and voluntary participation. The questionnaires were filled in anonymously by individuals on site. We assigned four to six trained investigators to each site, who answered questions in real-time during the investigation. If

participants were unable to fill out the questionnaire independently, the investigators were available to offer face-to-face assistance. At the end of the investigation, the questionnaires were collected on the spot, investigators were checked by themselves and checked each other. Invalid questionnaires such as too many missed answers, logical errors and skipping answers errors were eliminated. In the end, a total of 550 questionnaires were sent out, and 518 valid questionnaires were recovered, with an effective recovery rate of 94.18%. Written informed consent was obtained from all participants in this study. This study was approved by the Ethics Committee of Weifang Medical University.

Measurement

The dependent variable of the study was presence of loneliness. We used one question to measure the loneliness of middle-aged and older adult people during the epidemic. Respondents were asked to answer "Do you feel lonely?" The answer is "yes" and "no," where 1 is "yes" and 0 is "no." We simply defined loneliness as: loneliness is a feeling and experience of subjectively being isolated and estranged from others or society. At the scene of the investigation, the investigator gives a detailed explanation. The independent variables were Internet use ("Do you use the Internet?"; 1 = yes, 0 = no), length of Internet use ("How long do you use the Internet every day?"; 1 = less than 1 h, 2 = 1–3 h, 3 = 3–5 h, 4 = more than 5 h), and content of Internet use. Content of Internet use included contacting relatives and friends, watching the news, watching videos, getting health codes (a QR code used to provide personal health information during the epidemic prevention and control period), searching for health information, online payment, online shopping, playing games, and managing money (27, 32, 35). In addition, we collected the following characteristics of the respondents as control variables: gender (1 = male, 2 = female), age (1 = under 60 years old, 2 = 60 years old and above), marital status (1 = not married, 2 = married), residence (1 = rural, 2 = urban), education level (1 = primary school and below, 2 = junior high school, 3 = senior high school and above), employment status (1 = inactive, 2 = active).

Statistical analysis

SPSS software was used to process the data. Firstly, the basic demographic characteristics and loneliness of the respondents were analyzed descriptively. Secondly, the chi-square test was used to compare the differences of loneliness among people with different characteristics. Thirdly, taking loneliness as the dependent variable, and taking Internet use, Internet use length and Internet use content as the independent variables, the relationship between Internet use and loneliness of middle-aged and older adult people was tested by binary logistic regression model, and the significance level was set as $p < 0.05$. Finally, we used Model 1 of the PROCESS program in SPSS to analyze the moderating effect. In Model 1, presence of loneliness was taken as the dependent variable, Internet use as the independent variable, residence as the moderating variable, and other variables as the control variable, to test the moderating effect of residence on the relationship between Internet use and presence of loneliness.

Results

Socio-economic and demographic characteristics of respondents and presence of loneliness

A total of 518 middle-aged and older adult people were investigated, including 227 males, accounting for 43.8%, and 291 females, accounting for 56.2%. There were 286 people under 60 years old, accounting for a 55.2%, and 232 people over 60 years old, accounting for a 44.8%. There were 450 persons (86.9%), with the status of being married. 408 people (79.2%) live in rural areas. There are 197 people with primary school education and below, accounting for 38.0%, and 191 people with high school education and above, accounting for 36.9%. The employment status was active in respect of 331 persons (63.9%).

Of the 518 middle-aged and older adult people, 240 felt lonely, accounting for 46.3%. The results of the chi-square test are shown in Table 1. The presence of loneliness of the interviewees varied with marital status ($p < 0.05$) and educational level ($p < 0.05$). The proportion of participants who were not married felt lonely was higher than those who were married, and the proportion of participants with primary school education or below felt lonely was higher than those with junior high school education, senior high school education or above.

Internet usage status of respondents

Among the respondents, 302 person use the Internet, accounting for 58.3%, and 216 person do not use the Internet, accounting for 41.7%. Among the middle-aged and older adult people who use the Internet, the majority of them spend 1–3 h online every day, with 146 people, accounting for 40.8%. Most people use the Internet to communicate with relatives and friends, with 212 people, accounting for 19.6%. In addition, our study found that middle-aged and older groups differed in Internet use, duration, and content. The results of the chi-square test showed that the presence of loneliness of respondents varied with Internet use ($p < 0.05$), Internet content ($p < 0.05$), and Internet duration ($p < 0.05$). The proportion of participants who were not use internet felt lonely was higher than those who were used, and the participants who spent less than 1 h online were more likely to felt lonely than those who spent more than 5 h, 3–5 h, and 1–3 h. The proportion of participants who used the Internet for online payments felt lonely was higher than those who used it for other purposes (see Table 1).

The relationship between Internet use and presence of loneliness

We used a logistic regression model to examine the relationship between Internet use and presence of loneliness. Loneliness was the dependent variable (0 = no, 1 = yes), and Internet use was the independent variable, which were included in the logistic regression model. Model 1 in Table 2 reports results without control variables. Model 2 reports results with control variables. As shown in Model 1, middle-aged and older adult people who use the Internet were less

10.3389/fpubh.2024.1284180

TABLE 1 Sociodemographic characteristics and the presence of loneliness among total study group.

Variables	Total *N*	Lonely *N* (%)	Not lonely *N* (%)	χ^2	*p*
Gender					
Male	227	106 (46.7%)	121 (53.3%)	0.022	0.929
Female	291	134 (46.0%)	157 (54.0%)		
Age					
<60	286	127 (44.4%)	159 (55.6%)	0.953	0.332
≥60	232	113 (48.7%)	119 (51.3%)		
Marital status					
Not married	68	42 (61.8%)	26 (38.2%)	7.497	0.009
Married	450	198 (44.0%)	252 (56.0%)		
Residence					
Rural	408	183 (44.9%)	225 (55.1%)	1.909	0.191
City	107	56 (52.3%)	51 (47.7%)		
Education level					
Primary school and below	197	98 (49.7%)	99 (50.3%)	6.190	0.045
Junior middle school	130	48 (36.9%)	82 (63.1%)		
High school and above	191	94 (49.2%)	97 (50.8%)		
Employment status					
Unemployed	187	81 (43.3%)	106 (56.7%)	1.071	0.314
Employed	331	159 (48.0%)	172 (52.0%)		
Internet use					
Yes	302	127 (42.1%)	175 (57.9%)	5.333	0.025
No	216	113 (52.3%)	103 (47.7%)		
Internet duration					
less than 1 h	122	68 (55.7%)	54 (44.3%)	9.664	0.022
1–3 h	146	55 (37.7%)	91 (62.3%)		
3–5 h	62	25 (40.3%)	37 (59.7%)		
More than 5 h	28	14 (50.0%)	14 (50.0%)		
Internet content					
Connect with friends and family	212	84 (39.6%)	128 (60.4%)	23.205	0.006
Watch the news	175	65 (37.1%)	110 (62.9%)		
Watch the video	174	65 (37.4%)	109 (62.6%)		
Get a health code	172	63 (36.6%)	109 (63.4%)		
Search for health information	132	53 (40.2%)	79 (59.8%)		
Online payment	93	46 (49.5%)	47 (50.5%)		
Online shopping	87	37 (42.5%)	50 (57.5%)		
Play games	34	15 (44.1%)	19 (55.9%)		
Assets management	33	11 (33.3%)	22 (66.6%)		

likely to felt lonely (*OR* = 0.661, 95%*CI*:0.465, 0.940). This conclusion is still supported when control variables are included. As shown in Model 2, we found that marital status and employment status may be related to the presence of loneliness in middle-aged and older adult people. Married respondents were less likely to report loneliness (*OR* = 0.455, 95%*CI*:0.263, 0.787), and employed middle-aged and older adult people were more likely to report loneliness (*OR* = 1.585, 95%*CI*:1.034, 2.430). However, when we stratified the middle-aged and older adult samples, we found that the effect of Internet use on loneliness in middle-aged and older adult people was not significant, which we believe may be due to insufficient sample size.

The influence of Internet use duration and content on presence of loneliness

We used a logistic regression model to further examine the relationship between the duration and content of Internet use and

TABLE 2 Effects of Internet use on loneliness.

Variables	Dependent variable: loneliness (0 = no, 1 = yes)		
	Model 1	Model 2	Model 3
	OR (95%*CI*)	*OR* (95%*CI*)	*OR* (95%*CI*)
Internet use (ref = No)	0.661 (0.465, 0.940)**	0.652 (0.465, 0.940)**	0.618 (0.418, 0.913)**
Gender (ref = Male)		0.975 (0.675, 1.408)	0.967 (0.418, 0.913)**
Age (ref = <60)		1.276 (0.818, 1.990)	1.338 (0.857, 2.092)
Marital status (ref = Not married)		0.455 (0.263, 0.787)***	0.453 (0.262, 0.785)***
Education level (ref = Primary school and below)		0.998 (0.774, 1.286)	0.981 (0.760, 1.266)
Employment status (ref = Unemployed)		1.585 (1.034, 2.430)**	1.575 (0.760, 1.266)**
Residence (ref = Rural)		1.539 (0.944, 2.510)	1.934 (1.112, 3.363)**
Internet use × Residence			0.295 (0.098, 0.888)**
Constant	1.097	0.713	1.117
R^2	0.014	0.050	0.063

**$p < 0.05$, ***$p < 0.01$.

TABLE 3 Effects of duration and content of Internet use on loneliness.

变量	Dependent variable: loneliness (0 = no, 1 = yes)					
	Model 4			Model 5		
	OR	95%*CI*	*P*	*OR*	95%*CI*	*p*
Internet usage time (ref = less than 1 h)						
1–3 h	0.464	0.275, 0.784	0.004			
3–5 h	0.484	0.247, 0.946	0.034			
More than 5 h	0.623	0.261, 1.490	0.288			
Internet usage content						
Connect with friends and family				0.488	0.292, 0.818	0.006
Search for health information				1.022	0.567, 1.842	0.942
Watch the news				0.485	0.277, 0.848	0.011
Watch the video				0.615	0.368, 1.026	0.063
Play games				1.976	0.726, 5.380	0.183
Assets management				0.297	0.109, 0.812	0.018
Get a health code				1.117	0.598, 2.087	0.728
Online payment				3.101	1.413, 6.807	0.005
Online shopping				0.699		0.361
Control variable	YES			YES		
Constant	1.662		0.583	1.076		0.938
R^2	0.112			0.187		

loneliness. The presence of loneliness was taken as the dependent variable (0 = no, 1 = yes), the duration of Internet use (model 4) and the content of Internet use (model 5) were taken as the independent variables to be included in the logistic regression model. As shown in Table 3, compared with middle-aged and older adult people who used the Internet for less than 1 h per day, those who used the Internet for 1–3 h (*OR* = 0.464, 95% *CI*: 0.275, 0.784) and 3–5 h (*OR* = 0.484, 95%*CI*: 0.247, 0.946) were less likely to felt lonely. There was no statistically significant effect when the duration of use was more than 5 h. In addition, different contents of Internet use have different effects on middle-aged and older adult people. Using the Internet to contact relatives and friends (*OR* = 0.488, 95%*CI*:0.292, 0.818), read the news (*OR* = 0.485, 95%*CI*:0.277, 0.848), assets management (*OR* = 0.297, 95%*CI*:0.109, 0.818) middle-aged and older adult people were less likely to report loneliness, while those who made online payment (*OR* = 3.101, 95%*CI*:1.413, 6.807) were more likely to report loneliness.

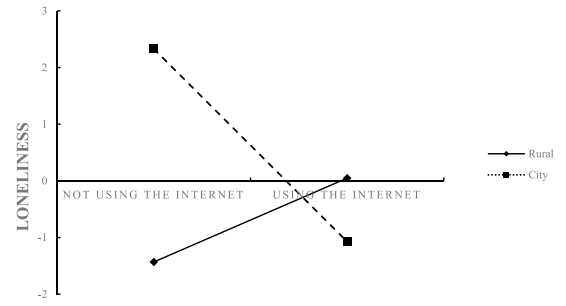


FIGURE 1
Discussion of the moderating role of residence.

Moderating role of place of residence between Internet use and loneliness

We used the presence of loneliness as the dependent variable, Internet use as the independent variable, residence as the moderating variable, and carried out the moderating effect analysis on the basis of controlling other variables. Model 3 in Table 2 showed that the interaction terms of Internet use and residence significantly predicted loneliness ($p < 0.05$, $OR = 0.295$, 95%CI: 0.098, 0.888). A further simple slope test, as shown in Figure 1, showed that Internet use was not a significant predictor of loneliness in middle-aged and older adult people living in rural areas ($p > 0.05$, $OR = 0.815$, 95%CI: 0.536, 1.237), and in urban areas. Internet use was a significant predictor of loneliness among middle-aged and older adult people ($p < 0.05$, $OR = 0.229$, 95% CI: 0.080, 0.655). Internet use had a more significant effect on loneliness among middle-aged and older adult people in urban areas relative to those in rural areas.

Discussion

This study investigated the current situation of Internet use in the middle-aged and older adult people and the impact of whether to use the Internet, the content of use and the duration of use on presence of loneliness. We learned about the Internet use behavior of middle-aged and older adults during the COVID-19 pandemic. The results of the study can further elucidate the relationship between Internet use and presence of loneliness in the middle-aged and older adult people, and provide reference for the development of interventions to improve the well-being of them.

First, in terms of Internet use, 58.3% respondents use the Internet. It is higher than the Internet access rate of the older adult aged 60 and over in China (38.6%) (1). However, compared with young people, the proportion is still low (36). Although the Internet usage rate of middle-aged and older adult people is relatively low, the proportion of middle-aged and older adult Internet users is increasing year by year. With regard to the content of Internet use, consistent with the research of Loipha et al., the needs of the older adult for the Internet are relatively simple, and most of them use it to contact relatives and friends, watch news, watch videos, search for health information, pay online and obtain health codes during the epidemic (37, 38). Studies have shown that older people are interested in the Internet primarily for health reasons and are more likely to search for health information online than other age groups (39, 40). In addition, the number of Internet applications in China has increased steadily, with the most obvious growth in short video, online payment and online shopping, which has also affected the daily life of middle-aged and older adult people to a certain extent (41). With regard to the duration of Internet use, the results of our study showed that most of the older adult use the Internet for less than 3 h a day, which is not much different from the survey results of the 51st Statistical Report on the Development of Internet in China (41), and is lower than that of the older adult in the United States (42).

Second, there is a significant negative correlation between Internet use and loneliness in middle-aged and older adult people, and residence plays a moderating role in the relationship between them. The results of our study showed that middle-aged and older adult people who used the Internet were less likely to report loneliness than those who did not use the Internet, which is consistent with the results of Heo, Xu, Khalaila and others (43–45). In addition, the COVID-19 pandemic has reinforced the role of the Internet in reducing loneliness during social distancing (46). The reasons are as follows. On the one hand, the Internet has the advantages of real-time convenience and convenient interaction, which can break the time and space constraints, so that the older adult can keep close contact with relatives, friends and children (47). This way of communication plays an important role in delaying anxiety, improving the sense of belonging and reducing loneliness (48). On the other hand, the Internet provides an online social environment for the older adult (49), which can establish a harmonious social network relationship by meeting new friends, promote and enhance the social adaptability of the older adult (50). In addition, spending time on the Internet can enrich the leisure activities of the older adult, meet their social needs with the outside world, obtain external information, expand social interaction space, help to improve their life satisfaction (51, 52), and thus regulate individual psychological state (7).

However, residence played a moderating role in the relationship between Internet use and loneliness, and only middle-aged and older adult people in urban areas felt significantly less lonely when using the Internet. On the one hand, the main reason is that the Internet penetration rate, network infrastructure construction and other hardware conditions in rural areas lag behind those in urban areas. The development of the Internet in China's urban areas is faster than that in rural areas. The Internet penetration rate in urban and rural areas is 81.3 and 57.6%, respectively. The scale of Internet users in rural areas still lags behind that in cities, and the middle-aged and older adult people in cities have more convenient access to the Internet. The cost and speed of Internet access may affect the willingness of the older adult people in rural areas to use the Internet (9, 25). On the other hand, due to the long-term impact of China's urban–rural dual structure, rural and urban residents are different in many aspects, including education, income, available resources, interpersonal relationships and living communities (32). Middle-aged and older adult people living in urban communities have a relatively closed living environment, and independent high-rise buildings restrict their social activities. However, community management organizations provide a higher level of public services, and they are more likely to use the Internet to participate in community activities to alleviate loneliness. Compared with cities, villages where rural residents live are more in line with the traditional way of "living in groups" and have close interpersonal communication. And the rural older adult do not have a

fixed retirement age, they are still engaged in agricultural work after the age of 60, enriching their daily activities, the Internet has little impact on their lives, and has not played a role in alleviating loneliness (53).

Thirdly, for the middle-aged and older adult people who use the Internet, there are significant differences in the impact of different Internet use time and content on loneliness. In terms of the duration of Internet use, compared with the older adult who use the Internet for less than 1 h a day, the older adult who use the Internet for 1–3 h and 3–5 h a day have less risk of loneliness, while the duration of Internet use for more than 5 h is not statistically significant. Although there is a negative correlation between Internet use and presence loneliness, overuse may offset its positive effects, reduce communication in real life, increase the sense of isolation between people, and have a negative impact on their mental health (25, 54). In terms of the content of Internet use, different contents have different effects on the loneliness of middle-aged and older adult people. Middle-aged and older adult people who use the Internet to contact with family and friends, read the news and manage money were less likely to report loneliness. This conclusion is consistent with the findings of Jin and Choi, whose research results show that the leisure provided by the Internet enriches people's lives (55), and that social software such as Weixin, Weibo and QQ can improve the level of social interaction, thereby alleviating loneliness (29). In addition, our study also found that middle-aged and older adult people who use the Internet for online payment were more likely to report loneliness. Cham's research showed that most seniors were skeptical about using online payments (56). First, they lack sufficient trust in network security and worry about the leakage of personal information or the loss of personal property. Second, the complexity of Internet technology may make them anxious about technology use. This also confirms the research of Erceg et al., who believe that certain online activities can lead to compulsive use of the Internet, resulting in higher levels of anxiety and loneliness, affecting mental health (57).

The advantage of this study is that it further confirms the negative relationship between Internet use and loneliness in middle-aged and older adult people, explores the role of residence in it, and provides new evidence for the relationship between the length and content of Internet use and loneliness. The study also has some limitations. Firstly, this study used only one self-reported item to measure loneliness. Because the survey time should not be too long during the epidemic period, and the small sample size of the survey limited the length of the questionnaire, we did not design too many questions. In the design of the questionnaire, we refer to a large-scale survey in China, the health status survey data of China's older adult population (CLHLS), to measure loneliness by "do you feel lonely." Which can only explore the relationship between Internet use and the presence of loneliness, but can not measure the degree of loneliness. Moreover, the inclusion of other control variables in the study was limited. In the future, the Likert scale should be used to measure the intensity, duration, and frequency of loneliness in subsequent studies, and include as many control variables as possible, taking into account family characteristics, social support, health status and other factors of middle-aged and older adult people. Secondly, the explanation of the difference in the moderating effect of residence in this study is only an empirical and theoretical inference, and the deeper mechanism behind the phenomenon needs additional special discussion. Third, due to the limitation of data, there may still be some endogenous problems that are difficult to eliminate in the study process. The cross-sectional studies cannot determine causality, so the results presented in this study cannot answer whether Internet use contributes to the key variables of loneliness in middle-aged and older adult people. We will further analyze the relationship between Internet use and loneliness in future studies.

This study revealed that middle-aged and older people who used the Internet were less likely to report loneliness. In addition, different types of Internet use content have different effects on loneliness, and contacting relatives and friends, watching news and managing money were related to lower loneliness, while online payment was related to higher loneliness. At the same time, the longer they used the Internet, the less likely they were to report loneliness, but overuse may have a negative impact. In general，the impact of Internet use on middle-aged and older adult people has two sides. On one hand, Internet use gives possibility to reduce the presence of loneliness and mental-health improvement. On other, there is also a risk of Internet addiction when using the Internet excessively for a long time. Connection between loneliness and Internet addiction could be a direction of the future studies. Therefore, we should continue to pay attention to the relationship between Internet use and loneliness of middle-aged and older adult people. Manufacturers can develop smart products for aging, which are convenient for their daily operation and use, and reduce the barriers for them to use the Internet. Family members should encourage and guide them to actively use the Internet to strengthen social interaction, and pay attention to the time of surfing the Internet. Society should establish a good network environment to protect their safe use of the network and avoid telecommunications fraud, personal information leakage and other incidents.

Data availability statement

The datasets generated and analyzed during the current study are not publicly available as data analysis has not been completed but is available from the corresponding author on reasonable request.

Ethics statement

Written informed consent was obtained from all participants in this study. This study was approved by the Ethics Committee of Weifang Medical University.

Author contributions

QL: Data curation, Investigation, Writing – original draft, Conceptualization, Methodology, Writing – review & editing. ChuY: Conceptualization, Data curation, Writing – review & editing, Investigation, Methodology, Writing – original draft. ZZ: Conceptualization, Data curation, Investigation, Methodology, Writing – original draft, Writing – review & editing. CheY: Data curation, Investigation, Methodology, Writing – original draft, Writing – review & editing. ZC: Conceptualization, Data curation, Investigation, Methodology, Writing – original draft, Writing – review & editing. DH: Conceptualization, Funding acquisition, Methodology, Supervision, Writing – original draft, Writing – review & editing. WY: Conceptualization, Data curation, Funding acquisition, Writing – original draft, Writing – review & editing.

Funding

The author(s) declare financial support was received for the research, authorship, and/or publication of this article. This study was supported by the Graduate Student Research Grant from Weifang Medical University, the Natural Science Foundation of Shandong Province (ZR202110260009), the National Natural Science Foundation of China (72274140) and the Key Research and Development Program of Shandong Province (Soft Science Project) (2022RKY07002).

Acknowledgments

The authors are grateful to all participants for their contributions to this study.

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

All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

References

1. Sun XR, Yan WX, Zhou H, Wang ZQ, Zhang XY, Huang S, et al. Internet use and need for digital health technology among the elderly: a cross-sectional survey in China. *BMC Public Health*. (2020) 20:8. doi: 10.1186/s12889-020-09448-0

2. Yang HL, Zhang S, Zhang SQ, Xie L, Wu YY, Yao YD, et al. Internet use and depressive symptoms among older adults in China. *Front Psych*. (2021) 12:12. doi: 10.3389/fpsyt.2021.739085

3. Dong XB, Meng SJ, Chen DB. How does the internet enhance the subjective well-being of elderly individuals in China? *Front Psychol*. (2022) 13:1036169. doi: 10.3389/fpsyg.2022.1036169

4. Fang EF, Scheibye-Knudsen M, Jahn HJ, Li J, Ling L, Guo H, et al. A research agenda for aging in China in the 21st century. *Ageing Res Rev*. (2015) 24:197–205. doi: 10.1016/j.arr.2015.08.003

5. Deng SL, Li YJ. Research on the coping behavior of middle-aged and elderly people with false health lnformation in the sudden public health situation. *Inf Doc Serv*. (2021) 42:43–51. doi: 10.12154/j.qbzlgz.2021.02.006

6. National Bureau of Statistics. China Population census Yearbook 2020. (2021). Available at: http://www.stats.gov.cn/sj/pcsj/rkpc/7rp/indexch.htm (Accessed November 18, 2023).

7. Lu ZY, Wang H, Liang S. Influence of internet use on loneliness of middle-aged and elderly people. Hubei. *Agric Sci*. (2023) 62:220–226+232. doi: 10.14088/j.cnki.issn0439-8114.2023.02.041

8. Tang D, Zhang K, Qi XR. The lmpacts of lnternet use on social networks and loneliness among older adults: a study based on the purposes of internet use. *Popul Res*. (2022) 46:88–101.

9. Yan N, Xie YT, Hu YQ. Internet use and depression among Chinese older adults: the mediating effect of interpersonal relationship. *Front Public Health*. (2023) 11:1102773. doi: 10.3389/fpubh.2023.1102773

10. Nie P, Sousa-Poza A, Nimrod G. Internet use and subjective well-being in China. *Soc Indic Res*. (2017) 132:489–516. doi: 10.1007/s11205-015-1227-8

11. Silva P, Matos AD, Martinez-Pecino R. Can the internet reduce the loneliness of 50+living alone? *Inf Commun Soc*. (2022) 25:17–33. doi: 10.1080/1369118X.2020.1760917

12. Zhang J, Xu LZ, Li JJ, Sun L, Ding G, Qin WZ, et al. Loneliness and health service utilization among the rural elderly in Shandong, China: a cross-sectional study. *Int J Environ Res Public Health*. (2018) 15:11. doi: 10.3390/ijerph15071468

13. Golden J, Conroy RM, Bruce I, Denihan A, Greene E, Kirby M, et al. Loneliness, social support networks, mood and wellbeing in community-dwelling elderly. *Int J Geriatr Psychiatry*. (2009) 24:694–700. doi: 10.1002/gps.2181

14. Holwerda TJ, Deeg DJ, Beekman AT, van Tilburg TG, Stek ML, Jonker C, et al. Feelings of loneliness, but not social isolation, predict dementia onset: results from the Amsterdam study of the elderly (AMSTEL). *J Neurol Neurosurg Psychiatry*. (2014) 85:135–42. doi: 10.1136/jnnp-2012-302755

15. Igbokwe CC, Ejeh VJ, Agbaje OS, Umoke PIC, Iweama CN, Ozoemena EL. Prevalence of loneliness and association with depressive and anxiety symptoms among retirees in northcentral Nigeria: a cross-sectional study. *BMC Geriatr*. (2020) 20:10. doi: 10.1186/s12877-020-01561-4

16. Perissinotto CM, Stijacic Cenzer I, Covinsky KE. Loneliness in older persons: a predictor of functional decline and death. *Arch Intern Med*. (2012) 172:1078–83. doi: 10.1001/archinternmed.2012.1993

17. Teguo MT, Simo-Tabue N, Stoykova R, Meillon C, Cogne M, Amieva H, et al. Feelings of loneliness and living alone as predictors of mortality in the elderly: the PAQUID study. *Psychosom Med*. (2016) 78:904–9. doi: 10.1097/PSY.0000000000000386

18. Mellor D, Firth L, Moore K. Can the internet improve the well-being of the elderly? *Ageing Int*. (2008) 32:25–42. doi: 10.1007/s12126-008-9006-3

19. Chopik WJ. The benefits of social technology use among older adults are mediated by reduced loneliness. *Cyberpsychol Behav Soc Netw*. (2016) 19:551–6. doi: 10.1089/cyber.2016.0151

20. Gaia A, Sala E, Cerati G. Social networking sites use and life satisfaction. A quantitative study on older people living in Europe. *Eur Soc*. (2020) 23:98–118. doi: 10.1080/14616696.2020.1762910

21. Shillair RJ, Rikard RV, Cotten SR, Tsai HY. *Not so lonely surfers: loneliness, social support, Internet use and life satisfaction in older adults*. In iConference 2015 Proceedings. (2015).

22. Lam S, Jivraj S, Scholes S. Exploring the relationship between internet use and mental health among older adults in England: longitudinal observational study. *J Med Internet Res*. (2020) 22:e15683. doi: 10.2196/15683

23. Wang Y, Zhang H, Feng T, Wang H. Does internet use affect levels of depression among older adults in China? A propensity score matching approach. *BMC Public Health*. (2019) 19:1474. doi: 10.1186/s12889-019-7832-8

24. Cotten SR, Ford G, Ford S, Hale TM. Internet use and depression among older adults. *Comput Hum Behav*. (2012) 28:496–9. doi: 10.1016/j.chb.2011.10.021

25. Jae-Hyun L. Internet, traditional media, and time-use pattern: proposal of a time reallocation hypothesis. *Korean J Journal Commun Stud*. (2005) 49:224–54.

26. Nie NH, Hillygus DS, Erbring L. Internet use, interpersonal relations, and sociability: a time diary study. John Wiley and Sons Ltd. (2002) 213–43. doi: 10.1002/9780470774298.ch7

27. Stepanikova I, Nie NH, He X. Time on the internet at home, loneliness, and life satisfaction: evidence from panel time-diary data. *Comput Hum Behav*. (2010) 26:329–38. doi: 10.1016/j.chb.2009.11.002

28. Cotton SR, Anderson WA, Mccullough BM: The impact of ICT use on loneliness and contact with others among older adults. Gerontechnology. (2012) 11:e39.

29. Choi NG, Dinitto DM. The digital divide among low-income homebound older adults: internet use patterns, eHealth literacy, and attitudes toward computer/internet use. *J Med Internet Res*. (2013) 15:e93. doi: 10.2196/jmir.2645

30. Ma JQ, Sheng L. Internet use time and mental health among rural adolescents in China: a longitudinal study. *J Affect Disord*. (2023) 337:18–26. doi: 10.1016/j.jad.2023.05.054

31. Suris JC, Akre C, Piguet C, Ambresin AE, Zimmermann G, Berchtold A. Is internet use unhealthy? A cross-sectional study of adolescent internet overuse. *Swiss Med Wkly*. (2014) 144:w14061. doi: 10.4414/smw.2014.14061

32. Nie WH, Hu MZ, Ye X. Internet use and rural-urban mental health inequalities: evidence from China. *Front Public Health*. (2023) 11:1107146. doi: 10.3389/fpubh.2023.1107146

33. Xu JY, Zhang QQ. The relationship between internet use and mental health of the elderly: analysis of the differences between urban and rural. *PLoS One*. (2023) 18:e0280318. doi: 10.1371/journal.pone.0280318

34. Haase KR, Cosco T, Kervin L, Riadi I, O'Connell ME. Older adults experiences of technology use for socialization during the COVID-19 pandemic: a random cross-sectional survey. *JMIR Aging*. (2021) 4:e28010. doi: 10.2196/28010

35. Mu A, Yuan SS, Liu ZY. Internet use and depressive symptoms among Chinese older adults: two sides of internet use. *Front Public Health*. (2023) 11:1149872. doi: 10.3389/fpubh.2023.1149872

36. Neves BB, Fonseca JRS, Amaro F, Pasqualotti A. Social capital and internet use in an age-comparative perspective with a focus on later life. *PLoS One*. (2018) 13:27. doi: 10.1371/journal.pone.0192119

37. Loipha S. Thai elderly behavior of internet use. *Procedia Soc Behav Sci*. (2014) 147:104–10. doi: 10.1016/j.sbspro.2014.07.125

38. Jia Z, Pei-Luen P, Rau G. Salvendy: older adults' use of smart phones: an investigation of the factors influencing the acceptance of new functions. *Behav Inform Technol*. (2013) 33:552–60. doi: 10.1080/0144929X.2013.780637

39. Salovaara A, Lehmuskallio A, Hedman L, Valkonen P, Näsänen J. Information technologies and transitions in the lives of 55–65-year-olds: the case of colliding life interests. *Int J Hum Comput Stud*. (2010) 68:803–21. doi: 10.1016/j.ijhcs.2010.06.007

40. Zhu SB, Deng XZ. Study on influence factors of older Adults' online health information seeking Library and Information Service (2015) 59: 60–67+93. doi: 10.13266/j.issn.0252-3116.2015.05.010

41. China Internet Network Information Center. The 51st Statistical Report on the Development of China's Internet (2023). Available at: https://www.cnnic.net.cn/n4/2023/0303/c88-10757.html (Accessed November 18, 2023).

42. Zheng R, Spears J, Luptak M, Wilby F. Understanding older Adults' perceptions of internet use: an exploratory factor analysis. *Educ Gerontol*. (2015) 41:504–18. doi: 10.1080/03601277.2014.1003495

43. Xu XW, Li ZZ, Gao Q. Does internet use affect the loneliness of the elderly: an empirical study based on CHARLS data. *J Shandong Univ Financ Econ*. (2021) 33:100-108+120.

44. Khalaila R, Vitman-Schorr A. Internet use, social networks, loneliness, and quality of life among adults aged 50 and older: mediating and moderating effects. *Qual Life Res*. (2018) 27:479–89. doi: 10.1007/s11136-017-1749-4

45. Heo J, Chun S, Lee S, Lee KH, Kim J. Internet use and well-being in older adults. *Cyberpsychol Behav Soc Netw*. (2015) 18:268–72. doi: 10.1089/cyber.2014.0549

46. Hajek A, Konig HH. Social isolation and loneliness of older adults in times of the COVID-19 pandemic: can use of online social media sites and video chats assist in mitigating social isolation and loneliness? *Gerontology*. (2021) 67:121–4. doi: 10.1159/000512793

47. Yu RP, McCammon RJ, Ellison NB, Langa KM. The relationships that matter: social network site use and social wellbeing among older adults in the United States of America. *Ageing Soc*. (2016) 36:1826–52. doi: 10.1017/S0144686X15000677

48. Hong SI, Hasche L, Bowland S. Structural relationships between social activities and longitudinal trajectories of depression among older adults. *Gerontologist*. (2009) 49:1–11. doi: 10.1093/geront/gnp006

49. Sinclair TJ, Grieve R. Facebook as a source of social connectedness in older adults. *Comput Hum Behav*. (2017) 66:363–9. doi: 10.1016/j.chb.2016.10.003

50. Szabo A, Allen J, Stephens C, Alpass F. Longitudinal analysis of the relationship between purposes of internet use and well-being among older adults. *Gerontologist*. (2019) 59:58–68. doi: 10.1093/geront/gny036

51. Zhou D, Peng L: *The relationship between the gender gap in subjective well-being and leisure activities in China*. Springer Netherlands. (2018), *19*, 2139–2166.

52. Choi S, Lehto XY. Internet use as a leisure pastime: older Adults' subjective well-being and its correlates. *Int J Tour Sci*. (2009) 9:49–72. doi: 10.1080/15980634.2009.11434618

53. Xie L, Yang HL, Lin XY, Ti SM, Wu YY, Zhang S, et al. Does the internet use improve the mental health of Chinese older adults? *Front Public Health*. (2021) 9:673368. doi: 10.3389/fpubh.2021.673368

54. Wu J, Wang YM. The Curent situation and lnfluencing factors of lnternet use of older people in China: an analysis based on data from CGSS (2017). *Sci Res Aging*. (2021) 9:43–58.

55. Jin YA, Liu WL, Zhao MH, Wang DH, Hu WB. Short video APP use and the life of mid-age and older adults: an exploratory study based on a social survey. *Popul Res*. (2021) 45:31–45.

56. Cham TH, Cheah JH, Cheng BL, Lim XJ. I am too old for this! Barriers contributing to the non-adoption of mobile payment. *Int J Bank Mark*. (2022) 40:1017–50. doi: 10.1108/IJBM-06-2021-0283

57. Erceg T, Buljan Flander G, Brezinšćak T. The relationship between compulsive internet use and symptoms of depression and anxiety in adolescence. *Alcohol Psychiatry Res*. (2018) 54:101–12. doi: 10.20471/dec.2018.54.02.02

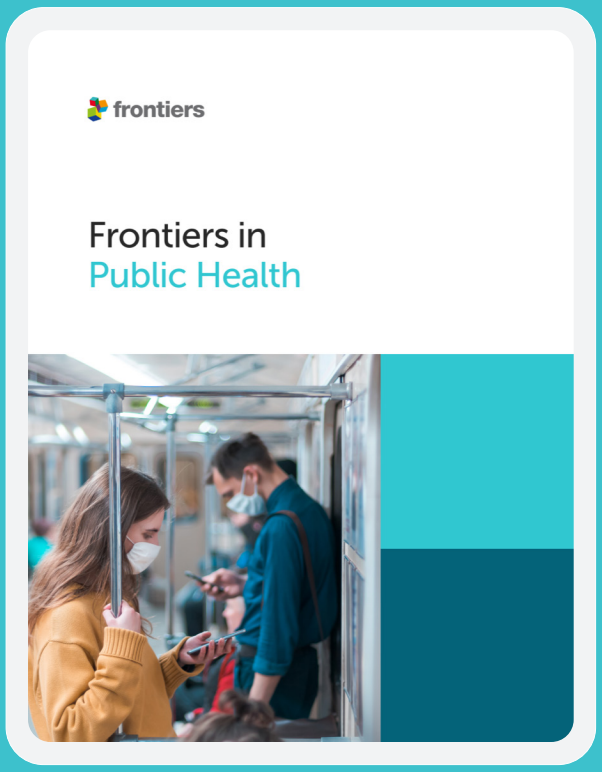
Frontiers in Public Health

Explores and addresses today's fast-moving healthcare challenges

One of the most cited journals in its field, which promotes discussion around inter-sectoral public health challenges spanning health promotion to climate change, transportation, environmental change and even species diversity.

Discover the latest Research Topics

See more →



Frontiers

Avenue du Tribunal-Fédéral 34
1005 Lausanne, Switzerland
frontiersin.org

Contact us

+41 (0)21 510 17 00
frontiersin.org/about/contact