THE OBESITY EPIDEMIC: CAUSES, CONTEXT, PREVENTION

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THE OBESITY EPIDEMIC: CAUSES, CONTEXT, PREVENTION

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Editorial: The obesity epidemic: Causes, context, prevention

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Editorial on the Research Topic
The obesity epidemic: Causes, context, prevention

Introduction

Obesity (body mass index $\geq$ 30 kg/m^2) is a growing public health crisis across the world. The available data suggest that the global burden of obesity has more than tripled since 1975 (1). It is particularly high in some first world countries. However, recent data show that obesity is spreading very fast in low-and middle-income countries (LIMICs), and has reached world record level in some of them (2). At the country level, around 42% of adults in the US are obese, compared to estimates four decades earlier of about 13%. Similarly, in the United Kingdom, prevalence has increased to about 25%. In the LMICs, high obesity is apparent in Brazil, China, Egypt, South Africa, India, Indonesia, Mexico, Pakistan and Russia, while prevalence is more than 75% in countries such as Tonga, Samoa, and Kiribati (3). Obesity forecasts (4) are for continuing growth, with the study (Nianogo and Arah) proposing a micro-simulation model for forecasting cohort obesity.

In racial and ethnic minority sub-groups, such as non-Hispanic blacks in the US, obesity has reached half the adult population. There is also considerable variation between socio-economic groups and geographic areas in the obesity burden: for example, the prevalence of adult obesity varies widely across upper tier local authorities in England, ranging from 11 to 40%.

Obesity is a major cause of premature death, is implicated in recent slowing in improved life expectancy (5), and increases the risk of a range of chronic diseases. There is a seven times greater risk of diabetes in the obese as against those of healthy weight, with a three-fold increase in risk for overweight people (6). Elevated body mass index (BMI) is thought to account for 20% of hypertension and coronary-heart disease (6).

There are many contributing factors to obesity in individual behavior patterns, such as poor food choices and over-eating, sedentary lifestyles, and genetic disposition (with heritability estimates of 40–70%). Adverse trends are apparent in both food consumption patterns and activity levels (7). However, the responsible factors extend far beyond individual behavior (8).

Adverse trends show not only in food consumption and activity levels in higher income countries, but in the geographic diffusion of obesity and overweight. The "nutrition transition" characterizes changing food consumption in low and middle income countries, with many facing a "double burden" of obesity and undernutrition, as well as an upturn in non-communicable disease linked to obesity and overweight (9). For example, the special issue paper by Reddy et al. highlights the nutrition transition and its impacts in South Africa.

Causes: Proximal influences

Excess consumption of less healthy foods and inadequate activity (surplus of energy intake compared to energy expenditure) can be seen as the proximate cause of obesity (8, 10). There is considerable debate around the dietary patterns implicated, whether overall calories intake (the energy balance model) or processed carbohydrates (11, 12).

Distinct dietary pattern subtypes have been identified, such as Western vs. prudent (13). Kopp (14) characterizes the Western diet as containing "large amounts of high-glycemic/high-insulinemic carbohydrate foodstuff like refined cereals, corn, potatoes and sugars (in particular sucrose and fructose), dairy products, as well as high amounts of fat and substantial amounts of protein". In LMICs, urbanization typically is associated with adoption of Western diet, and associated declines in cardiometabolic health (15).

The Global Burden of Disease study tracking trends in food consumption between 1990 and 2017 in 195 countries estimates that one in five deaths globally are associated with poor diet, with diet contributing to obesity and a range of chronic diseases.

Reduced activity levels are the other main immediate driving factor for increased obesity. In line with many studies looking beyond individual behaviors, the review (16) argues that "a systems approach that focuses on populations and the complex interactions among the correlates of physical inactivity, rather than solely a behavioral science approach focusing on individuals, is the way forward to increase physical activity worldwide".

Contextual influences on obesity

The broader distal context to increased obesity is set by policy, and structural "obesogens" of the built, food and social environments. The broader obesogenic context is multifactorial, with the relevance of particular features varying between countries and between subpopulations (17).

Obesity is associated with the emergence of a food industry producing, and marketing (e.g., through advertising), convenient, highly-processed foods. Food advertising content has been linked to growing child obesity (18), and may provide a misleading perspective on nutritional value (19). Food outlets are also increasingly diverse, providing convenience or fast food, with less need for preparing meals at home (20, 21).

A system perspective emphasizes the role of the capitalism in shaping dietary behavior and consumption. Thus, Wells (22) argues that the key to understanding obesity is an "obesogenic niche" caused by the logic of capitalism. Thus, "historically, capitalism contributed to the under-nutrition of many populations through demand for cheap labor. As the limiting factor for economic growth switched to consumption, capitalism has increasingly driven consumer behavior inducing widespread over-nutrition".

The global food system interacts with local environmental characteristics to create wide variation in obesity levels between populations, and in the obesogenic context (17). For example, obesity, especially through reduced activity, has been linked to urban sprawl. This type of residential dispersal to low density suburban settings—especially in North America and Australasia—is linked to reduced walkability, disconnected street networks, and greater reliance on car use (23, 24).

Influence on activity levels is also the relevant mechanism for studies into green space access and obesity (25), and research into obesity and access to exercise opportunities (26). The Australian study (Jayasinghe et al.) exemplifies research into access to physical activity infrastructure using a seven category breakdown based on the work of Lee et al. (27).

By contrast, access to healthy food and hence dietary influences on obesity are paramount in studies of the food environment (28). Food store type and location is one aspect of the food environment: supermarkets, and fruit and vegetable markets, are associated with improved access to healthy food, as opposed to fast-food restaurants or outlets, small groceries and convenience stores.

Obesity context and population sub-groups

US studies find population subgroups (income and ethnic groups) differing considerably in access to healthy food outlets (29), while in the UK there are more fast food outlets in deprived areas than in more affluent areas (30). Food deserts have been designated to describe neighborhoods where poverty, poor public transport, and lack of large supermarkets nearby, limit access to affordable fresh fruit and vegetables (31).

Lesser activity levels have also been reported among females than males (32, 33). For example, the Ethiopian study (Biadgilign et al.) investigates gender differences in physical activity among adolescents.

Obesity prevention

Many interventions to reduce obesity focus on individual behaviors, for example to promote healthy diets (34) or physical activity (35). Most often such interventions involve face-to-face counseling or group therapy combined with recording of dietary intake and physical activity. For example, the study (Yang et al.) considers a longitudinal weight management program in China.

However, advances in technology provide opportunities to deliver eHealth interventions using the web, phone apps and other digital media (36). For example, the systematic review (37) showed that eHealth intervention had potential to effectively promote physical activity in obese adults, while the Research Topic paper (Reddy et al.) mentioned the benefits of eHealth interventions in sub-Saharan contexts as these can reach large populations at low cost.

There is a growing recognition of the importance of population-level interventions and market interventions (38), though the potential for these remains to be fully explored. Thus, the study (39) mentioned that although early child education settings are often an untapped opportunity for supportive nutrition and physical activity changes, while for older children suitable interventions include comprehensive school-based physical activity programs and improved school nutrition environments. Similarly the study (40) estimated that a 20% tax on sugar sweetened drinks would lead to a reduction in the obesity in the UK of 1.3% (around 180,000 people). Studies of the impact of such taxes, where implemented, indicate significant effects on consumption (41).

Often prior consultation with the relevant community will indicate an appropriate design for an intervention. The Saudi study (Almughamisi et al.) is an example of co-identifying actionable priorities for interventions. The importance of the degree of agency in groups targeted by population interventions has also been emphasized (42).

Author contributions

Text written initially by PC. Subsequent amendments by DA included. Both authors contributed to the article and approved the submitted version.

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REVIEW
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Mobile Health Interventions Addressing Childhood and Adolescent Obesity in Sub-Saharan Africa and Europe: Current Landscape and Potential for Future Research

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Child and adolescent overweight is a growing public health problem globally. Europe and low and middle-income (LMIC) countries in Sub-Saharan Africa provide sufficiently suitable populations to learn from with respect to the potential for mobile health (mHealth) interventions in this area of research. The aim of this paper is to identify mHealth interventions on prevention and treatment of childhood and adolescent obesity in Sub-Saharan Africa and Sweden and report on their effects, in order to inform future research in this area. A search of peer-reviewed publications was performed using PubMed, ScienceDirect, EBSCOhost, and Scopus. The search included all articles published up to August 2019. The search strings consisted of MeSH terms related to mHealth, overweight or obesity, children, adolescents or youth and individual countries in Europe and Sub-Saharan Africa. Second, a combination of free-text words; mobile phone, physical activity, exercise, diet, weight, BMI, and healthy eating was also used. Seven studies were reported from Europe and no eligible studies from Sub-Saharan Africa. The results of this narrative review indicate a lack of research in the development and testing of mHealth interventions for childhood and adolescent obesity. There is a need for an evidence base of mHealth interventions that are both relevant and appropriate in order to stem the epidemic of overweight and obesity among children and adolescents in these countries. Uptake of such interventions is likely to be high as there is high penetrance of mobile phone technology amongst adolescents, even within poor communities in Africa.

Keywords: childhood obesity, mHealth, adolescent obesity, Sweden, South Africa

INTRODUCTION

Over the past 20 years overweight and obesity has emerged as a serious nutritional and public health problem worldwide (1). In 2016, 39% of adults aged 18 years and older were overweight and 13% were obese. The overweight and obesity prevalence in 5–19-year olds has increased dramatically from 4% in 1975 to more than 18% in 2016 (2). The United Nations Sustainable Development Goals (SDGs) are recognized as the blueprint to address daily societal challenges, which include poverty, inequality, peace, and issues relating to the environment and sustainable resources. In particular, SDG 2 focuses on ending malnutrition and improving health and nutrition in both children and adults (3). Currently the global overweight prevalence for children under age five is 6.1%. SDG 2 has a target to eliminate childhood overweight and obesity by the year 2030 (4).

The aetiology and pathogenesis of obesity is multi-faceted. The determinants include both non-modifiable and modifiable risk factors such as genetic, gender, metabolic, environmental, socio-cultural, commercial, and psychological factors (5). Modifiable risk behaviours such as unhealthy eating, physical inactivity, tobacco and alcohol use are the result of a complex interplay of various factors. The obesity epidemic, first documented in the USA and many Western countries, is now growing in low- and middle-income countries (LMICs). Low- and middle-income countries have been undergoing a nutrition transition, where there is a shift from traditional diets high in fibre and low in salt, flour, refined oils and sugar; to diets that are high in fats, sugar and refined carbohydrates, and animal products. In addition, irregular, nutritionally unbalanced meals, and aggressive fast food sales and marketing aggravate the problem (6). The global increase in dietary sugars can be partly attributed to high consumption of sugar-sweetened beverages that contribute to the obesity epidemic, especially in LMICs where globalization and trade liberalization influence the availability and pricing of foods (6). Food is perceived not just as providing nutritional satisfaction but also as a health and beauty tool or medication; and changing sociocultural perceptions are spread amongst peers through social media (7). The utilization of foods rich in sugars and fats is also promoted through culture and the traditional perceptions regarding body size. For example, in South Africa and within Black communities, overweight is often seen positively as a sign of affluence and happiness (8). While local tradition emphasizes the desirability of a larger body size, and thinness is associated with HIV and illness, Black women feel pressured as they are subjected to the norms of westernization (9).

Data suggests that the nutrition transition is occurring at an accelerated pace in Sub-Saharan Africa, where there are relatively high rates of tobacco-use and overweight, and low physical activity compared to other LMICs. The speed at which the transition is occurring in SA is particularly striking (10) as are its effects on young people. Specifically, in 2002, 2008, and 2011 the SA Youth Risk Behaviour Survey was conducted, which measured heights and weights for 10,699, 9,648, and 9,617 high school learners, respectively (11). The Youth Risk Behaviour Survey (YRBS) provided evidence of an incoming wave of chronic disease. Over a 9-year period from 2002 to 2011, SA adolescents showed rapid changes in overweight and obesity. Overweight rates doubled from 6.3 to 12.8% in male adolescents; and among female adolescents' overweight rates increased from 24.3 to 32.8%. Obesity more than doubled among male adolescents from 1.6 to 3.6% and doubled from 5 to 10% among female adolescents (11). The YRBS also revealed the presence of over nutrition and undernutrition amongst different children in the same classes.

The dramatic increase in obesity in SA's children and youth is also occurring in other Sub-Saharan African (SSA) countries experiencing similar chronic disease transitions (12–16). Childhood malnutrition in Cameroon is still not recognized as a health concern. Data from a previous Demographic Health Survey (DHS) indicated that between 1991 and 2006 overweight prevalence in children aged 5 years and younger had doubled from 4.7 to 9.6% (17). A study using data of the 4th DHS identified 8% of children as overweight, of which 1.7% were obese (18). In Libya, obesity increases in children with age. National surveys conducted in 2008–2009 revealed that in children 5 years and younger obesity was 16.9%, and in adolescents aged 10–18 years, the prevalence was 6.1%. Further analysis identified a striking 42% prevalence in adolescents aged 10–12 years of age (19–21). Kenya has been struggling with issues of undernutrition and the growing concern of overweight and obesity. According to the DHS conducted, overweight prevalence in children aged 5 years and younger dropped slightly from 5% in 2008–2009 to 4% in 2014. In 2016, overweight in school-aged children and adolescents was recorded at 11.3% (22). Overweight/obesity prevalence in Rwanda in children aged five and younger increased from 7% in the DHS 2010 to 8% in the DHS 2014–2015 (23). A systematic review in 2019 noted that overweight and obesity is on the rise and a matter of concern in several SSA countries, including those mentioned above, in children and adolescents aged 0–18 years (24). As a result of the nutrition transition, over nutrition has begun to replace undernutrition as the primary cause of preventable mortality in several LMICs. This is accompanied by rapid urbanization, which leads to increasingly sedentary lifestyles (11). LMICs are thus currently facing the double burden of under and over nutrition, and the latter may be contributing to overweight and obesity, and associated cardiometabolic disorders, thereby placing greater pressure on their often underdeveloped health systems (9).

This research study arises from a Sweden/South Africa collaboration initiative to build bi-lateral, multi-disciplinary academic relationships that bring together public health and information technology. These two regions provide diverse examples of the growing global obesity problem

Abbreviations: LMICS, low and middle-income; SDGs, sustainable development goals; YRBS, Youth Risk Behaviour Survey; SSA, Sub-Saharan Africa; DHS, Demographic Health Survey; WHO, world health organization; COSI, Childhood Obesity Surveillance Initiative; HBSC, Health Behaviour in the School-aged Children; HIC, high income countries; MINISTOP, Mobile-Based Intervention Intended to Stop Obesity in Preschoolers; ICT, information and communication technology.

that can be collaboratively addressed through innovative technological solutions.

In Sweden, obesity is one of the five main risk factors that contributes to morbidity. According to the WHO, in 2008, of the adult population aged 20 years and older, 53.3% were overweight, while 18.6% were obese. Overweight prevalence was higher in males (60.2%) in comparison to females (46.6%), and obesity prevalence followed a similar trend of being higher in males (19.9%) in comparison to their female counterparts (17.3%) (25). According to a national survey in 2011, in participants aged 16–84 years of age, the overweight and obesity prevalence were 49 and 13%, respectively, where 14% of males and 13% of females were obese (26). Among children in Sweden, overweight and obesity have doubled over the past few decades (27). According to the WHO European Childhood Obesity Surveillance Initiative: 2008 (COSI), in children aged 7 years, 22% of females and 23.5% of males were overweight, while 5.1% of females and 6.8% of males were obese (28). In children aged 8 years, overweight prevalence in females was 23.5 and 26.3% in males, while obesity was 6.8 and 9.7%, respectively (29). The Health Behaviour in the School-aged Children (HBSC) survey, conducted amongst Swedish adolescents in 2009/2010 identified overweight and obesity in 11 year old females at 16% and males at 24% (note 2 of WHO), whilst in the 13 year old group, overweight and obesity was 11% in females and 20% in males. In the 15-year-old group, the prevalence was 8% in females and 20% in males (28). In high-income countries (HICs) such as Sweden, who have already undergone nutrition transitions, with the associated urbanization, economic growth and lifestyle changes, there is now an inverse relationship between wealth and obesity. Sweden appears to be following the global trend of accelerating child obesity, and this requires urgent attention.

It is evident that in order to attenuate the effects of child and adolescent obesity, and to improve the health and well-being of the future generation of adults, strategies must be developed to improve child and adolescent nutrition, physical activity, and tobacco-use behaviours (11). Healthy eating and physical activity are significant positively contributing factors in child development. Establishing and maintaining desirable health promoting behaviours, attitudes, social norms, outcome expectancies and overall health needs to be initiated during this formative period. The breakdown in creating the desire for healthy eating behaviours, facilitated by commercial factors such as advertising of fast foods, has resulted in the current global childhood obesity epidemic. Hence, the weight-gain trend in children and adolescents ultimately results in adult obesity (30). Furthermore, it is also during this growth period that co-morbidities such as high blood pressure, some forms of cancers, diabetes, stroke, and heart disease, as well as mortality and mental illness (30) may appear as short-term health consequences but may well-progress into adulthood (31). There is a need for interventions that address the unique behavioral (dietary, physical activity), psychological (stress, loss of support systems), and environmental determinants (availability/accessibility to fast food) of obesity in children and adolescents in different country contexts. Obesity determinants in children and adolescents differ in HICs and LMIC settings. Determinants identified in Western societies often fail to generalize to the unique and rapidly changing social, cultural, political and economic systems in LMICs, including those in SSA (11). It follows then that the interventions found to be effective in HIC settings may not be as effective in LMIC settings.

Behavioural intervention research on youth obesity prevention has been primarily conducted in the US, UK, Europe, and other high-income countries (HICs) (32–41). These studies found improvements in physical activity and eating behaviours with some corresponding changes in BMI z-scores. In South Africa or other Sub-Saharan African countries experiencing nutrition transitions, on the other hand, there is little-to-no behavioural intervention research addressing youth obesity related behaviours (42). Obesity preventative and treatment interventions that can reach large populations at low cost are required. Electronic mobile technologies such as smartphones and applications (apps) have become an integral part of society. The high usage of smartphones enables mobile health (mHealth) interventions to be viable options for obesity related programmes, including amongst children and adolescents. mHealth interventions can reach a wider audience of users and enable individualized flexibility-of-use and communication, real time data monitoring and feedback and analysis (43). Advancement in communication and digital media technology mean that obesity mHealth programmes can also be used as data collection, assessment, and behaviour self-monitoring tools (44–47).

Sweden had an early focus on adopting and integrating eHealth interventions to improve health care. Digitization is at the heart of health informatics and poses challenges to health care and services and the interaction between health care professionals and patients (48). In the Scandinavian countries, welfare is closely connected to technological development (48). The first national eHealth strategy was presented by the social democratic government in Sweden in as early as 2006 (49). In Sweden, key organizers in the healthcare sector describe the development and deployment of eHealth as a paradigm shift aimed at enabling patients' increased access to information about themselves to improve their health situation by patient empowerment. In the policy document, Vision for eHealth 2025, the Swedish Government together with the Swedish Association of Local Authorities and Regions state that Sweden should be world leading by 2025 in its use of the opportunities offered by eHealth (50). Healthcare in Sweden, including access to electronic records, is largely digitized and integrates mobile health solutions (51).

In 2007, 79.1% of Swedish children aged 7–14 years reported having mobile phone access (52). Today nearly all young people in Sweden use smartphones daily. Among 10-year olds for example, 88% use their own mobile phone (53). Smartphone ownership is fast growing in SSA, where in 2015 it was highest in South Africa, and ranged between 30–35% for Kenya, Nigeria, Senegal and Ghana (54). Young people were the most frequent users. In South Africa smartphone penetration among the general population doubled over the last 2 years and is currently at 81.7% (55). In 2011 72% of SA high school learners reported having their own cell phones, a figure which is likely to have

grown significantly since (11). Young people in urban and rural areas of SA use their mobile phones most of the time for communicating socially as well as to seek information on career advice, entertainment, education and research and health (56).

The mHealth Strategy 2015–2019 of SA envisions a healthy and long life for all South Africans, by including and applying mHealth as an integral component of health care service delivery so that the needs of the health system such as health education, data management and information communication are met (57). Internationally, there has been a considerable amount of investment in mHealth research. However, locally in SA, this is limited due to insufficient funding.

The mHealth arena provides a timely opportunity for HICs such as Sweden, who were early adopters of and are now established users of health technology, to collaboratively develop intervention programmes with LMICs to efficiently address their unique determinants of childhood and adolescent obesity. This type of collaborative intervention research enable technology transfer from an HIC to an LMIC. The primary aim of this paper is to identify existing mHealth interventions on prevention and treatment of childhood and adolescent obesity in Sub-Saharan Africa and Europe, with a specific focus on South Africa and Sweden in order to inform future research in this area.

METHODS

Search Strategy

We searched for peer-reviewed publications using four databases, namely Medline (PubMed), ScienceDirect, EBSCOhost, and Scopus. The search included all articles published up to August 2019. The search strings consisted of Mesh terms related to mHealth, overweight or obesity, children, adolescents or youth and individual countries in Europe or Sub-Saharan Africa. Second, a combination of free-text words; mobile phone, physical activity, exercise, diet, weight, BMI, and eating was also used. **Supplementary Table 1** shows the search strings used. In addition, reference lists of relevant reviews were scanned. Retrieved records were assessed against the selection criteria in three stages—screening of titles, abstracts, and full texts.

Selection

Search results using the MeSH terms were screened for relevance, based on the inclusion criteria.

We included experimental research studies that fulfilled the following criteria:

- Used mobile phones to deliver health education or promotion to children or adolescents
- Targeted weight control, exercise or physical activity, or healthy eating behaviours
- Were administered to either children/adolescents or to their parents in any country in either Europe or Sub-Saharan Africa.

Findings

The search yielded 1951 titles for Sub-Saharan Africa, of which 14 abstracts were screened. The search for Europe yielded 856 titles, of which 71 abstracts were screened. After a careful examination taking into consideration the selection criteria, one study on mHealth interventions for children or adolescent obesity prevention and/or treatment was found for Sweden and there were no eligible studies in Sub-Saharan Africa, with six studies from other European countries (**Figure 1**).

RESULTS

From the seven studies yielded for Europe, six studies looked at adolescents improving their lifestyle through diet and/or physical activity interventions. The PEGASO study was conducted in four sites, namely Spain, Italy, and UK (England, Scotland). The app includes adolescents' preferences, a technology combination that includes an entertainment, advisory, self-monitoring, and social support tool. However, actual data could not be retrieved for this study (58). The remaining studies utilized text messaging to promote healthy behaviors in children aged 8–10 years (59); investigated the impact of web and mobile technologies for type 1 diabetes therapy (60); the use of short message services (SMS) to promote lifestyle behaviors and psychological wee-being in children aged 7–12 years (61); and the use of mHealth to explore healthy eating in ethnic minority first or second year students (62).

The MINISTOP (Mobile-Based Intervention Intended to Stop Obesity in Preschoolers) intervention was the core mHealth intervention used in the Swedish study found (63). MINISTOP is a mHealth programme delivered via a smartphone application to parents of preschool children. It was designed for parents to help their children achieve a healthy weight and body fat, and improve their diets and physical activity. The content areas included healthy and fast food, breakfast, meals sizes and frequencies, snacking, physical activity, and sedentary behaviour. Information and strategies on how to change unhealthy behaviours were provided for each focus area. Parents were asked to record their child's consumption of selected food groups and sedentary time; and graphic feedback and automated comments were provided in response to the information they recorded. The design element included some tailored feedback mechanisms based on information inputs on food consumption and sedentary time. The study used a 2-arm parallel design randomised-controlled-trial and was conducted over 6 months among 313 children and their parents [54% boys, mean age: 4.5 (S.D = 0.1)]. At 6-month follow-up the study found no statistically significant intervention effect for fat mass index (FMI) (the primary outcome). However, there was a significant intervention effect for a mean composite score comprised of diet and physical activity variables and this effect was more pronounced in children with a higher FMI. The study was conducted among general samples of children, that is those with and without higher-fat body compositions, and this is likely to have diluted the effects. Since stopping use of the application, the composite score effect was not maintained at the 12-month follow-up (64). The results of this literature review suggest more room for intervention research on the development and testing of mHealth interventions addressing child and adolescent obesity in Europe and SSA.

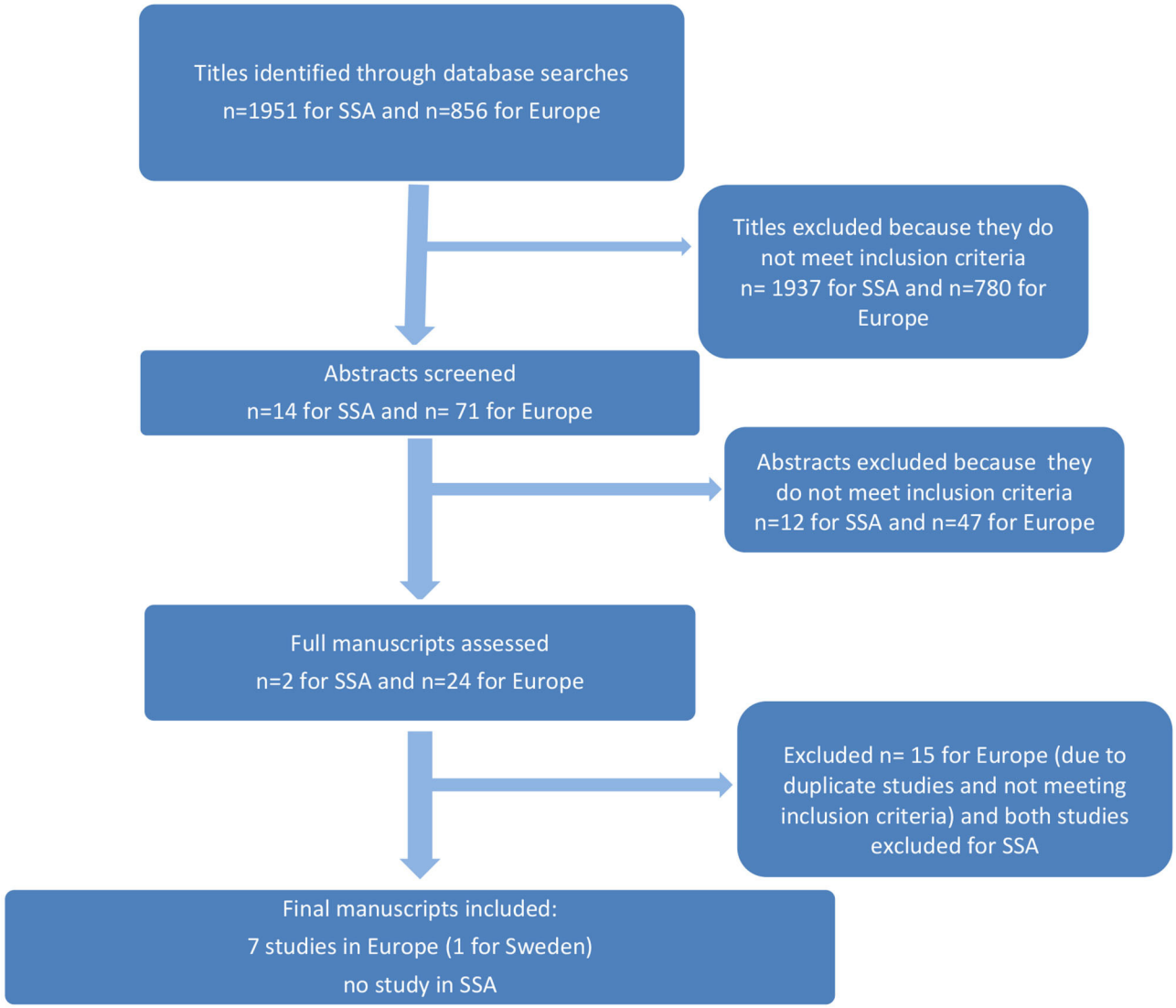

FIGURE 1 | Flowchart of different stages of the review.

In SSA, while there were no studies on adolescents and children, there are some mHealth intervention studies in adults that are designed to promote weight control, physical activity, and healthy eating. These were all, however, administered to people with chronic conditions such as Diabetes (65), hypertension (66, 67), or stroke survivors (68). They were primarily text messaging based including goal-targeted exercise programmes. One study did use mHealth for malnutrition prevention, but the study focused on improving infant and child feeding practices and therefore did not match the criteria outlined (69). There is therefore a need to build mHealth interventions for children and adolescents in SSA that are technologically on par with similar applications in HICs.

IMPLICATIONS FOR SOUTH AFRICA AND SWEDEN

Sweden is an early adopter of eHealth and mHealth technology in general and has valuable expertise in this area. However, regarding mHealth interventions targeting obesity-related behaviours for adolescents and children specifically, this review shows that interventions in Sub-Saharan Africa or in Sweden are rare. Mobile devices are ubiquitous in most regions of the world and provide unprecedented access to test health interventions in the context that obesity is an ever-growing, worldwide health burden. The findings provide an opportunity for Sweden and SA to jointly develop relevant interventions. This paper lays the foundational research

for the broader Sweden-South Africa collaboration study that seeks to develop and test an mHealth intervention aimed at reducing BMI in overweight children aged 10–18 years, that is tailored for use in the South Africa and Swedish contexts.

Creative mHealth applications are able to transform health services in low-, medium- and high-income countries by, among other things, bringing health care to unserved or underserved populations (70). Mobile phones can create entirely new opportunities for health care, especially in countries with shortcomings in infrastructure, expertise and human resources in the health care system (70). Confidence is growing that mHealth solutions can alleviate the problems of health systems caused by under-funding, lack of qualified staff, and inefficient procedures (71).

Cross-country collaborations are likely to be more effective in finding mHealth solutions to the obesity epidemic in young people, and the collaboration will provide an opportunity to enhance digital literacy in SSA. Given the high smartphone use among children and adolescents in Sweden and Sub-Saharan Africa, the area of mHealth interventions is a key focus for the future. Interventions that are multi-sectoral and multidisciplinary in nature have been shown to be more effective in addressing risk behaviours among young people, including behaviours that place young people at risk for obesity. In the developing and testing of mHealth interventions for obesity prevention, the public health sector can improve their health outcomes by bringing in the technical expertise from the information and communication technology (ICT) sector. Additionally, the interventions should be grounded in cognitive social theory and evidence based behavioural change techniques. Determinant studies should be conducted to establish the unique obesity related determinants in different country contexts, and thereby inform tailoring by socio-economic status, culture and political context.

Furthermore, this literature review provides some insights into design implications for a mHealth intervention. Due to the widespread availability and access to mobile devices, any mHealth intervention must be device neutral and able to run on any platform and device, and therefore a progressive web application that can run on any modern device with a web browser and access to the Internet is to be preferred. Additionally, it would be interesting to expand beyond mobile devices and explore the use of wearables, especially fitness trackers and smartwatches, as an extension of an intervention that could even automatically gather real-time, objective, quantitative biological data. Mobile technology affords several features to obesity related mHealth applications, which would enhance usability and uptake in children and adolescents. For example, the MINISTOP study, used a tool, which allowed users to photograph their meals and answer a food-frequency questionnaire, from which the tool calculated energy intake (72).

Two key aspects to discuss regarding the results of this narrative literature review on mHealth interventions to address childhood obesity in Europe, especially Sweden and SSA are why there is such a lack of mHealth interventions and what are the exact affordances that a mHealth intervention offers that more traditional interventions do not. Regarding the lack of research, there are several possible influencing factors such as lack of research funding, technical expertise or political guidance. Though speculative, it is reasonable to envision that mHealth interventions have not taken place or been prioritized because political and research institutions have not encouraged or focused on mHealth interventions for childhood obesity, despite the obvious affordances that mobile devices provide. Regarding affordances, mobile environments are commonplace in both SA and SSA and afford interactivity, real-time data collection and analysis, support multimedia and game-based learning, tailor-made and adaptive solutions, and parental monitoring and tracking. In short, the obvious affordances of an mHealth intervention for childhood obesity directly contradicts the current lack of research and should sound an alarm for more research in the intersection of mHealth and childhood obesity.

Therefore, it would be beneficial to develop and test mHealth interventions in SA and Sweden that are administered to children and adolescents and involve their parents. However, within a health systems approach, obesity prevention and treatment is often a multi-pronged strategy, where parents, children and health care workers interact and work together to help children with, or at risk of, obesity, to achieve desired weight management and behaviour change for improved long-term health. **Figure 2** shows the nexus between obesity prevention and treatment roles, mobile device affordances, and activities between the key stakeholders who are the children, parents, and health workers. Health workers play an important role in monitoring and tracking patients and capturing this information into the health system records. Therefore, a comprehensive mHealth strategy would target children, parents and health care workers involved in youth and paediatric care.

Lessons from previous research in behavioural obesity treatment in children in general has shown that behavioral treatment for obesity should be started at an early age to increase the chance for positive results and childhood obesity treatment should be continued for at least 3 years (38). An early, long-term targeted intervention is key to effect change in obesity (40) and healthy eating habits are a key factor in effecting weight change (39). Design elements of future interventions would be enhanced by including educational and motivational components that are tailored on an individual level. In this way, users can submit information and have interactive interfaces, where they can respond to messages or media and receive automated tailored feedback. For example, interactive game-based learning would be optimal for children. The viability of mHealth interventions is likely to be high in both Sweden and South Africa, as the use of smart phones by adolescents is pervasive even in poor communities. Furthermore, the influence of social peers is strong amongst adolescents; and is often disseminated through social media and mobile phone messaging.

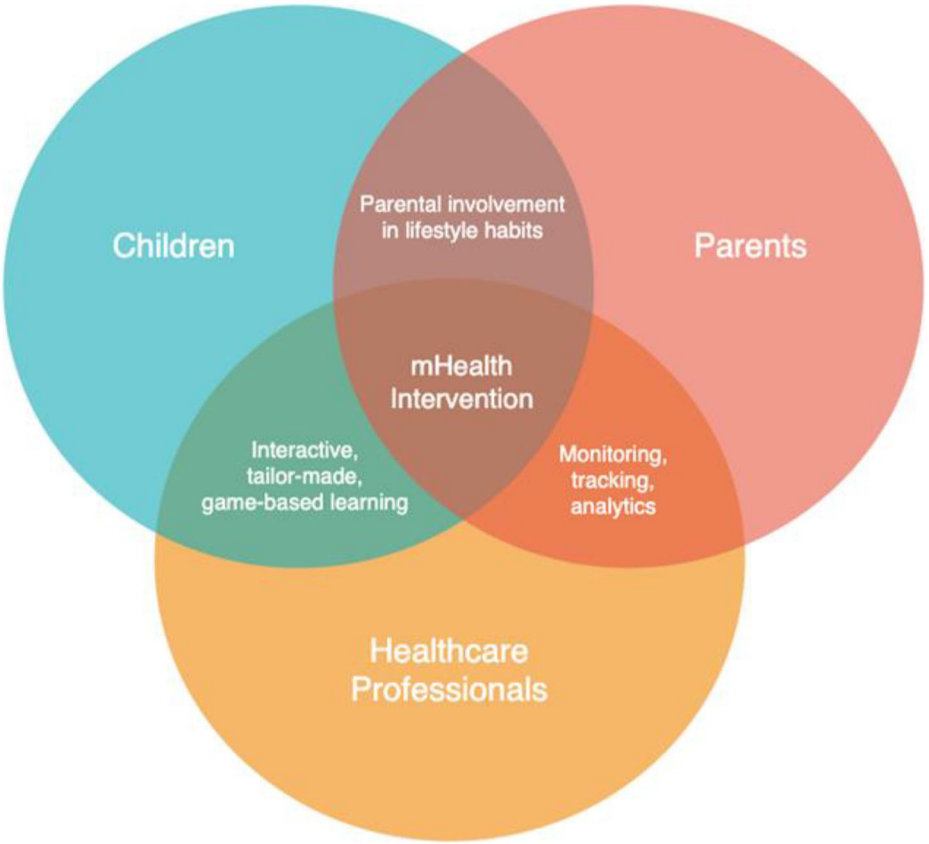

FIGURE 2 | The affordances and key stakeholders of a mHealth intervention.

CONCLUSION

Given the lack of existing mHealth research regarding childhood and adolescent obesity in Europe and SSA, the affordances that mobile devices and wearables can offer for health behaviour change, and the potential for a Sweden-South Africa collaborative study to enhance health technology transfer from HIC to LMIC countries, the paper provides the impetus to develop or adapt an mHealth intervention to address childhood obesity and perform controlled trials to test its efficacy in both Sweden and South Africa. Aside from the direct benefits that successful interventions would bring to these diverse regions, they would also add depth to this relatively young field of global study.

AUTHOR CONTRIBUTIONS

PR devised the project and the main conceptual idea. PR, ND, and RS gathered, reviewed the documents, took the lead in writing the manuscript, and wrote it in consultation with ME, NK, and WJ. PR, ND, and RS revised the first draft of manuscript. All authors proofed the final draft of manuscript.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpubh.2021.604439/full#supplementary-material

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

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Study on Environmental and Lifestyle Factors for the North–South Differential of Cardiovascular Disease in China

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Human death and life span are closely related to the geographical environment and regional lifestyle. These factors considerably vary among counties and regions, leading to the geographical disparity of disease. Quantitative studies on this phenomenon are insufficient. Cerebrovascular and heart diseases are the leading causes of death. The mortality rate of cerebrovascular and heart diseases is statistically higher in northern China than in southern China; the *p*-value of *t*-test for cerebrovascular and heart diseases was 0.047 and 0.000, respectively. The population attribution fraction of 12 major risk factors for cardiovascular disease (CVD) in each province was calculated based on their exposure and relative risk. The results found that residents in northern China consume high sodium-containing food, fewer vegetables, and less sea food products, and tend to be overweight. Fine particulate matter is higher in northern China than in southern China. Cold temperatures also cause a greater number of deaths than hot temperatures. All these factors have resulted in a higher CVD mortality rate in northern China. The attributive differential for sodium, vegetable, fruit, smoking, $PM_{2.5}$, omega-3, obesity, low temperature, and high temperature of heart disease between the two parts of China is 9.1, 0.7, −2.5, 0.1, 1.4, 1.3, 2.0, 4.7, and −2.1%, respectively. Furthermore, the attributive differential for the above factors of cerebrovascular disease between the two parts of China is 8.7, 0.0, −5.2, 0.1, 1.0, 0.0, 2.4, 4.7, and −2.1%. Diet high in sodium is the leading cause of the north–south differential in CVD, resulting in 0.71 less years of life expectancy in northern compared with that in southern China.

Keywords: mortality rate, Northern China, Southern China, environmental factors, life style factors, cardiovascular disease

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INTRODUCTION

Cardiovascular disease (CVD), tumors, and respiratory diseases are the three leading causes of death in China in both the rural and urban populations, jointly accounting for ∼80% of all-cause mortality (1). The risk factors of diseases can be divided into two categories.

The first category includes geographical and environmental factors, which include temperature, air quality, air pollution, and elevation. Several studies have shown that extreme temperatures have a significant impact on mortality (2, 3). An excess of deaths is observed during both winter and summer (4–7). Typically, a *U*-shaped relationship between temperature and death is observed with

mortality risk decreasing from the lowest temperature to an inflection point and then increasing with higher temperatures (8). Studies have also found that extremely cold temperatures can affect deaths occurring not only on that same day but also on several subsequent days, a phenomenon called delayed effects (9). Outdoor and indoor air pollution are leading risk factors for disease burden (10, 11), and $PM_{2.5}$, NOx, SO_2, and O_3 can induce CVD and respiratory disease (12–18).

The second factor includes lifestyle issues, which include sodium intake, vegetable and fruit intake, smoking and second-hand smoke exposure, alcohol usage, physical activity, lack of sleep, obesity, and mental status. Physical activity is an effective way to reduce the risk of stroke and heart disease (19). Some studies have demonstrated that moderately intense physical activities will decrease the risk of CVD by 14% [hazard ratio (HR) = 0.86; 95% CI, 0.80–0.93] (20). High dietary sodium intake is the primary dietary risk factor globally, and it is the main cause of hypertension and CVD especially in Eastern Asia and China (21, 22). There is a strong positive correlation between obesity and ischemic stroke, with the risk of ischemic stroke increasing by 30% (HR, 1.30; 95% CI, 1.28–1.33) for every 5 kg/m^2 increase in body mass index (23). Smoking is associated with 1.3 million cardiovascular events and accounts for approximately one-third of the male CVD burden in China in 2011 (24). Lack of vegetables and fruit is also an important risk factor for disease with the risk of hypertension decreasing with an increase in daily vegetable intake (25).

Mainland China has 31 provinces with the north–south boundary of China being Qingling Mountain and the Huai River. This results in southern and northern China each containing 15 provinces, excluding Tibet in either northern or southern China. Although Tibet is geographically located in the south, the average elevation is over 4,500 m, and its temperature, atmospheric pressure, and oxygen content are far lower than those of other provinces, and it is known as the third pole of the Earth. **Figure 1** shows the provinces of northern and southern China.

The land of China, as one of the biggest countries in the world, covers a range of 4,000 km from the north to the south, with varying environmental and lifestyle factors. Although the factors noted above have important effects on disease and health, the geographic distribution of each factor and its attribution to the north–south differential within China is obscure. To address these conundrums, this study collected age-standardized mortality rates for all-cause, CVD, tumors, and respiratory diseases data in each province. Statistical tests were used to determine the significant difference of the above diseases between northern and southern China. The leading risk factors for the diseases in each province were collected, and their attributable risk proportion, the standardized mortality rate, and reduced life expectancy were calculated.

DATA AND METHODOLOGY

Data

Data of Four Major Fatal Diseases

To study the underlying differences in mortality between northern and southern China, the mortality rate of major fatal diseases in China from 2008 to 2017 was reviewed. The data is taken from the yearly China Health Statistics Yearbook edited by the National Health Commission of China (1). Of all deaths in rural and urban areas, CVD-related deaths accounted for 45.50 and 43.16%, respectively, followed by tumor-related deaths, 22.92 and 26.06%, and respiratory disease-related deaths, 12.02 and 11.24%, respectively. Overall, the three diseases accounted for 80.44 and 80.46% of all deaths in rural and urban areas, respectively.

Cardiovascular disease can be further categorized into cerebrovascular disease and heart disease. Information on the mortality rates of these four major diseases was collected and mapped using provincial mortality rate data (26–28) (**Figure 2**). In this figure, major tumors include lung, liver, stomach, colon, and rectal cancer. The proportion of each disease and the corresponding total age-standardized mortality rates are summarized in **Figure 3**.

Data Collection and Calculation of Each Risk Factor on CVD

To study why the age-standardized mortality rate for CVD is significantly lower in southern than in northern China, the primary risk factors for CVD in China were reviewed (24). The top lifestyle factors associated with CVD in China include high dietary sodium intake; current smoking; physical inactivity; a diet low in marine omega-3 fatty acids; overweight and obesity; alcohol intake; and a diet low in fruit, fiber, nuts, whole grains, and vegetables. The primary environmental factors are temperature extremes (high and low temperatures) and air pollution (especially $PM_{2.5}$). There are no accurate provincial data on physical inactivity and alcohol intake. Therefore, the following 12 risk factors were studied:

1) Vegetables, nuts, whole grain, fiber, and fruit intake

Data on per-capita vegetable (including vegetables and edible fungi), nuts, whole grain, fiber, and fruit intake from all 31 provinces were obtained from the China Statistical Yearbook (2016, 2017, and 2018, http://www.stats.gov.cn/tjsj/ndsj/) and China Food Composition Tables, Standard Edition (**Figures 5A–E**).

2) Tobacco

Tobacco exposure is one of the primary risk factors for CVD. Investigation of tobacco exposure involves smoking rate, smoking amount, cessation, relapse rate, etc. Data on smoking rates in the same region collected by different institutions over different periods are quite different. Therefore, data on per-capita tobacco sales, rather than smoking rates, were used. Data on tobacco sales were obtained from statistics on the tobacco sales website in China (http://www.yanb2b.com). The calculation method is shown in Equation 1 with the per-capita tobacco sales data for each province shown in **Figure 5F**.

$$T_i = \frac{K_i}{P_i},\ P_i = L_i + M_i \tag{1}$$

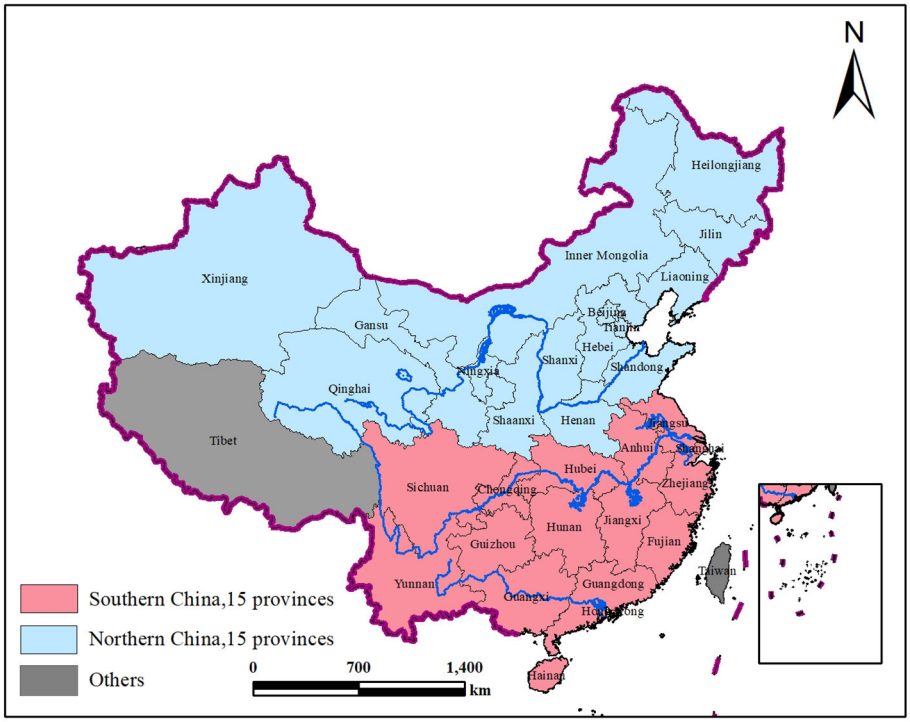

FIGURE 1 | Northern and southern China.

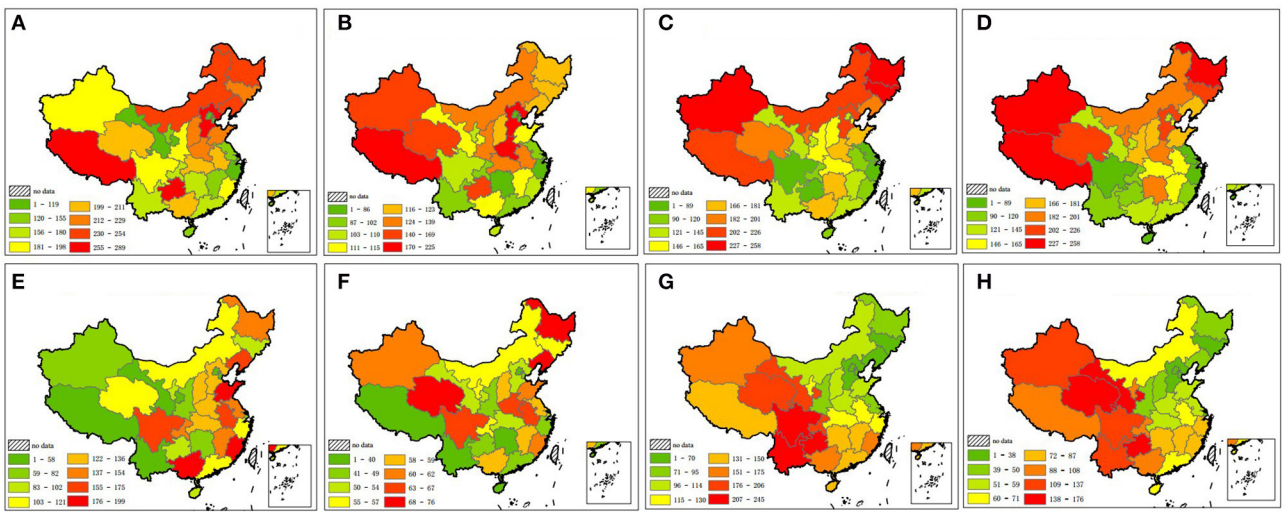

FIGURE 2 | Distribution of age-standardized mortality rates of four major fatal diseases. Warmer colors indicate a higher mortality rate. **(A)** Cerebrovascular disease in male. **(B)** Cerebrovascular disease in female. **(C)** Heart disease in male. **(D)** Heart disease in female. **(E)** Major tumors in male. **(F)** Major tumors in female. **(G)** Respiratory disease in male. **(H)** Respiratory disease in female.

Equation 1: T_i, per-capita tobacco sales for each province; K_i, tobacco sales for each province; P_i, total population of each province; L_i, permanent residents of each province; M_i, floating population of each province.

3) Sodium intake

Data on regional salt intake varied among different studies. The data for each province in different studies (29, 30) were averaged, and the results are illustrated in **Figure 5G**.

4) $PM_{2.5}$

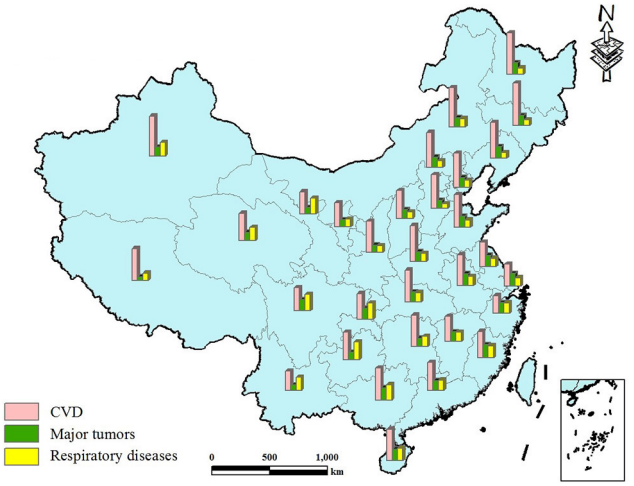

FIGURE 3 | Each disease's percentage of total age-standardized mortality rate.

Data on $PM_{2.5}$ are from the national urban air quality real-time publishing platform (http://106.37.208.233:20035/) owned by China's Environmental Monitoring Center. The daily $PM_{2.5}$ data from 1,619 stations located in 31 provinces from May 13, 2014, to December 31, 2019, were collected. The distribution of the 1,619 $PM_{2.5}$ monitoring stations is noted in **Figure 4** (right). The inverse distance-weighted method was used to produce the $PM_{2.5}$ concentration grid graph of China (resolution, 1 × 1 km). The average $PM_{2.5}$ data of the monitoring stations in each province cannot accurately represent the $PM_{2.5}$ of several residential areas because many provinces comprise both flat and steep mountainous areas with a population density higher in the flat areas. Therefore, a 1 × 1 km population density grid map (http://www.resdc.cn) was collected, and a population density-weighted average $PM_{2.5}$ (PDP) for each province was calculated. Areas with greater populations were given greater weights in the average $PM_{2.5}$ calculation, which can be expressed as follows:

$$PDP_i = \frac{\sum_{i=1}^{n} (PO_i \times PM_i)}{\sum_{i=1}^{n} PO_i} \quad (2)$$

Equation 2: n, number of grids for each province; PO_i, population of grid i (1 km ×1 km); PM_i, $PM_{2.5}$ of grid i (1 km ×1 km)

The PDP map was created based on Equation (2), and the results are illustrated in **Figure 5H**.

5) Seafood intake

Data on seafood intake are from the China Statistical Yearbook (http://www.stats.gov.cn/tjsj/ndsj/) and China Fisheries Statistical Yearbook (2016–2018). The average annual seafood intake of each province from 2016 to 2018 was collected, and the per-capita seafood intake is shown in **Figure 5I**.

6) Obesity and overweight rate:

Data on obesity and overweight rates are from the Chinese Center for Disease Control and Prevention (31) and represent the data collected in 2013 (**Figure 5J**).

7) Low and high temperatures

Temperature data are from the China Meteorological Data Network (http://data.cma.cn). Daily temperature data from 756 temperature-monitoring stations across the country in 2000 and 2010 were collected. The geographical distribution of national temperature monitoring stations is shown in **Figure 4** (left). By calculating average data for the same day at each provincial station, the daily average temperature for each province was obtained. Relevant studies have shown that an average daily temperature of >26 or <10°C will lead to an increase in death and CVD (32). The risk increases with temperatures of >26 or <10°C. Based on the monitoring data from each station, we calculated the yearly number of days for each temperature range (26–27, 27–28, 28–29, 29–30, 30–31, >31, 5–9, 0–4, −5 to −1, −10 to −6, −15 to −11, <-15) for each province (**Figures 5K,L**).

Methods

Statistical Methods

The normal distribution and statistically significant difference between the two parts of China for each disease were studied using normal distribution tests (method: Shapiro–Wilk test) and t-test. All statistical analyses were performed using SPSS 25, and the statistical significance was set at $p < 0.05$, $p < 0.01$, and $p < 0.001$, respectively.

Calculation of Each Disease's Proportion to the North–South Difference in Mortality Rate

To evaluate correlations among the four major diseases and the north–south difference in mortality rate, **Equation 3** was developed.

$$P_i = (M_i^{North} - M_i^{South})/(M_t^{North} - M_t^{South}) \quad (3)$$

P_i indicates the proportion of disease i to the north–south division; M indicates the age-standardized mortality rate; t indicates the total mortality rate of the four diseases; $P_i > 0$ indicates that the disease is positively related to the north–south division.

Attribution of Each Factor to Provincial CVD

To quantitatively assess the attribution of the 12 risk factors on provincial CVD mortality, the estimation of attributable disease burden according to the theory and methodology in the Global Burden of Disease (GBD) was calculated (33). In GBD, the estimation of disease burden attributed to the various risk factors is conducted under the framework of comparative risk assessment theory. The core content of this theory is that when the exposure level of other independent risk factors remains unchanged, the proportion of disease burden attributed to a particular risk factor, the population attribution fraction (PAF), is calculated by comparing the exposure distribution of that factor with the theoretical minimum risk exposure distribution. The

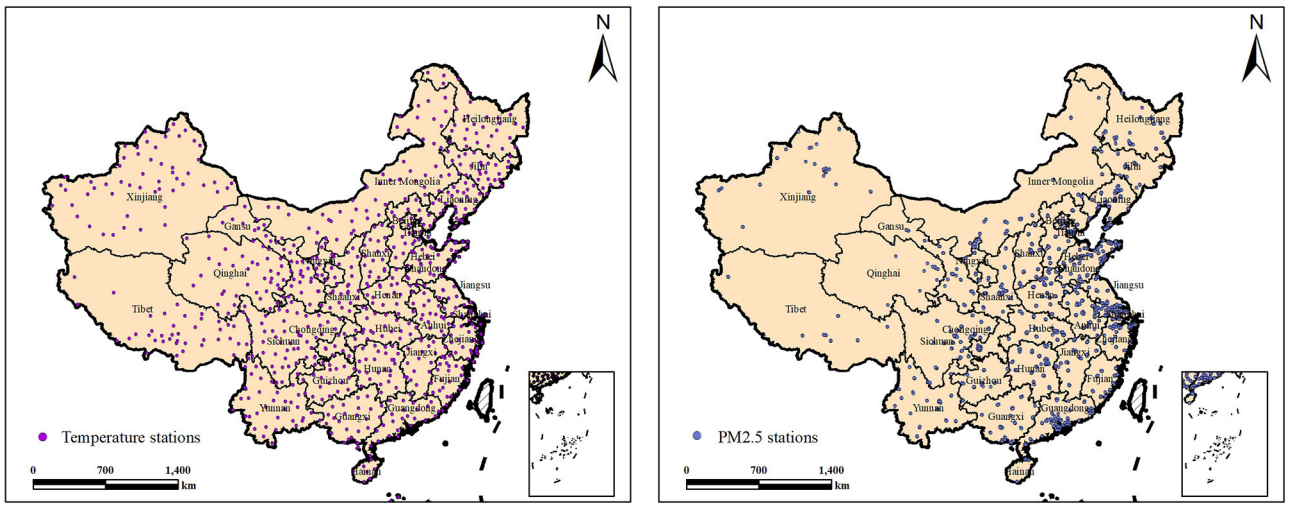

FIGURE 4 | Location of temperature and $PM_{2.5}$ monitoring stations.

formula for PAF is shown in Equation 4, and the attributed death and mortality rate is calculated in Equation 5.

$$PAF = \frac{\sum_{i=1}^{n} P_i(RR_i - 1)}{\sum_{i=1}^{n} P_i(RR_i - 1) + 1} \tag{4}$$

RR_i, relative risk at exposure level I; P_i, proportion of population at exposure level I; the RR and its 95% CI for each risk factor are from the GBD 2017 (http://ghdx.healthdata.org/gbd-2017).

$$AM = PAF \times M \tag{5}$$

AM, attributed number of deaths to a risk factor; M number of deaths for each CVD.

Calculation of the 12 risk factors can be divided into two categories. First, the attributable risk proportion of $PM_{2.5}$; obesity; smoking; a diet low in vegetable, fruit, omega-3 fatty acids, nuts, fiber, and whole grain content; and a diet high in sodium intake are calculated using Equations 4, 5. The per-capita omega-3 fatty acid intake of each province was calculated based on the provincial seafood intake and average omega-3 fatty content of various seafood products in China.

The second is the determination of the risk of high and low temperatures. Temperature is an important risk factor for CVD. Numerous studies have shown that both a high- and low-temperature environment will increase the incidence of CVD and mortality. Temperature has a lagging effect on CVD. High-temperature effects appear to last for several days, whereas low-temperature effects may persist for up to several weeks (34). The RR of annual high and low temperatures for each province was based on the number of lag days for each high and low temperature (Equation 6).

$$RR_k^{one\ year} = 1 + \sum \left(\frac{\sum_{i=1}^{n} RR_k^i - n}{365} \times d_k\right) \tag{6}$$

k, average temperature per day; low temperature $k \in (-25C, 9C)$; at high temperature $k \in (26C, 33C)$; n lag days that RR and its 95% CI are both >1; RR_i, relative risk of temperature k at day i of lag; $i \in (0, 30)$; d_k, number of days in a year that average temperature = k.

RESULTS

Difference in Mortality Rate Between Northern and Southern China

The provincial data of diseases correspond to normal distribution. **Table 1** presents the comparison of differences in mortality rates between northern and southern China.

Table 1 shows that cerebrovascular and heart diseases present a statistically significant difference between northern and southern China (cerebrovascular disease, $P < 0.05$; heart disease, $P < 0.001$), with the mortality rate of cerebrovascular and heart diseases higher in northern China than in southern China (northern China: 338.3/100,000; southern China: 254.6/100,000), and the significance of heart disease higher than that of cerebrovascular disease. Although major tumors and respiratory diseases are lower in northern China than in southern China and all-cause mortality rates are higher in northern China than in southern China, there is no obvious north–south difference in the distribution of major tumors ($P = 0.458$), respiratory diseases ($P = 0.057$), and all-cause mortality rates ($P = 0.336$).

Table 2 presents the proportion of major diseases and the corresponding north–south difference in all-cause mortality rate.

In **Table 2**, P_i (calculated by **Equation 3**) of cerebrovascular and heart diseases of >0 indicates that the diseases are positively

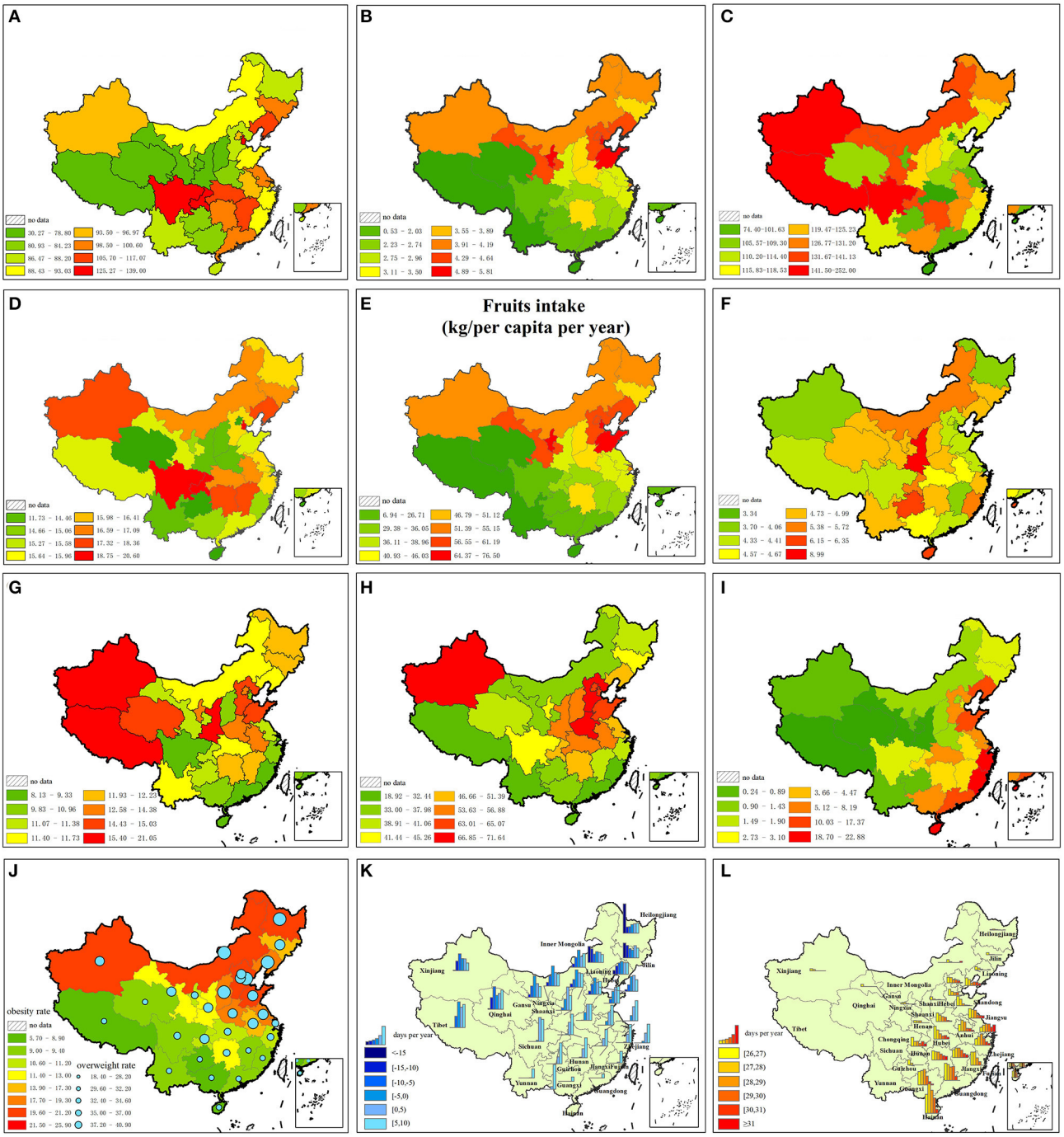

FIGURE 5 | Risk factors for CVD. **(A)** Diet low in vegetables. **(B)** Diet low in nuts and seeds. **(C)** Diet low in whole grains. **(D)** Diet low in fibre. **(E)** Diet low in fruits. **(F)** Smoking. **(G)** Diet high in sodium. **(H)** PM2.5. **(I)** Diet low in seafood omega-3 fatty acids. **(J)** Obesity. **(K)** Low temperature. **(L)** High temperature.

related to the north–south division. P_i of heart disease (167% for male and 90% for female), which is higher than that of cerebrovascular disease (73% for male and 35% for female), indicates that the proportion of heart disease is higher than that of cerebrovascular disease. P_i of respiratory diseases of <0 indicates that the disease is negatively related to the north–south division.

Differences in Mortality Rate Based on 12 Risk Factors of CVD Between Northern and Southern China

The standardized CVD mortality rate of the 12 risk factors for each province is illustrated in **Figure 6**. The average value of attributable risk proportion in 15 northern and 15 southern

TABLE 1 | Age-standardized mortality rates (1/100,000) and *t*-tests of major diseases between northern and southern China.

	Index	Sample size	Position	Cerebrovascular disease	Heart disease	Major tumors	Respiratory diseases	All causes
Age-standardized mortality	Average value (STD)	15	North	168.0 (29.6)	170.3 (29.3)	94.1 (14.1)	85.7 (43.0)	573.7 (84.9)
		15	South	143.6 (31.5)	111.0 (30.4)	98.2 (15.5)	117.0 (43.5)	539.9 (78.1)
t-tests		*T*-value		2.190	5.437	−0.753	−1.983	0.979
		P-value		0.037*	0.000***	0.458	0.057	0.336

STD, standard deviation.
**Significant at $p < 0.05$ level.*
***significant at $p < 0.01$ level.*
****significant at $p < 0.001$ level.*

TABLE 2 | Age-standardized mortality rates with leading causes of death and their proportion on north–south differences in all-cause mortality rate in 2013.

	Age-standardized mortality rate (1/100,000)					Proportion to north–south difference (P_i)			
	CV	HD	RD	MT	Total	CV	HD	RD	MT
Males, north	199.84	196.6	99.18	130.4	626.02	73%	167%	−111%	−29%
Males, south	170.88	129.9	143.4	142	586.18				
Females, north	136.15	144	72.2	57.91	410.26	35%	90%	−32%	7%
Females, south	116.3	92.2	90.68	53.6	352.78				

CV, cerebrovascular disease; HD, heart disease; RD, respiratory diseases; MT, major tumors.

provinces is illustrated in **Tables 3**, **4**. The reduction in life expectancy caused by each risk factor for CVD is illustrated in **Table 5**.

Residents in northern China consume more sodium (2.32 g/per capita per day higher than southern China), more fruits (16.07 kg/ per capita per year higher than southern China), fewer vegetables (12.04 kg/ per capita per year lower than in southern China), and less seafood products (5.86 kg/ per capita per year lower than in southern China), and tend to be overweight (7.52% higher than in southern China). $PM_{2.5}$ is higher in northern China than in southern China (13.16 $\mu g/m^3$ higher than in southern China). Diet low in nuts and seeds, whole grains, and fiber is not related to CVD in China because the provincial intake is higher than the minimum safety value (**Figure 6**, **Tables 3**–**5**). Attributable risk proportion of sodium, vegetable, $PM_{2.5}$, omega-3, obesity, and low temperature is higher in northern China than in southern China, whereas that of fruit and high temperature is lower in northern China than in southern China. Smoking is approximately balanced between northern and southern China; the differential of attributable fraction is 0.1 for both heart disease and cerebrovascular disease. Sodium is the leading cause of north–south differential for CVD; the differential of attributable fraction is 9.1% for heart disease and 8.7% for cerebrovascular disease. The total attributive differential for the 12 risk factors for heart disease (14.7%) between northern and southern China is higher than that of cerebrovascular disease (9.6%), which is in accordance with the result of *t*-tests.

DISCUSSION

The distribution of cerebrovascular disease ($P = 0.037$) and heart disease ($P = 0.000$) was positively related to the north–south differential for age-standardized mortality rates because mortality owing to cerebrovascular and heart diseases is higher in northern China than in southern China. Except for cerebrovascular and heart diseases, the sum of all other causes for mortality was higher in southern China (285.3/100,000) than in northern China (235.4/100,000). Therefore, the difference in CVD mortality rate is the fundamental reason for the difference in mortality rate between northern and southern China.

The mortality rate from CVD is generally lower in southern China than in northern China, which is consistent with the findings of other studies. Gelin et al. (35) found that nine provinces in northern China, Heilongjiang, Jilin, Liaoning, Inner Mongolia, Hebei, Beijing, Ningxia, Tibet, and Xinjiang, have a high incidence of stroke, essentially constituting a stroke belt. The stroke incidence in this zone was 236.2/100,000, which was significantly higher than that in areas outside this zone (109.7/100,000). Similar findings have been noted in other countries where a stagnating decline in CVD mortality was the primary cause of no increase in life expectancy since 2010 (36).

Among the 12 risk factors, exposure to six of the factors is higher in northern China than in southern China. Residents living in northern China have a lower vegetable intake, higher sodium intake, higher $PM_{2.5}$ exposure, lower intake of seafood products, higher obesity and overweight rate, and exposure to lower temperatures than those living in southern China. However, those living in southern China have a higher exposure risk to only lower fruit intake and exposure to higher temperatures. There was no obvious difference between northern and southern China in the exposure risk to tobacco, whole grain, fiber, and nuts.

Salt intake is significantly higher in northern China than in southern China. A diet high in sodium has the greatest impact on blood pressure. A total of 40% of hypertensive incidents are caused by a high salt-containing diet, and hypertension is the

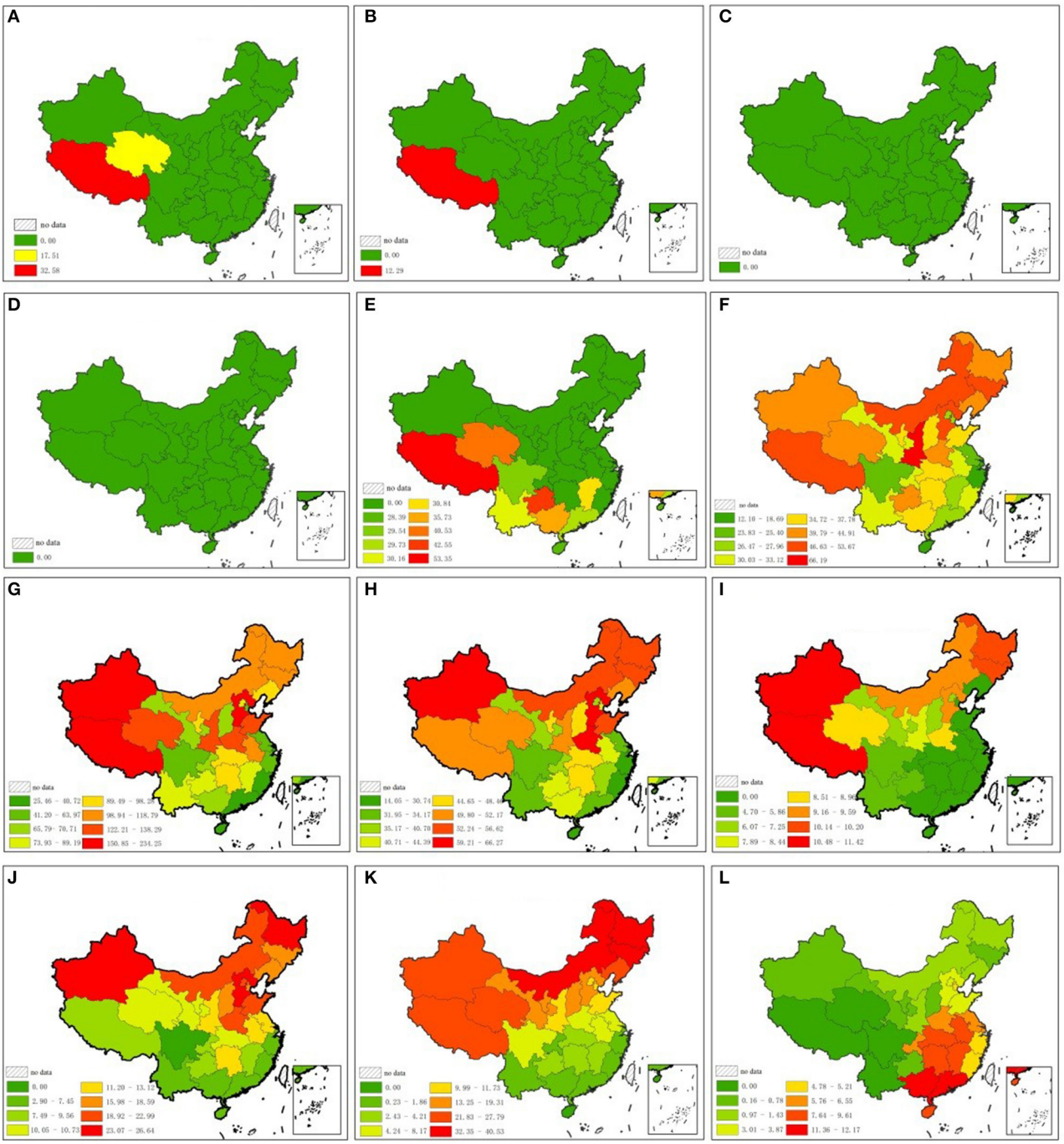

FIGURE 6 | Attributable proportion of 12 risk factors for CVD in each province. **(A)** Vegetables and edible fungi intake (kg/per capita per year). **(B)** Nuts and seeds intake (kg/per capita per year). **(C)** Whole grain intake (kg/per capita per year). **(D)** Fibre intake (kg/per capita per year). **(E)** Fruits intake (kg/per capita per year). **(F)** Tobacco sales (cigarettes/per capita per year). **(G)** Salt intake (g/per capita per year). **(H)** $PM_{2.5}$ ($\mu g/m^3$). **(I)** Seafood intake (kg/per capita per year). **(J)** Obesity and overweight rate. **(K)** Yearly number of days for each low temperature range. **(L)** Yearly number of days for each high temperature range.

primary risk factor for CVD and all-cause mortality in the GBD (33). Sodium exposure is a leading risk factor for CVD in China, which is similar to the results of other studies (21, 22), and sodium exposure is also the leading cause of the north–south differential in CVD mortality rate.

Regions with generally higher $PM_{2.5}$ concentrations are located in northern China, particularly in areas around Beijing. It is the area with the most intensive heavy industry and consumes the greatest quantity of coal. Additionally, China's Huai River Policy (Huai River is 0 centigrade isotherm in January in China)

TABLE 3 | Attributable fraction of risk factors for heart disease in northern and southern China.

	Sodium	Vegetable	Fruit	Smoking	$PM_{2.5}$	Omega-3	Obesity	LT	HT
Northern China (% and 95% CI)	38.1%	0.7%	0.5%	14.7%	18.1%	4.3%	4.7%	5.6%	0.6%
	21.0–70.5%	0.3–1.0%	0.2–0.7%	11.6–20.8%	16.1–20.1%	1.8–7.0%	4.0–7.4%	3.0–8.1%	0.5–0.8%
Southern China (% and 95% CI)	29.0%	0%	3.0%	14.6%	16.7%	3.0%	2.7%	0.9%	2.7%
	15.0–65.8%	0.0–0.0%	1.1–4.5%	11.5–20.6%	14.6–18.7%	1.4–5.4%	2.3–4.4%	0.5–1.3%	2.0–3.3%
Differential	9.1%	0.7%	−2.5%	0.1%	1.4%	1.3%	2.0%	4.7%	−2.1%

LT, low temperature; HT, high temperature.

TABLE 4 | Attributable fraction of risk factors for cerebrovascular disease in northern and southern China.

	Sodium	Vegetable	Fruit	Smoking	$PM_{2.5}$	Omega-3	Obesity	LT	HT
Northern China (% and 95%CI)	34.9%	0.0%	1.0%	9.5%	12.3%	0.0%	5.9%	5.6%	0.6%
	24.0–44.4%	0.0–0.0%	0.6–1.5%	8.9–22.8%	9.6–14.3%	0.0–0.0%	4.2–9.5%	3.1–8.0%	0.5–0.8%
Southern China (% and 95%CI)	26.2%	0.0%	6.2%	9.4%	11.3%	0.0%	3.5%	0.9%	2.7%
	17.4–34.6%	0.0–0.0%	3.5–9.1%	8.7–22.6%	8.9–13.3%	0.0–0.0%	2.5–5.7%	0.5–1.3%	2.0–3.3%
Differential	8.7%	0.0%	−5.2%	0.1%	1.0%	0.0%	2.4%	4.7%	−2.1%

TABLE 5 | Attributable fraction of risk factors for reduced life expectancy caused by CVD (year).

CVD	$PM_{2.5}$	Sodium	LT	HT	Fruit	Vegetable	Obesity	Smoking	Omega-3
Northern China	0.553	1.398	0.118	0.012	0.023	0.017	0.201	0.377	0.078
Southern China	0.384	0.688	0.012	0.038	0.121	0.000	0.078	0.253	0.042

proposed in the 1950's provides free or heavily subsidized coal for indoor heating during winter to regions north of the Huai River but not to those to the south; the rural residents usually use solid fuel for heating. This results in a large amount of particulate matter emission in northern China; it causes more death and reduces life expectancy (37, 38). In the current study, $PM_{2.5}$ is the primary reason for the north–south differential in CVD mortality rate.

The rates of obesity and overweight are significantly higher in northern China than in southern China. The 10 provinces with the highest obesity rates are all located in the north. The result is consistent with those of other studies. Northern residents, including non-Han ethnic groups, have significantly taller and larger body mass than southern residents (39). Studies found that there are six gene frequencies that are different among people from both northern and southern China. A variation in the gene FADS2 is more commonly found in the northern population than in the southern population. This gene helps people metabolize fatty acids, which suggests a diet rich in high animal fat content, affects the dietary differences between northern and southern China, and affects the body shape (40, 41).

Seafood intake is higher in the south than in the north. This is primarily owing to the geographic differences between the two regions. Among the 11 coastal provinces in China, seven are located in the south and only four in the north. Southern China has a longer coastline, vaster and deeper sea area, more fishing grounds, and more abundant fishery resources. This results in the daily consumption of seafood being higher in southern China than in northern China. This study found that there are 23 provinces, Tibet, 13 northern provinces, and 9 southern provinces, with <100 mg/day omega-3 fatty acids intake (the 2017 GBD standard).

Although both intensely hot and cold temperatures will cause an increase in the mortality rate (42), the relationship between the two extremes and death is different. Some studies have reported more cold-related than heat-related deaths (43–45). The effect of cold temperature persists for several days (46, 47), whereas that of high temperature is limited to the day of death or the immediately preceding day (48). Additionally, winter temperature is much lower in northern China than in regions with the same latitude in the world, and the temperature in January in northeastern China is usually as low as −15-−25°C, which is far lower than that in southern China, whereas differential summer temperature between the two parts of China is far less than the winter temperature. This explains the higher number of deaths caused by extreme temperature in northern China than in southern China.

To the best of our knowledge, this was the first study examining the relationship between dietary and environmental factors and death between southern and northern China. These results provide evidence for differences in CVD caused by the geographical environment and lifestyle. The winter in northern China is colder than regions of the same latitude throughout the world. The temperature in January in northeastern and northwestern China is lower than −20°C, although the latitude of most residential areas is <50° N, whereas it is >20°C

in Hainan Island in southern China. These large temperature differences contribute to significantly different lifestyles and eating habits.

There are some limitations to this study. First, because it was difficult to collect all data, not all risk factors affecting mortality were included; i.e., physical inactivity and alcohol intake are important risk factors of CVD, but we did not find accurate data on provincial physical inactivity. Because many types of wine are not only produced by wineries but also brewed by residents themselves, it is very difficult to obtain provincial alcohol consumption data in China. In addition, the alcohol content of different types of wine varies greatly. Hence, only 12 risk factors for CVD were analyzed on a provincial scale. Second, GBD estimates aggregated studies across the world, but these do not necessarily apply to the Chinese population as the risk factor and disease patterns in China may be substantially different from the "global average." Errors are inevitable in estimating the relative risk of China using GBD data. Third, the periods of risk factors are not entirely consistent with each other, which affects the accuracy of the results because the dose of each factor varies over the years. For example, PM2.5 in China decreases year by year, and the 2014–2019 PM2.5 data may exaggerate its attributable risk compared with the 2016–2018 data on diet factors.

CONCLUSION

This study examined the north–south difference in the mortality rate of major diseases. The proportion of heart disease, cerebrovascular disease, major tumors, and respiratory disease on the differential for all-cause mortality rate in northern and southern China was calculated. The results found that the mortality rate of cerebrovascular and heart diseases is statistically higher in northern China than in southern China.

A total of 12 important risk factors for CVD were selected to try to determine reasons for the regional difference in mortality. Based on the relative risk for each factor in GBD 2017, the PAF of each of the 12 factors in each province was calculated, and the age-standardized CVD mortality rate attributed to each factor was obtained.

The results found that the residents of northern China have higher exposure and attributable risk proportion to six risk factors. They eat more sodium, fewer vegetables, and less sea products, and they are likely to be overweight. The $PM_{2.5}$ is higher in northern China than in southern China. Lastly, cold temperatures cause a greater number of deaths than hot temperatures owing to the fact that northern China is colder than regions in the world with the same latitude. All these factors lead to a higher CVD mortality rate in northern China.

DATA AVAILABILITY STATEMENT

Publicly available datasets were analyzed in this study. This data can be found at: http://106.37.208.233:20035, http://www.stats.gov.cn/tjsj/ndsj/, http://data.cma.cn.

AUTHOR CONTRIBUTIONS

MW, YS, JC, and XL collected the data and drew the maps. YH designed ideas of the paper and was a major contributor in writing the manuscript. All authors read and approved the final manuscript.

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

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Impact of an Educational Training Program on the Knowledge, Attitude, and Perceived Barriers of Community Pharmacists Towards Obesity and Overweight Management in Malaysia

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Objective: To evaluate the impact of an educational training program on the knowledge, attitude and perceived barriers of community pharmacists (CPs) towards obesity and overweight management.

Methods: This interventional study, which consisted of an educational training program, was conducted on a single cohort of Malaysian CPs. Thirty CPs attended the educational training program. The educational training program was delivered through didactic lectures, case studies and small group discussions, and consisted of various sessions covering different topics related to weight management. A validated questionnaire was used to assess the impact of the intervention on the CPs' knowledge, attitude, and perceived barriers.

Results: The overall mean knowledge score increased both immediately after (14.93 ± 1.62) and 30 days following the intervention (17.04 ± 2.51), and the increment was statistically significant 30 days following the intervention ($p = 0.001$) compared to both pre-intervention and immediate-post intervention stages. After the intervention, the participants had a more positive attitude towards the provision of weight management service (WMS) in community pharmacies. They had significantly stronger perceptions about the importance of their role to manage overweight and obesity and their professional competence to treat obese patients. In addition, the barrier of not having space in pharmacy to perform proper counselling for weight management and the barrier of not having training sessions in the area of obesity management were perceived to be significantly less important post-intervention.

Conclusion: This study showed the potential positive impact of an educational training program on CPs knowledge, attitudes and perceived barriers towards WMS.

Keywords: weight management, community pharmacist, community pharmacy, obesity, overweight, educational training

INTRODUCTION

Community pharmacy-based weight management service (WMS) is a potential key area through which community pharmacists (CPs) can contribute to the public health agenda, especially amid the background of increasing prevalence of obesity in populations around the world and its burden on society. A systematic review of 10 studies worldwide had demonstrated the effectiveness of pharmacy-based weight management interventions in producing positive outcomes, including clinically significant weight loss (1).

CPs providing WMS would be expected to be well-versed with knowledge regarding various aspects of evidence-based obesity management such as dietary approaches, physical activity recommendations, and pharmacological therapies, as well as associated health risks. However, a lack of knowledge and training related to obesity management or weight reduction counseling have been reported as barriers to pharmacist-led interventions. This was exemplified in a mail survey of Texan CPs where they were only somewhat comfortable with counseling patients on the various aspects of the management of obesity and were neutral in terms of their confidence to achieve positive outcomes as a result of their counseling activities (2). This perception was related to their years in practice in which the longer they were in practice, the more confident they were in achieving positive outcomes without the use of medication (2). In addition, semi-structured interviews with Australian CPs highlighted the lack of proper training in weight management-related issues in terms of dietary approaches, physical activity recommendations, or behavioral therapies (3). Another Australian study that utilized case vignettes to evaluate CPs' weight management recommendations commented that some of their recommendations were not evidence-based (4).

CPs have also expressed their willingness to participate in training and accreditation in order to obtain wider acknowledgment of their professional expertise in WMS (3). In fact, a study that reported perceived lack of knowledge as a barrier also expected an improvement in this perception as well as self-confidence with proper training (2). Perceived training needs in weight management identified by CPs include various aspects such as diet, exercise, behavioral therapy, obesity-related comorbidities, point-of-care testing (measurement of cholesterol, estimation of body fat), consultation skills, and counseling on weight-loss drugs (5).

Educational opportunities in weight management should be offered for CPs, including continuing pharmaceutical education programs and seminars that provide focused training on disease state management strategies in obesity and the administration and interpretation of point-of-care testing and physical assessment. This study aimed to evaluate the impact of an educational training program on the knowledge, attitude, and perceived barriers of CPs toward obesity and overweight management.

METHODS

Study Design

This interventional study, which consisted of an educational training program, was conducted on a single cohort of Malaysian CPs. The invitation to participate in this educational training program was extended through the Malaysian Pharmacists Society (MPS) to all CPs who were currently practicing in Klang Valley, Malaysia. Thirty CPs attended the educational training program.

The one-day educational training program on 18 November 2017 at the MPS headquarters in Puchong, Selangor, lasted for 8 hours. The educational training program was delivered by several experts in weight management, consisting of pharmacists, a nutritionist, and a dietitian. The content and materials for the educational training program were designed based on a training manual for pharmacists for management of obesity and overweight. This manual was developed through collaboration between the Malaysian Academy of Pharmacy and the MPS for a community service program (MyWeight MyHealth). The educational training program was delivered through didactic lectures, case studies and small group discussions, and consisted of various sessions covering different topics related to weight management as follows: (i) overview of overweight and obesity (ii) developing an individualized care plan (iii) dietary approaches and exercises in weight management (iv) behavioral modifications in weight management (v) pharmacotherapy in weight management and (vi) roles of CPs in the management of overweight and obese patients.

Questionnaire Development and Dissemination

A questionnaire was developed for the purpose of this study. Content validation of the questionnaire was done by experts (pharmacists, nutritionists, dietitians). The questionnaire comprised of several sections including (1) sociodemographic and practice characteristics of CPs, (2) knowledge of CPs about obesity and overweight, diet, nutrition, behavioral aspects of obesity and its management, and pharmacotherapy of overweight and obesity, (3) attitudes of CPs towards weight management and weight management training programs, and (4) perceived barriers of CPs regarding weight management.

The knowledge section of the questionnaire was divided into four subsections and consisted of 20 items, for which participants selected either "true" or "false" for each item. Each correct response on the knowledge section was scored '1', while each incorrect response was scored '0'. The mean score for each knowledge subsection and overall mean knowledge score were calculated for all CPs. On the other hand, responses for the attitudes and barriers sections were recorded using a five-point Likert scale, ranging from 1 = strongly disagree to 5 = strongly agree.

The questionnaire was distributed to all CPs who attended the educational training program, and they were requested to complete it at the start of the program. At the end of the educational training program, the CPs were requested to fill

TABLE 1 | Sociodemographic and practice characteristics of community pharmacists ($N = 30$).

Characteristics		Frequency (*n*)	Percentage (%)
Age group (years)	18–24	6	20.0
	25–34	11	36.7
	35–44	3	10.0
	45–54	1	3.3
	55–64	6	20.0
	65 and above	3	10.0
Gender	Male	11	36.7
	Female	19	63.3
Ethnicity	Malay	9	30.0
	Chinese	18	60.0
	Indian	3	10.0
Highest education level	Bachelor of Pharmacy degree	23	76.7
	Master's degree	5	16.7
	Doctorate degree	1	3.3
	Other	1	3.3
Years of experience as a community pharmacist (in years)	<1	5	16.7
	1–5	14	46.7
	6–10	4	13.3
	More than 10	7	23.3
Participants working in a pharmacy that had a proper weight management programme		5	16.7
Participants attending training on weight management for the first time		24	80.0
On an average of a month, number of patients visiting the pharmacy to get treatment/counseling regarding weight management issues	0–1	10	33.3
	2–5	8	26.7
	5–10	8	26.7
	10–15	4	13.3
Type of community pharmacy	Independent pharmacy	13	43.3
	Chain pharmacy	13	43.3
	Other	4	13.3

the same questionnaire again to assess the immediate impact of the educational training program on their knowledge, attitudes, and perceived barriers. After 30 days, the same questionnaire was mailed to the participants again to assess knowledge retention, and changes in attitudes and perceived barriers. The participation of CPs in this study was voluntary with no compensation paid. Written consent was obtained from the participants before dissemination of the questionnaire.

Statistical Analysis

Statistical analysis was performed using SPSS version 18. Descriptive statistics were used to describe the demographic characteristics of the participants. Wilcoxon's Signed-Rank Tests were used to evaluate the impact of interventions, wherever applicable. The significance level for all statistical analyses was set as $P < 0.05$.

RESULTS

Sociodemographic and Practice Characteristics

Table 1 displays the demographic and practice characteristics of the 30 participants. Female participants ($n = 19$, 63.3%) were almost twice the number of male participants ($n = 11$, 36.7%). Those in the age group of 25–34 years constituted the highest number of participants ($n = 11$, 36.7%). In terms of educational level, more than three-quarters of the participants had a Bachelor of Pharmacy degree ($n = 23$, 76.7%) as their highest qualification. Nearly half of the participants had between 1–5 years of experience as a community pharmacist ($n = 14$, 46.7%), and an equal number of participants ($n = 13$, 43.3%) worked in chain pharmacies and independent pharmacies, respectively. Only five participants (16.7%) worked in a pharmacy with a proper weight management program, while 24 participants (80.0%) attended training on weight management for the first

time. Twenty (66.7%) participants had at least two patients visiting their pharmacy in a month to obtain treatment or counseling regarding weight issues.

Impact of the Educational Training Program on Knowledge of Weight Management

Table 2 shows the knowledge scores at pre-, immediate-post-, and 30-days post-intervention stages of the participants. Before the intervention, the overall mean knowledge score was 14.50 ± 2.45. The overall mean knowledge score increased both immediately after (14.93 ± 1.62) and 30 days following the intervention (17.04 ± 2.51). The increment was statistically significant 30 days following the intervention ($P = 0.001$) compared to both pre-intervention and immediate-post intervention stages. The knowledge score for each section increased both immediately after and 30 days following the intervention, except that there was a non-significant decline in knowledge score in the section of "Diet, Nutrition, and Physical Activity" immediately after intervention (from 3.07 ± 2.16 to 2.76 ± 1.17; $P = 0.657$). Besides, statistically significant increments of knowledge scores for all sections of the knowledge test were also achieved 30 days following the intervention compared to both pre-intervention and immediate-post-intervention stages.

Impact of the Educational Training Program on Attitude Towards Weight Management Training and Weight Management Service

Table 3 shows participants' attitudes towards weight management training and WMS before, immediately after, and 30 days after the intervention. Regarding participants' attitudes towards weight management training, there was a significantly stronger level of agreement that only certified pharmacists who have attended such training should be eligible to offer WMS ($P = 0.007$, pre- vs. 30-day post-intervention).

Participants had a significantly stronger level of agreement on the importance of their role to manage overweight and obesity following the intervention ($P = 0.037$, pre- vs. 30-day post-intervention). In addition, participants also had a significantly stronger level of agreement, both immediately and 30-day post-intervention, that they are professionally competent to treat obese patients ($P = 0.013$ and $P = 0.001$ respectively). There was a significantly stronger level of disagreement on the following statements "I think as a pharmacist I should refer overweight/obese patients to other professionals rather than to attempt to treat them" ($P = 0.004$, pre- vs. 30-day post-intervention) and "I think I should only counsel patients who are overweight and obese when the patient requests it" ($P = 0.001$, pre- vs. 30-day post-intervention).

Following the intervention, participants also had stronger agreement on the importance of providing WMS in their pharmacy, such as obesity screening services and provision of anti-obesity drugs ($P = 0.016$ and $P = 0.001$ respectively, pre-vs. 30-day post-intervention). Participants also reported a stronger level of disagreement that they do not prefer to advise

TABLE 2 | Knowledge score of participants.

Sections		Pre-intervention scores[f] Mean (SD)	Immediate post-intervention scores[f] Mean (SD)	*P* value[g]	Pre-intervention scores[f] Mean (SD)	30-day post-intervention scores[f] Mean (SD)	*P* value[g]	Immediate post-intervention scores[f] Mean (SD)	30-day post-intervention scores[f] Mean (SD)	*P* value[g]
Section 1[a]	Overview of Overweight and Obesity	6.40 (0.81)	6.53 (0.63)	0.973	6.40 (0.81)	6.80 (0.50)	**0.040**	6.53 (0.63)	6.80 (0.50)	**0.039**
Section 2[b]	Diet, Nutrition, and Physical Activity	3.07 (2.16)	2.76 (1.17)	0.657	3.07 (2.16)	3.40 (0.91)	**0.018**	2.76 (1.17)	3.40 (0.91)	**0.047**
Section 3[c]	Behavioral Intervention	2.20 (0.55)	2.76 (0.86)	**0.003**	2.20 (0.55)	3.36 (0.95)	**0.001**	2.76 (0.86)	3.36 (0.95)	**0.009**
Section 4[d]	Pharmacotherapy	2.83 (0.75)	2.87 (0.68)	0.843	2.83 (0.75)	3.48 (0.71)	**0.007**	2.87 (0.68)	3.48 (0.71)	**0.014**
Overall[e]		14.50 (2.45)	14.93 (1.62)	0.233	14.50 (2.45)	17.04 (2.51)	**0.001**	14.93 (1.62)	17.04 (2.51)	**0.001**

SD, standard deviation. Possible score range: [a]Section 1 = 0–7, [b]Section 2 = 0–4, [c]Section 3 = 0–5, [d]Section 4 = 0–4, [e]Overall=0–20, [f]Higher score represents higher knowledge, [g]P values are based on Wilcoxon's Signed-Rank Test. Note: The bold values in the tables indicate statistical significance at p < 0.05.

anything related to lifestyle or dietary modifications ($P = 0.001$, pre-vs. 30-day post-intervention), and would give anti-obesity medications only to achieve weight loss ($P = 0.019$, pre- vs. 30-day post-intervention).

Impact of the Educational Training Program on Perceived Barriers Towards Weight Management Service

Perceived barriers of participants towards WMS were assessed before, immediately after, and 30 days after the intervention (**Table 4**). Following the intervention, there was a significantly stronger level of agreement with barriers related to the lack of manpower and reluctance of patients to pay pharmacists ($P = 0.001$ and $P = 0.004$ respectively, pre- vs. 30-day post-intervention).

On the other hand, a number of barriers were perceived to be less important following the intervention with participants recording a lower level of agreement for these barriers 30-days post-intervention. These included the lack of weight management education materials ($P = 0.001$) and clinical practice guidelines ($P = 0.018$), lack of training sessions in weight management ($P = 0.001$) and lack of space for proper counseling ($P = 0.003$). There was also a lower level of agreement on barriers related to the reluctance among patients to obtain advice from pharmacists ($P = 0.030$, pre- vs. 30-day post-intervention) and preference among patients to purchase anti-obesity medications instead of obtaining lifestyle modification advice ($P = 0.001$, pre-vs. 30-day post-intervention).

DISCUSSION

To the best of the authors' knowledge, this is the first study to evaluate the impact of an educational intervention on the knowledge, attitude, and perceived barriers regarding weight management among Malaysian CPs.

The educational intervention improved the knowledge of CPs regarding various aspects of weight management over time. These findings are in line with the study by Sarayani et al. (6), in which knowledge scores on weight management among Iranian CPs significantly improved following an educational intervention. Interestingly, participants' knowledge scores in the present study were significantly higher after 30 days compared to immediately following the intervention. It should be noted that the participants had a relatively high pre-intervention mean knowledge score (14.5 out of 20); this could explain the minimal improvement immediately after the educational intervention. However, participants could have applied what had been learned during the educational training program on clients seeking weight management advice, and thus further enhanced their knowledge on weight management 30 days after the training program. This is supported by participants' reports of frequent encounters with clients requiring advice regarding weight management issues, where two-third of participants had at least two clients visiting the pharmacy every month to obtain weight-related advice. Indeed, after the intervention, the participants may have a higher appreciation towards the importance of knowledge and skills learned in the training program, and thus expressed significantly higher agreement that only certified pharmacists who have attended weight management training should be eligible to offer WMS. Another possible reason for the observation may lie in the design of the educational training program itself, where training programs with a mixed-method instructional design (lectures in combination with small group training and case discussions) may be effective in improving longer-term knowledge in weight management (7). This was demonstrated in the study by Sarayani et al. (6), in which lectures in combination with small group training resulted in better learning retention over time, compared to didactic lectures or lectures in combination with case discussions.

Within the literature, CPs generally expressed positive views on their role in weight management. They believe that as trained health care professionals, they hold a unique position and therefore have a definite role to play in weight management (8–11). CPs regarded their pharmacies and their WMS offered to be accessible, given that their advice is provided free of charge (8, 9). In this study, after the intervention, the participants had a more positive attitude towards WMS provision in community pharmacy. They had significantly stronger perceptions about the importance of their role to manage overweight and obesity and their professional competence to treat obese patients. It is also encouraging to observe that the participants portrayed more enthusiasm in the provision of WMS after the intervention, in which they perceived significantly more strongly that obesity screening services are important to provide in the pharmacy, and that they should not only provide assistance to overweight/obese patients upon request. These positive attitudes were found to be retained 30 days after the intervention.

CPs have been subjected to scrutiny, where criticism from consumers emerged in the public social media with regards to the perceived conflicts of interest of CPs in selling weight loss products to increase their net revenue (3, 12). The educational intervention may be a good approach to discourage the practices of merely selling weight loss products to manage overweight or obese patients while disregarding non-pharmacological interventions. This was evidenced in our study where the participants significantly more strongly disagreed that they would like to give anti-obesity medications only to achieve weight loss instead of advice on lifestyle/dietary modifications, and that they do not prefer to advise anything on lifestyle/dietary modifications to overweight/obese patients. These beliefs were retained 30 days after the intervention.

Frequently cited barriers in the literature on the provision of community pharmacy-based WMS included a lack of knowledge of obesity and its treatment, a lack of pharmacist time, and a lack of appropriate counseling space (2–5, 8, 9, 13, 14). Educational interventions may help CPs to overcome some of these perceived barriers. For instance, after the intervention, the barrier of not having space in pharmacy to perform proper counseling for weight management and the barrier of not having training sessions in the area of obesity management were perceived to be significantly less important. In contrast, after the intervention, participants perceived significantly more strongly that they do not have manpower at their pharmacy to

TABLE 3 | The impact of the intervention on attitude of participants towards weight management training and weight management services.

Item Description	Pre-intervention Mean (SD)[a]	Immediate post-intervention Mean (SD)[a]	*P* value[b]	Pre-intervention Mean (SD)[a]	30-day post-intervention Mean (SD)[a]	*P* value[b]	Immediate post-intervention Mean (SD)[a]	30-day post-intervention Mean (SD)[a]	*P* value[b]
I think I need training on weight management.	4.50 (0.51)	4.37 (0.49)	**0.046**	4.50 (0.51)	4.52 (0.59)	0.746	4.37 (0.49)	4.52 (0.59)	0.288
I think weight management training will improve my confidence while managing patients who are overweight/obese.	4.57 (0.50)	4.40 (0.50)	0.096	4.57 (0.50)	4.56 (0.51)	0.892	4.40 (0.50)	4.56 (0.51)	0.288
I think professionals from other professions such as nutritionists and dieticians should also be a training provider.	4.47 (0.7)	4.40 (0.56)	0.666	4.47 (0.7)	4.64 (0.57)	0.320	4.40 (0.56)	4.64 (0.57)	0.132
I think weight management training should be provided by the Ministry of Health in conjunction with Malaysian Pharmaceutical Society and pharmaceutical companies dealing with anti-obesity drugs/supplements.	4.10 (0.85)	4.03 (0.96)	0.714	4.10 (0.85)	4.36 (0.86)	0.172	4.03 (0.96)	4.36 (0.86)	0.119
I think only certified pharmacists who have attended weight management training should be eligible to offer weight management services.	3.33 (0.88)	3.33 (0.96)	0.927	3.33 (0.88)	4.00 (1.11)	**0.007**	3.33 (0.96)	4.00 (1.11)	**0.014**
I think minor weight loss can produce good clinical outcome for overweight and obese patients.	4.07 (0.64)	4.23 (0.50)	0.166	4.07 (0.64)	4.52 (0.59)	**0.012**	4.23 (0.50)	4.52 (0.59)	0.077
I think I have an important role to manage overweight and obesity.	4.27 (0.52)	4.37 (0.49)	0.257	4.27 (0.52)	4.60 (0.58)	**0.037**	4.37 (0.49)	4.60 (0.58)	0.169
I think I am professionally competent to treat patients with BMI more than 30 kg/m^2.	3.13 (0.97)	3.63 (0.81)	**0.013**	3.13 (0.97)	4.04 (1.14)	**0.001**	3.63 (0.81)	4.04 (1.14)	**0.047**
I think as a pharmacist I should refer overweight/obese patients to other professionals rather than to attempt to treat them.	2.83 (0.91)	2.73 (1.01)	0.670	2.83 (0.91)	2.24 (0.83)	**0.004**	2.73 (1.01)	2.24 (0.83)	**0.040**
I think I should only counsel patients who are overweight and obese when the patient requests it.	2.77 (0.97)	2.60 (1.00)	0.379	2.77 (0.97)	1.84 (0.90)	**0.001**	2.60 (1.00)	1.84 (0.90)	**0.002**
I think I should not provide any assistance to overweight /obese patients if I am not reimbursed for the service.	2.47 (0.86)	2.17 (0.70)	0.118	2.47 (0.86)	1.96 (0.45)	**0.001**	2.17 (0.70)	1.96 (0.45)	0.068
I think medications for weight management should only be offered when other risk factors such as diabetes mellitus or hypertension are present.	2.77 (1.10)	2.73 (1.01)	0.789	2.77 (1.10)	2.40 (0.82)	0.056	2.73 (1.01)	2.40 (0.82)	0.081
I think adults with BMI above 25kg/m^2 should be offered anti-obesity drugs.	2.53 (0.82)	2.33 (0.88)	0.318	2.53 (0.82)	2.28 (0.89)	0.289	2.33 (0.88)	2.28 (0.89)	0.763
I think adults with BMI above 30 kg/m2 should be offered anti-obesity drugs.	3.47 (0.94)	3.97 (0.89)	**0.007**	3.47 (0.94)	4.48 (0.82)	**0.001**	3.97 (0.89)	4.48 (0.82)	**0.032**
I think the following services/practices are important for me to provide in my pharmacy:									
a) Obesity screening services	4.10 (0.66)	4.30 (0.53)	0.124	4.10 (0.66)	4.52 (0.59)	**0.016**	4.30 (0.53)	4.52 (0.59)	0.155
b) Counseling about dietary habits	4.30 (0.47)	4.23 (0.50)	0.782	4.30 (0.47)	4.56 (0.58)	0.087	4.23 (0.50)	4.56 (0.58)	**0.033**
c) Counseling about physical activity	4.27 (0.52)	4.27 (0.45)	0.796	4.27 (0.52)	4.56 (0.58)	0.057	4.27 (0.45)	4.56 (0.58)	0.051
e) Provide anti-obesity drugs from pharmacy	3.57 (1.01)	3.87 (0.90)	0.139	3.57 (1.01)	4.40 (0.77)	**0.001**	3.87 (0.90)	4.40 (0.77)	**0.017**
I do not prefer to advise anything to overweight/obese patients on lifestyle/dietary modifications as I know these methods are not effective in weight management.	2.20 (1.06)	2.10 (0.92)	0.736	2.20 (1.06)	1.40 (0.58)	**0.001**	2.10 (0.92)	1.40 (0.58)	**0.001**
I would like to give anti-obesity medications only to achieve weight loss instead of advises on lifestyle/dietary modifications.	1.90 (0.89)	1.87 (0.82)	0.870	1.90 (0.89)	1.44 (0.58)	**0.019**	1.87 (0.82)	1.44 (0.58)	0.100

SD, standard deviation; BMI, body mass index. [a]Mean reflects the score on a 5-point Likert Scale (1 = strongly disagree; 5 = strongly agree). [b]P values are based on Wilcoxon's Signed-Rank Test.
Note: The bold values in the tables indicate statistical significance at $p < 0.05$.

TABLE 4 | The impact of the intervention on perceived barriers of participants towards weight management services.

Item Description	Pre-intervention Mean (SD)[a]	Immediate post-intervention Mean (SD)[a]	*P* value[b]	Pre-intervention Mean (SD)[a]	30-day post-intervention Mean (SD)[a]	*P* value[b]	Immediate post-intervention Mean (SD)[a]	30-day post-intervention Mean (SD)[a]	*P* value[b]
Lack of time	2.57 (0.90)	2.50 (0.82)	0.554	2.57 (0.90)	2.38 (0.65)	0.288	2.50 (0.82)	2.38 (0.65)	0.337
Lack of manpower	2.70 (0.95)	2.70 (1.05)	0.859	2.70 (0.95)	3.54 (0.78)	**0.001**	2.70 (1.05)	3.54 (0.78)	**0.001**
Lack of weight management education material	3.37 (1.00)	3.57 (1.04)	0.305	3.37 (1.00)	2.46 (0.83)	**0.001**	3.57 (1.04)	2.46 (0.83)	**0.001**
Lack of useful clinical practice guideline for obesity	2.77 (0.86)	3.07 (0.94)	0.177	2.77 (0.86)	2.29 (0.46)	**0.018**	3.07 (0.94)	2.29 (0.46)	**0.001**
Lack of proper referral system for overweight/obese patients	3.53 (0.97)	3.50 (1.04)	0.644	3.53 (0.97)	3.75 (0.53)	0.234	3.50 (1.04)	3.75 (0.53)	0.256
Lack of training sessions in the management of overweight/obesity	3.30 (1.02)	2.93 (1.17)	0.073	3.30 (1.02)	2.33 (0.70)	**0.001**	2.93 (1.17)	2.33 (0.70)	**0.012**
Lack of space for proper counseling	3.03 (1.07)	2.97 (1.19)	0.939	3.03 (1.07)	2.37 (0.64)	**0.003**	2.97 (1.19)	2.37 (0.64)	**0.014**
Lack of awareness among overweight/obese patients	3.57 (0.97)	3.67 (0.80)	0.591	3.57 (0.97)	3.75 (0.53)	0.402	3.67 (0.80)	3.75 (0.53)	0.839
Reluctance among overweight/obese patients to obtain advice from community pharmacists	2.67 (0.99)	2.93 (0.98)	0.340	2.67 (0.99)	2.21 (0.42)	**0.030**	2.93 (0.98)	2.21 (0.42)	**0.001**
Reluctance among overweight/obese patients to pay pharmacists for weight management services	3.77 (0.77)	3.70 (0.99)	0.924	3.77 (0.77)	4.33 (0.82)	**0.004**	3.70 (0.99)	4.33 (0.82)	**0.015**
Preference among overweight/obese patients to purchase anti-obesity medications instead of getting advice on lifestyle/dietary modification	3.23 (1.04)	3.33 (0.92)	0.593	3.23 (1.04)	2.33 (0.57)	**0.001**	3.33 (0.92)	2.33 (0.57)	**0.001**

SD, standard deviation. [a]Mean reflects the score on a 5-point Likert Scale (1 = strongly disagree; 5 = strongly agree). [b]P values are based on Wilcoxon's Signed-Rank Test.
Note: The bold values in the tables indicate statistical significance at $p < 0.05$.

manage overweight/obese patients. This may be related to the awareness of participants after the educational intervention on various aspects of weight management besides sales of weight loss products, which may require the participants to engage in more personalized and focused patient interactions. In fact, the participants had less strong perceptions of the barrier regarding the tendency of overweight/obese patients to purchase anti-obesity medications instead of getting advice from the pharmacist on lifestyle/dietary modification after the intervention. The situation is probably made worse by difficulties in recruiting and retaining competent auxiliary staff, such as dietitians and nutritionists, to lighten the burden of CPs, especially those who operate the pharmacy independently (9).

CPs frequently cited lack of remuneration or reimbursement to be one of the top barriers to the delivery of WMS (2, 5, 8, 9, 13). In this study, after the intervention, the participants had significantly stronger perceptions about the reluctance of overweight/obese patients to pay pharmacists for WMS as being a barrier, although they were willing to participate in the services even without reimbursement. While the participants expressed significantly higher agreement after the intervention that they should not assist overweight/obese patients only upon being reimbursed, a fee-for-service model would serve to encourage patients' recognition of CPs, who have gone the extra mile to be accredited for the skills of the WMS. This is in line with the findings of a qualitative study among community pharmacists in the United Kingdom of whom most had attended training courses on weight management, where they appeared to be satisfied by their remuneration even though they were not funded for their service, and they expressed their intention to assist more customers by having more advertisements (14).

With the global transition in focus of CPs' roles towards patient-centered services, competency-based weight management training programs may equip pharmacists with professional knowledge and thus facilitate the delivery of WMS. The training intervention in the current study demonstrates that the knowledge and attitude of community pharmacists regarding weight management can be positively improved through a carefully designed training program based on identified needs. In fact, certain barriers to the delivery of WMS were perceived to be less important after the training program. The findings demonstrate the potential effectiveness of brief training interventions for CPs directed towards WMS. In Malaysia, no party has been responsible for providing accredited weight management education for CPs. The findings can serve as a reference for the future planning of such education since key elements of the training program (e.g., dietary and exercise intervention, behavioral modification, pharmacotherapy) are relevant across all community pharmacy settings in Malaysia. It may be pertinent for policymakers to consider a specialized weight management course for CPs that follows the design of the educational training program described in this paper, to provide accreditation and subsequently to reimburse accredited weight management providers among CPs. Importantly, the educational training program should be conducted frequently to ensure sustainability of any positive changes from the intervention. A study among community pharmacists in the United Kingdom has suggested that it would be beneficial if the refresher training on weight management happens on a regular basis (14).

This study had several strengths. This is the first study to evaluate an educational training program to improve weight management knowledge and attitudes among CPs in Malaysia. Another strength of the study was the participation of CPs from both independent and chain pharmacies. However, as the study involved a pilot intervention and was designed to be exploratory, the small sample size may be a limitation that limits the generalizability of the study. In addition, the use of a self-evaluation questionnaire, which depends on accurate and honest reporting from respondents, could affect the responses as it may be subjected to the respondent or recall bias. Furthermore, the use of limited questions may be another limitation of the objective evaluation of knowledge.

CONCLUSION

In this study, the educational intervention program improved the knowledge of CPs regarding various aspects of weight management over time. Upon educational intervention, the CPs portrayed more enthusiasm in the provision of WMS in the pharmacy, including obesity screening services. Although certain barriers to WMS were perceived to be less important after the intervention, others such as the lack of reimbursement for services were still perceived to be important, signaling the need for these barriers to be addressed for better implementation of WMS in the community pharmacies across Malaysia.

DATA AVAILABILITY STATEMENT

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

ETHICS STATEMENT

Ethical approval for this study was obtained from National University of Malaysia, Malaysia (UKMPPI/111/8/JEP-2018-664). The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

RV and WC conceived the study, analyzed the data, and drafted the manuscript. NT and TP assisted with conceptualization of the study, data analysis, and manuscript revision. All authors read and approved the final manuscript.

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Screening the Influence of Biomarkers for Metabolic Syndrome in Occupational Population Based on the Lasso Algorithm

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Aim: Metabolic syndrome (MS) screening is essential for the early detection of the occupational population. This study aimed to screen out biomarkers related to MS and establish a risk assessment and prediction model for the routine physical examination of an occupational population.

Methods: The least absolute shrinkage and selection operator (Lasso) regression algorithm of machine learning was used to screen biomarkers related to MS. Then, the accuracy of the logistic regression model was further verified based on the Lasso regression algorithm. The areas under the receiving operating characteristic curves were used to evaluate the selection accuracy of biomarkers in identifying MS subjects with risk. The screened biomarkers were used to establish a logistic regression model and calculate the odds ratio (OR) of the corresponding biomarkers. A nomogram risk prediction model was established based on the selected biomarkers, and the consistency index (C-index) and calibration curve were derived.

Results: A total of 2,844 occupational workers were included, and 10 biomarkers related to MS were screened. The number of non-MS cases was 2,189 and that of MS was 655. The area under the curve (AUC) value for non-Lasso and Lasso logistic regression was 0.652 and 0.907, respectively. The established risk assessment model revealed that the main risk biomarkers were absolute basophil count (OR: 3.38, CI:1.05–6.85), platelet packed volume (OR: 2.63, CI:2.31–3.79), leukocyte count (OR: 2.01, CI:1.79–2.19), red blood cell count (OR: 1.99, CI:1.80–2.71), and alanine aminotransferase level (OR: 1.53, CI:1.12–1.98). Furthermore, favorable results

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with C-indexes (0.840) and calibration curves closer to ideal curves indicated the accurate predictive ability of this nomogram.

Conclusions: The risk assessment model based on the Lasso logistic regression algorithm helped identify MS with high accuracy in physically examining an occupational population.

Keywords: lasso regression algorithm, metabolic syndrome, occupational population, biomarkers, physical examination

INTRODUCTION

Metabolic syndrome (MS) refers to a group of metabolism-related diseases, including obesity, dyslipidemia, diabetes/impaired glucose tolerance, hypertension, and other diseases (1). The number of patients with MS has increased with the increasing number of obese patients worldwide (2). At present, the global prevalence of MS is about 25%, indicating that nearly one billion people are affected. Among these, the occupational population occupies a significant part and continues to increase (3). It has posed a substantial economic burden and has become a serious public health problem.

China ranks first in the world, with nearly 900 million working people. Every year, nearly 25 million workers suffer from health hazards, among which MS is already an important risk factor seriously affecting the health of the occupational population (4). Many studies were conducted on the relationship between the working environment of the occupational population and MS. Ma et al. confirmed that exposure to heavy metal elements in the work environment affected the body's metabolic function and increased the risk of MS in the Chinese population (5). (6) confirmed that the long-term exposure to noise in the work environment increased the chance of suffering from MS in the Chinese professional population (6). At the same time, some related studies confirmed the relationship of MS with the type of work in different occupational groups (7–9). Therefore, performing early MS screening for the occupational population is of great significance.

Machine learning, whereby a computer algorithm learns from prior experience, was recently shown to perform better than traditional statistical modeling approaches (10, 11). Machine learning algorithms have been widely used to screen biomarkers for related diseases with the rapid development of artificial intelligence (12–14). Various supervised machine learning models based on the least absolute shrinkage and selection operator (Lasso) regression algorithm have been successfully applied to medical data (15). However, no relevant studies used the Lasso algorithm to screen relevant biomarkers for MS.

Therefore, the risk of MS can be better predicted if the biomarkers related to MS are screened, and a risk prediction model is established for biomarkers used in routine physical examination. In this study, the Lasso logistic regression feature selection algorithm of machine learning was used to screen the biomarkers related to MS, and a risk prediction model was established.

Abbreviations: MS, Metabolic syndrome; OR, odds ratio; AUC, area under the curve; ROC, receiver operating characteristic; DCA, decision curve analysis; C-index, Concordance index.

MATERIALS AND METHODS

Population and Data Collection

This study included occupational workers with operations in Zhejiang Province, China, between September 2010 and September 2020. The ethics committee of the Affiliated Hospital of Hangzhou Normal University approved all the procedures performed. The working environment included the metallurgical industry (35%), including steelmaking, ironmaking, steel rolling, coking, and so forth; casting, forging, heat treatment, and so forth in the machinery manufacturing industry (40%); and kiln workers and furnace workers in the glass and refractory industries (25%). A total of 3,077 workers were examined, of which 233 workers were excluded due to incomplete records and errors. Finally, 2,844 workers were selected for the study. According to relevant studies, related inflammatory factors, factors of erythrocyte parameters, blood pressure factors, lipid metabolic factors, obesity factors, and glucose metabolic factors are related to metabolic syndrome (16). This study included 32 basic biomarkers for routine physical examination in the population (**Table 1**). All the included people were physically examined by professional doctors according to the diagnostic criteria of MS (17) in the Chinese population.

Lasso Regression Algorithm

Lasso regression feature selection is an unbiased estimation used to process high-dimensional complex collinearity data. The basic idea is to construct a penalty function to select the main variables with a strong correlation with the output parameters from the input variables and build a refined regression model (18). The penalty function constructed is as follows:

$$\hat{\beta}_0, \hat{\beta} = \arg\min \{ \sum_{i=1}^{n} \left(y_i - \beta_0 - \sum_{j=1}^{p} \beta_j X_{ij} \right)^2 \}$$

$$\text{Subjectto} \sum_{\text{j=1}}^{\text{p}} \left| \beta_j \right| \leq \lambda$$

where y_i is the dependent variable, $X_{ij} = (X_{i1}, X_{i1}, \ldots, X_{in})$ is an independent variable, β_j is the regression coefficient of the jth variable, and the value of λ can be $[0, +\infty)$. Lasso

TABLE 1 | Types of medical markers included in the study.

ID	Indicator name	ID	Indicator name	ID	Indicator name	ID	Indicator name
1	Red blood cell count	9	Large platelet ratio	17	Percentage of monocytes	25	Total bilirubin level
2	Total protein level	10	Red blood cell distribution width correlation variance (CV)	18	Leukocyte count	26	Globulin level
3	Ratio of plasma albumin to globulin	11	Red blood cell distribution width -standard deviation(SD)	19	Platelet count	27	Alanine aminotransferase level
4	Absolute value of eosinophils	12	Mean hemoglobin concentration	20	Mean platelet volume	28	Absolute number of monocytes
5	Percentage of eosinophils	13	Mean hemoglobin content	21	Absolute value of basophils	29	Percentage of lymphocytes
6	Absolute value of lymphocytes	14	Uric acid level	22	Percentage of basophils	30	Hemoglobin level
7	Percentage of neutrophils	15	Albumin level	23	Microscopic red blood cell count	31	Platelet volume distribution width
8	Hematocrit	16	Absolute number of neutrophils	24	Total bilirubin level	32	Hematocrit

feature selection compresses the model coefficients by increasing the penalty coefficient λ. When the absolute value of the regression coefficient Lasso estimate in the model is less than the absolute value of the minimum regression coefficient, some of the coefficients of the variables not strongly correlated are compressed to 0, and the variables corresponding to the coefficients with the estimated value of 0 are eliminated. In this way, the independent variables strongly related to the dependent variable are screened to achieve the purpose of feature selection. We used L1-penalized least absolute shrinkage and selection regression for multivariable analyses, augmented with tenfold cross-validation for internal validation.

Statistical Analysis

The continuous variables were analyzed by mean ± standard deviation, and the normality was tested by the Shapiro–Wilk method. A one-way analysis of variance was used to compare the differences between the metabolome and non-metabolome biomarkers in routine physical examination. The random sampling method was used to deal with the sample imbalance between workers with and without MS (19). The area under the receiving operating characteristic curve (AUC), true positive rate (also called sensitivity or recall), and false positive rate (specificity) are represented in a graphical plot. Based on the selected biomarkers, the logistic regression model was established, and the odds ratio (OR) value of each biomarker was given. Then, we established a nomogram risk prediction model. Two criteria, the concordance index (C-index) and the calibration curve, were used to validate the prediction model in the selected biomarker sets. The C-index, a value range between 0 and 1, is to assess the performance of the model. The larger the C-index (>0.70), the better the performance of the model. Calibration curves closer to ideal ones were thought to have the accurate predictive ability of this nomogram. Furthermore, we performed decision curve analysis (DCA) to visualize the net benefit for clinical decisions.

A test P-value < 0.05 indicated a statistically significant difference. The Lasso algorithm used the "glmnet" package for calculation. The nomogram was developed using the packages of "rms" and "foreign." All analyses were performed using the statistical programming environment R (version 3.6.0).

TABLE 2 | Basic characteristics of the population.

	Metabolic syndrome ($N = 655$)	Nonmetabolic syndrome ($N = 2,189$)
Sex		
Male	638	1,936
Female	17	253
Age (mean, year)	26.1	25.7
Weight (mean, kg)	78.4	64.9
Height (mean, cm)	169.9	171.4
SBP/DBP (mean, mm Hg)	86.5/154.1	72.4/118.5

RESULTS

A total of 2844 occupational workers were involved (**Table 2**), including 655 with MS (638 men and 17 women) and 2189 without MS (1936 men and 253 women). The body weight was greater in the MS group (78.4 kg) than in the non-MS group (64.9 kg). The average systolic blood pressure was higher in the MS group (86.5/154.1 mm Hg) than in the non-MS group (72.5/118.5 mm Hg). The one-way analysis of variance revealed differences in the expression of 14 physical examination biomarkers ($P < 0.05$) (**Table 3**).

TABLE 3 | Basic characteristics of routine physical examination markers.

	MS (mean + SD)	Non-MS (mean + SD)	*P*-value
Red blood cell count ($10^{12}/L$)	6.99 ± 1.67	5.76 ± 1.60	0.02
Total protein (g/L)	75.01 ± 3.67	73.94 ± 3.69	0.01
White blood cell ratio ($10^9/L$)	1.67 ± 0.22	1.78 ± 0.25	0.01
Absolute value of eosinophils ($10^9/L$)	0.17 ± 0.13	0.18 ± 0.18	0.78
Percentage of eosinophilic granule cells (%)	2.24 ± 1.36	2.38 ± 1.87	0.38
Absolute value of lymphocytes ($10^9/L$)	2.45 ± 0.69	2.39 ± 0.71	0.37
Percentage of neutrophils (%)	57.87 ± 8.67	55.04 ± 8.51	0.01
Hematocrit	0.47 ± 0.04	0.46 ± 0.03	0.17
Large platelet ratio (%)	32.74 ± 7.33	31.79 ± 7.78	0.14
Red blood cell distribution width CV (%)	13.00 ± 1.17	12.84 ± 0.93	0.04
Red blood cell distribution width SD (fl)	41.51 ± 2.85	41.45 ± 2.78	0.77
Mean hemoglobin level (pg)	334.92 ± 11.69	336.08 ± 10.62	0.19
Mean hemoglobin concentration (g/L)	29.58 ± 2.50	29.89 ± 2.05	0.06
Uric acid level (μmol/L)	5.93 ± 0.61	5.99 ± 0.61	0.21
Albumin level (g/L)	46.74 ± 2.85	47.05 ± 2.49	0.13
Absolute number of neutrophils ($10^9/L$)	4.32 ± 1.42	3.71 ± 1.25	0.01
Percentage of monocytes (%)	5.66 ± 1.44	5.89 ± 1.46	0.06
Leukocyte count ($10^9/L$)	7.37 ± 1.79	6.68 ± 1.65	0.01
Platelet count ($10^9/L$)	241.23 ± 66.96	227.95 ± 57.80	0.01
Mean platelet volume (fl)	10.97 ± 0.89	10.87 ± 0.96	0.21
Absolute value of basophils ($10^9/L$)	0.07 ± 0.16	0.05 ± 0.11	0.02
Percentage of basophils (%)	0.28 ± 0.20	0.32 ± 0.25	0.11
Red blood cells under the microscope	2.54 ± 14.50	4.11 ± 70.52	0.78
Total bilirubin level (μmol/L)	13.81 ± 6.73	14.48 ± 6.10	0.19
Globulin level (g/L)	28.27 ± 3.02	26.89 ± 3.25	0.01
Alanine aminotransferase level (U/L)	53.48 ± 120.12	28.89 ± 29.45	0.01
Absolute number of monocytes ($10^9/L$)	0.42 ± 0.15	0.39 ± 0.13	0.01
Percentage of lymphocytes (%)	33.90 ± 8.14	36.33 ± 7.98	0.01
Hemoglobin level (g/L)	287.23 ± 100.20	296.25 ± 92.73	0.24
Platelet volume distribution width (fl)	13.30 ± 2.01	13.16 ± 2.17	0.44
Platelet packed volume (fl)	0.27 ± 0.06	0.25 ± 0.05	0.01
Average red blood cell volume (fl)	88.22 ± 5.92	88.90 ± 5.00	0.10

The biomarkers were selected using the Lasso binary logistic regression model (**Figure 1A**). The tuning parameter (λ) selection in the Lasso model used tenfold cross-validation based on the minimum criteria. The area under the binomial deviance curve was plotted versus log (λ). Dotted vertical lines were drawn at the optimal values using the minimum criteria and the 1 standard error of the minimum criteria (the 1-SE criteria). Further, log (λ) = −4.331 was chosen (1-SE criteria) according to tenfold cross-validation of the Lasso coefficient profiles of the 32 features. A coefficient profile plot was produced against the log (λ) sequence (**Figure 1B**). A vertical line was drawn at the value selected using tenfold cross-validation, where optimal λ resulted in 10 nonzero coefficients. Finally, the 10 physical examination biomarkers related to MS were selected (**Figure 1C**). They were leukocyte count, platelet packed volume, alanine aminotransferase, absolute value of basophil, absolute number of monocytes, absolute number of neutrophils, red blood cell count, red blood cell distribution width CV, total protein, and percentage of neutrophils.

A multiple logistic regression model was established, and the accuracy of the model was compared. All 32 physical examination biomarkers were incorporated into the model. The predicted results of the model are shown in **Figure 2A**, indicating that the AUC of the model was 0.652 (95%CI:0.578–0.712). The prediction result of the model after incorporating the final 10 biomarkers into the model is shown in **Figure 2B**. The AUC of the model was 0.907 (95%CI:0.841–0.932).

A multiple logistic regression model was established using the 10 physical examination biomarkers selected; the analysis results are shown in **Figure 3**. The following five risk factors were not associated with MS ($P < 0.05$): absolute basophil count (OR: 3.38, CI:1.05–1.98), platelet packed count (OR: 2.63, CI:2.31–3.79), leukocyte count (OR: 2.01, CI:1.79–2.19), red blood cell count(OR: 1.99, CI:1.80–2.71), and alanine aminotransferase level (OR: 1.53, CI:1.12–1.98). Only two physical examination

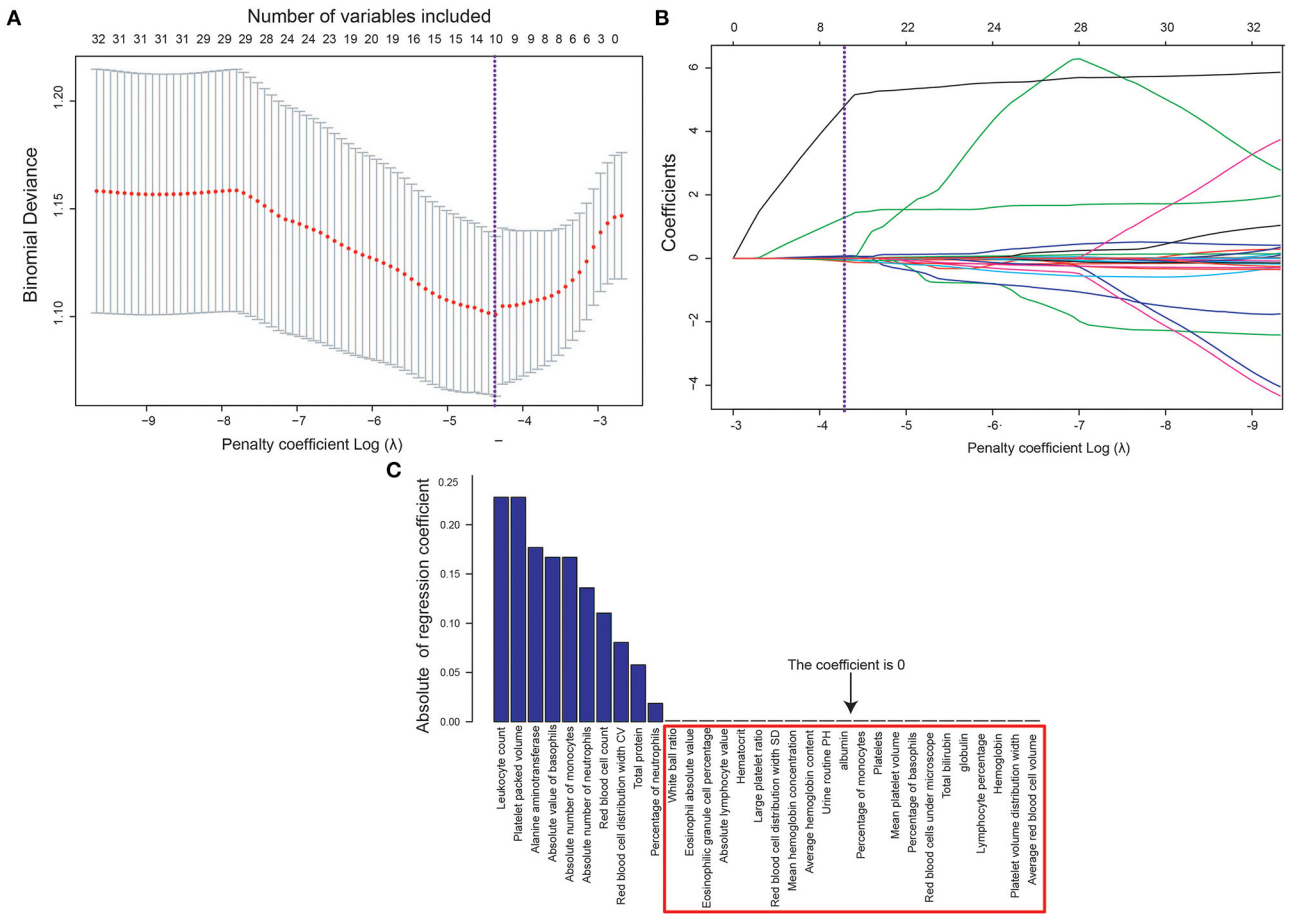

FIGURE 1 | (A) Tuning parameter (λ) selection in the Lasso model used tenfold cross-validation based on the minimum criteria. **(B)** Changes in 32 marker coefficients with the penalty parameter (λ). **(C)** 32 marker coefficients obtained according to the selected best penalty parameter (λ).

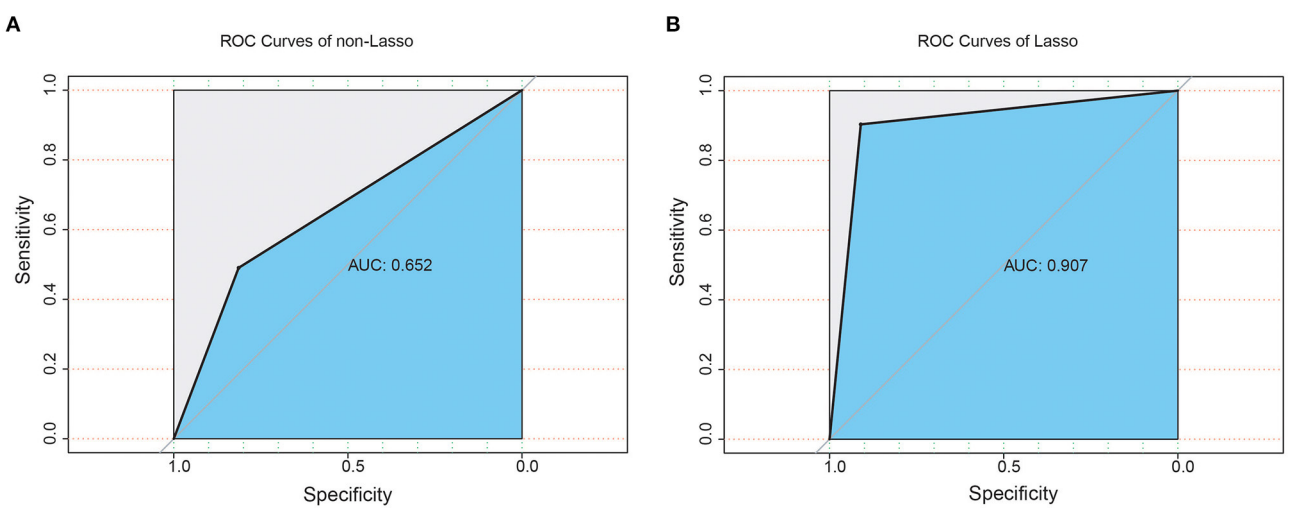

FIGURE 2 | Receiver operating characteristic (ROC) curve with area under the curve values for **(A)** non-Lasso regression and **(B)** Lasso regression.

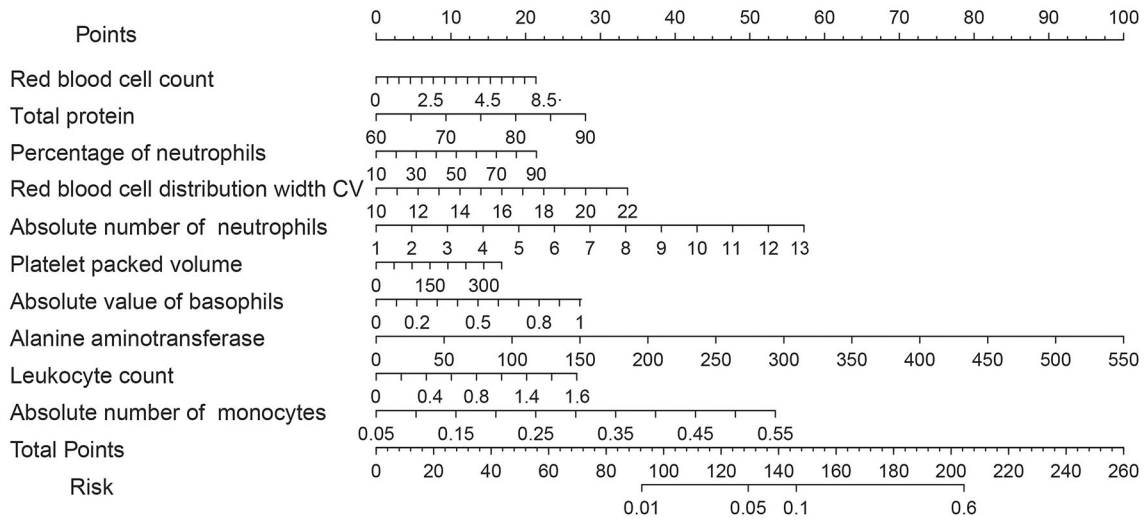

FIGURE 3 | Study population for multivariate logistic regression analyses.

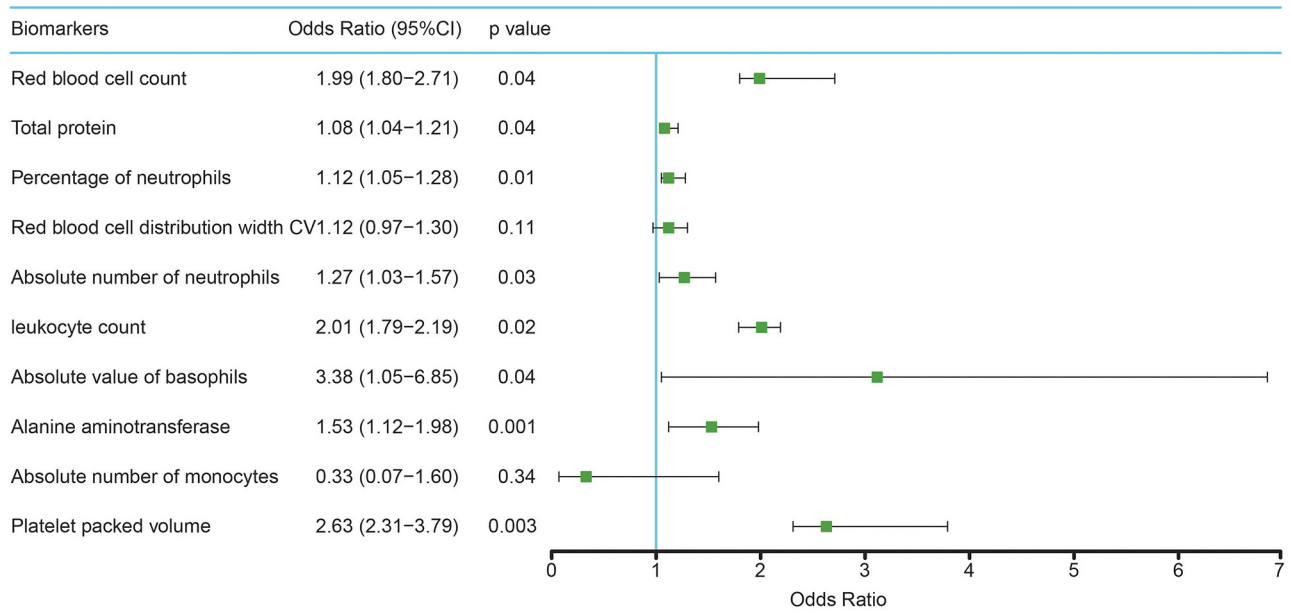

FIGURE 4 | Nomogram for the prediction of MS with Lasso selected biomarkers.

biomarkers showed no statistical significance in the prediction model ($P > 0.05$).

According to the selected biomarkers, we established a nomogram risk prediction model containing independent risk factors. The scores of the items displayed in the nomogram should be added up. As it is shown in **Figure 4**, alanine aminotransferase was associated with the highest risk, followed by the absolute number of neutrophils and the absolute number of monocytes.C-indexes were observed in both the selected biomarker sets (0.840); high agreements between ideal curves and calibration curves were observed. These results revealed a good discrimination ability of the nomogram prediction model (**Figure 5A**). The DCA curve revealed a more extensive range of cutoff probabilities shown by the nomogram. The threshold probabilities of the model had excellent net benefits and enhanced performance for predicting the patients with MS (**Figure 5B**).

DISCUSSION

This study selects the occupational population as the research object, with a large sample size and comprehensive inclusion

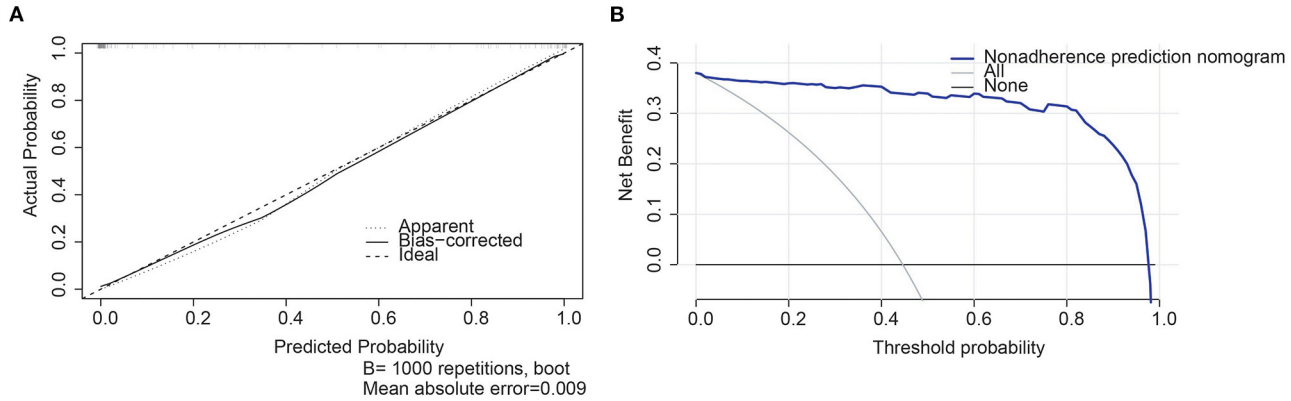

FIGURE 5 | (A) Calibration plots for predicting MS. X-axis: bootstrap-predicted; y-axis: actual outcome, **(B)** Decision curve analysis (DCA) of the novel nomogram for predicting MS. X-axis: cut-off probability; y-axis: net benefit.

indicators. We screened out 10 biomarkers related to MS in the occupational population. The established MS prediction model can be extended to clinical and physical examination centers to provide a judgment basis for the early risk assessment of MS in the occupational population.

The health of the occupational population has a strong relationship with the working environment. This population has high work pressure, disordered work and rest, irregular diet, and lack of exercise. These inevitable adverse factors increase the risk of MS (20). Hsiao and Yang conducted a 2-year (2003–2005) and 5-year (1997–2006) follow-up on a Chinese population (21). They both confirmed the routine examination of biomarkers such as serum cholesterol, triglyceride, and blood glucose levels, height, weight, blood pressure, and so forth. In this study, 10 biomarkers related to MS were further screened, including red blood cell count, total protein level, percentage of neutrophils, red blood cell distribution width CV, absolute number of neutrophils, leukocyte count, absolute value of basophils, alanine aminotransferase level, monocyte count, and platelet count. These potential biomarkers could be used to assess the risk of MS.

A low-level inflammatory state is considered to be a major potential mechanism of MS. Leukocyte is one of the most sensitive indicators reflecting inflammatory activity *in vivo*. Many studies have found that routine blood parameters are related to MS. A longitudinal cohort study of a healthy population in China showed a significant correlation between white blood cell count and MS (relative risk = 2.66). At the same time, the total numbers of white blood cells, neutrophils, monocytes, and basophils were the risk factors for obesity (22). (23) found a significant positive correlation between alanine aminotransferase level and risk of MS through quantitative and qualitative analyses, which had a predictive value for the incidence of MS (23). Further, a positive correlation was reported between red blood cell parameters, hematocrit, and MS for a large longitudinal cohort in China (24). Laufer et al. found that the prevalence of MS was 29% when the red blood cell distribution width was <14%, and the prevalence of MS was 34% when the red blood cell distribution width was more than 14% (25). Macrophage activation plays a crucial role in metabolic dysfunction, and neutrophils, as the representative of macrophages, must be closely related to metabolic syndrome (26). The findings on the biomarkers screened in the aforementioned studies were the same as those in the present study.

The research method in this paper is novel, and similar studies are rarely reported. This method effectively avoids the collinearity between independent variables so as to better screen biomarkers related to metabolic syndrome. Lasso is a method used to find out the essential structure of multivariate observation variables. However, the follow-up time of the longitudinal monitoring physical examination cohort constructed in this study is relatively short, and follow-up studies are needed to further verify the accuracy and effectiveness of the risk assessment model. In future research, we can continue to expand the sample size, verify the accuracy of the screened biomarkers, and finally establish the prediction model. We can use different research methods, such as decision trees (27), random forests (28), neural networks (29), and so forth, to compare the accuracy of each method in future studies.

CONCLUSIONS

This study selected 10 physical examination indicators related to MS based on the Lasso algorithm. An accurate risk prediction model for MS was established. The use of common indicators and examination items in the health examination of ordinary occupational populations provides a basis for using cost-effective and portable methods to realize the risk prediction of MS.

DATA AVAILABILITY STATEMENT

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

AUTHOR CONTRIBUTIONS

Y-RC and Z-HF conceived the study and designed the analysis. Z-YH, Y-MC, and C-JC curated the clinical data. M-WW, CW, and J-YK performed statistical analysis. Q-YX and M-WW wrote the first draft of the manuscript. X-YF and X-WZ participate in revision the manuscript. All authors contributed to revision of the manuscript.

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36-Month Evaluation of a Weight Management Programme in Chinese Overweight and Obese Adults

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Background: Few comprehensive lifestyle intervention programmes have been investigated on overweight and obese adults in China. This study was to evaluate the effect of a 36-month weight management programme on weight loss and its maintenance among overweight and obese patients in Ningbo, China.

Methods: Adults with BMI $\geq 24\,kg/m^2$ enrolled in this programme, including nutritional, physical activity, psychological and endocrinological counselling sessions, from July 2015 to January 2020. Adults participated in face-to-face counselling sessions and group-based education. Then, participants joined 21-day intensive programme using Bohe health APP and WeChat group to get personal advice of nutrition and lifestyle. In the end, participants were requested to join 33-month follow-ups including face-to-face counselling and personal advice on WeChat group. The main outcome was to evaluate the changes in weight at each followup from baseline weight.

Results: In total, 692 adults participated in this entire weight management programme. During follow-ups, 579, 475, 299, 219, and 135 adults participated at 3, 6, 12, 24, and 36 months, respectively. All participants had a significant initial weight loss at 3 months, then maintained the weight loss during 33-month follow-ups. At 36 months, 11.0%, 6.4%, and 3.5% of all participants achieved 5%, 10%, and 15% weight loss from the baseline weight, respectively. Adjusted weight at 36 months was significantly reduced from the baseline weight in both sex (−7.2 kg).

Conclusion: This weight management programme is suggested to benefit to reduce initial body weight and maintain long-term weight loss among overweight and obese adults.

Keywords: weight management, weight loss, weight maintenance, overweight, obesity, China

INTRODUCTION

Obesity is a worldwide epidemic (1). Obesity is defined as an excessive accumulation of body fat which causes significant comorbidities, including cardiovascular disease (CVD), type 2 diabetes (T2D), hypertension, dyslipidemia, certain types of cancer, and mortality (2–4). With rapid economic development, industrialisation and urbanisation for the past four decades, the determinants of overweight and obesity in China are the changes of dietary pattern and lifestyle. The prevalence of overweight and obesity in Chinese adults dramatically increased from 9.1% (5) and 2.0% (6) in 1989 to 41.3% and 15.7% in 2015 (7), respectively, thus, overweight and obesity have become one of important Chinese public health concerns.

Weight loss is an important way to decrease the prevalence of obesity and the risks of obesity-related chronic diseases. Evidence showed that short-term weight-loss intervention programme focusing on promotion of lifestyle involving nutrition and physical activity can result in clinically significant health benefits (8, 9). However, weight maintenance is a major challenge for weight loss in overweight and obese individuals. Recently, lifestyle intervention through strategies was suggested that higher autonomous motivation, self-efficacy, and self-regulation skills emerged might contribute to long-term weight control and weight loss maintenance (10).

Ningbo is one of the most economically developed cities in Zhejiang Province, which is located in the richest region of Yangtze River Delta, China. Recent research studies proved that the high prevalence of overweight and obesity in Ningbo (11, 12) was close to the national prevalence (7, 13), and reached similar prevalence of 20 European countries (14) and global prevalence (1).

To date, few comprehensive lifestyle intervention programmes have been investigated in overweight and obese adults in China. This weight management intervention programme was developed based on autonomous motivation and self-regulation focusing on long-term weight loss and weight control. Our previous 6-month feasibility study suggested that the lifestyle intervention strategy could benefit to weight treatment in overweight and obese patients (15). The objective of the present study was to evaluate the effectiveness of the 36-month comprehensive lifestyle intervention programme on weight loss and maintenance of weight loss in overweight and obese adults in Ningbo.

METHODS

Study Design and Setting

This study is a pragmatic evaluation of an ongoing weight management programme delivered in real life supported by Ningbo government. In total, 977 patients from July 2015 to January 2020, who were invited and willing to participate in this 36-month programme during outpatient counselling visits at Department of the Endocrinology of Ningbo First Hospital, Zhejiang Province, China. All adults aged 18–75 years with body mass index (BMI) $\geq$24 kg/m^2 were included in this programme (16). The exclusion criteria of this programme included: (1) age $<$18 years at baseline; (2) secondary obesity caused by other medical conditions or diseases; (3) diagnosis of any types of cancer or severe coronary heart disease; (4) receiving any related non-pharmaceutical/pharmaceutical intervention; (5) pregnancy or lactation; (6) mental illness; (7) cognitive impairment. The target goal of this programme is to achieve 5–15% weight loss in the overweight and obese patients.

The ongoing research programme is approved by the Ethics Committee of Ningbo First Hospital, China (No. 2019-R049). Written informed consents were obtained from all the participants.

Measurement of Baseline

All the eligible participants were asked to complete dietary behaviour and lifestyle questionnaires including socio-demography, dietary intakes for the past week, physical activity for the past week, medication record and medical history. Besides that, participants were asked to fill out questionnaire of Yale Food Addiction Scale (YFAS) to identify the addiction of their usual dietary intakes (17).

Health status including anthropometry, blood pressure and biomarkers was examined by experienced nurses. Anthropometry, including height, weight, waist circumference, hip circumference, basal metabolic rate, body fat percentage and muscle mass percentage, was examined by body composition detector (GAIA KIKA, Korea) (18). Blood pressure was measured using an electronic sphygmomanometer on the right or left arm after a 5-min rest. Biomarkers containing blood lipids (total cholesterol, triglyceride, low-density lipoprotein cholesterol, high-density lipoprotein cholesterol), fasting plasma glucose, fasting plasma insulin, fasting c-peptide, glycated haemoglobin A1c, uric acid, alanine aminotransferase, aspartate aminotransferase, and free fatty acids were examined by biochemical automatic analyzer.

Measurement of Follow-Ups

The body weight and height were measured at 3, 6, 12, 24, and 36-month follow-ups, after completing the same questionnaires in baseline.

Intervention

The weight management programme including nutrition, physical activity, psychology and endocrinology delivered by a multidisciplinary team consisting of three clinicians, two dieticians, two exercise specialists, and one psychologist (**Table 1**). All the participants were divided into 10-person groups and assigned to the intervention programme on group basis. One group leader was selected by the group members, who was a key factor to support our multidisciplinary team. The function of the group leaders was to motivate his/her members participating the rest of follow-ups and reminded them to record their daily dietary intake, physical activities and changes in their lifestyle. At the baseline visit, each individual participated in face-to-face counselling sessions for personal guidance according to the medical reports (**Table 1**). The purpose of nutritional advice was to reduce energy-dense foods by controlling diet portion size and regulating dietary intakes rationally. During

TABLE 1 | Multidisciplinary weight management programme.

Phase	Time	Programme	Individual/group	Duration
1	1st month	Face-to-face counselling	Individual	1 h
1	1st month	Face-to-face education	Group	2 h
2	21-day/1st month	Intensive programme Synchronous online (Bohe health APP on mobile)/WeChat	Individual	10 min
3	3–36 month	Face-to-face counselling	Individual	2 h
3	3–36 month	Synchronous online (Bohe health APP on mobile)/WeChat	Individual	10 min

the nutritional counselling session, each participant was advised to adjust their dietary patterns based on the distribution of daily energy intake from macronutrients and change dietary patterns appropriately (19). During the counselling session of physical activity, participants were motivated to join outdoor and indoor physical activity at conveniences, guided the appropriate types of physical activity and encouraged to exercise at least 150 min per week. The advice on physical activity followed the American College of Sports Medicine (ACSM)'s guideline for exercise testing and prescription tenth edition for overweight and obese adults (20). Participants at psychological counselling session were asked to report their recent mood status (happiness, satisfaction, self-esteem, depression stress, anxiety, and sleep quality) and their behaviour changes in their recent daily life were discussed with clinical psychologist. Participants were suggested to record their behaviour changes and mood status, and document the progress. During the endocrinology session, advice on medication and was delivered based on their baseline health examination. After face-to-face counselling sessions, all the participants as group unit gathered together for education programmes delivered by one general physican.

All the participants recorded their daily dietary intakes and physical activity via Bohe health APP on mobile. Bohe health APP was created for personal management to evaluate dietary patterns, nutrition status and anthropometric status (e.g., body weight) (21). Besides APP online programme, participant group basis joined WeChat group (22), organised by the multidisciplinary team. All adults participated in a 21-day intensive intervention programme (phase 2). During phase 2, participants were compulsory to report their anthropometry (e.g., body weight), daily dietary intakes and physical activity to the multidisciplinary team through WeChat. Self-measured body weight was suggested to participants reporting on WeChat online programme in order to motivate participants to self-regulate and self-control their body weight. At the WeChat online counselling session, participants got their personal feedbacks on personal advice, their doubts of weight management, performance, and progress.

During the follow-ups, advice on nutrition and physical activity was delivered face to face to provide their personal solution (phase 3). At the psychological counselling session, participants gained professional advice if they had questions and desired to have a chat with clinical psychologists. Moreover, participants on group basis followed synchronous online (Bohe health APP on mobile) and WeChat for further advice as well when they had doubts and questions. Each patient got personal feedback from our professional multidisciplinary team.

Parameters and Outcomes

Obesity Definition

Measured body weight was collected at Ningbo First Hospital to evaluate their weight loss during the follow-ups. BMI, used as a measure of obesity, was calculated as weight (kg)/height (m^2). Participants were classified into four BMI categories according to China Obesity Task Force (COTF) as follows: underweight (<18.5 kg/m^2), normal weight (18.5–23.9 kg/m^2), overweight (24.0–27.9 kg/m^2), and obesity ($\geq$ 28.0 kg/m^2) (16). Central obesity was defined according to WC values: WC >90 cm in men or >85 cm in women (16).

Socio-Demographic Status

Participants were asked to fill out a standard questionnaire about their socio-demographic status, designed and validated by the Ningbo First Hospital. Education were categorised into three levels including lower secondary education; vocational, technical or high school; higher education (bachelor, master, or above). Participants provided their marital status (Single/divorce/widowed/separated, married, and unknown status).

TABLE 2 | Recruitment and follow-up of participants.

	Total (*n*)	Male (%)
Recruited participants	977	40.9
Baseline	692	40.8
3 month	579	39.9
6 month	475	37.5
1 year	299	33.8
2 year	219	33.3
3 year	135	30.4

TABLE 3 | Baseline characteristics of participants (2015–2020).

	Total ($n = 692$)	**Men ($n = 282$)**	**Women ($n = 410$)**
Age (year)	30.0	30.0	28.4*
Weight (kg)	93.8 (19.2)	106.5 (18.3)	85.0 (14.3)*
BMI (kg/m^2)	33.5 (5.1)	34.7 (5.0)	32.6 (5.0)*
		n (%)	
Education	53 (7.7)	11 (3.9)	42 (10.2)
No education or lower secondary			
Vocational, technical, or upper secondary school	162 (23.4)	72 (25.5)	90 (22.0)
Higher education	477 (68.9)	199 (70.6)	278 (67.8)
Marital status			
Single/divorce/widowed/separated	321 (46.4)	157 (55.7)	164 (40.0)
Married	363 (52.5)	121 (42.9)	242 (59.0)
Unknown	8 (1.2)	4 (1.4)	4 (0.98)
Overweight	86 (12.4)	14 (16.2)	72 (86.0)
Obesity	606 (87.6)	268 (44.2)	338 (55.8)
Abdominal obesity[a]	651 (95.7)	272 (41.8)	379 (58.2)

Data represent mean with standard deviation or median.
[a]*The number of patients was 680.*
**Mean differences between men and women (P < 0.001).*

TABLE 4 | Adjusted weight change (kg) from baseline.

Gender	**3 month**	**6 month**	**12 month**	**24 month**	**36 month**
Total	−5.2 (0.360)[a]	−6.9 (0.530)[a,b]	−7.6 (0.705)[a,b]	−7.5 (0.800)[a,c]	−7.2 (0.881)[a]
Men	−5.9 (0.679)[a]	−7.0 (1.1)[a]	−7.8 (1.2)[a]	−7.4 (1.1)[a]	−7.0 (1.3)[a]
Women	−4.9 (0.408)[a]	−6.8 (0.621)[a,b]	−7.5 (0.893)[a,c]	−7.6 (1.1)[a]	−7.4 (1.1)[a]

Values of weight changes are mean with standard error.
**Difference in weight changes across follow-up periods was examined with Bonferroni correction for multiple comparisons by repeated measures analysis of covariance.*
[a]*Mean weight difference from baseline weight (P < 0.001), with Bonferroni correction for multiple comparisons.*
[b]*Mean weight difference from 3-month weight (P < 0.001), with Bonferroni correction for multiple comparisons.*
[c]*Mean difference from 3-month weight (P < 0.05), with Bonferroni correction for multiple comparisons.*

Statistical Analysis

Descriptive analysis was presented as number and percentage for category variables and mean and standard deviation (SD) or median for continuous variables. Statistical differences in age and biomarker parameters were compared between men and women by Student's *t*-test and Mann-Whitney *U* test. A sensitivity analysis was undertaken for comparison between participants' baseline weight and baseline weight among those dropout participants at 36 months aiming to detect whether missing values of dropouts affect the outcomes. Mean changes in weight across 36-month study period controlling for age, education levels and marriage status were examined with Bonferroni correction by repeated measures analysis of covariance. Mean weight loss at 36 month between men and women was tested by non-parametric test.

Results were considered statistically significant at a two-tailed level of 0.05. Statistical analysis were conducted using the STATA statistical software package version 15 (2017).

RESULTS

Attendance of Intervention and Follow-Ups

In total, 692 out of 977 adults (40.8% men) fulfilling all inclusion criteria and willing to participate in this 36-month programme were included in the baseline (**Table 2**). Among all the enrolled patients, 579, 465, 290, 204, and 122 patients participated in the follow-ups at 3, 6, 12, 24, and 36 months, respectively.

Baseline Characteristics of Participants

The baseline characteristics of participants was described in **Table 3**. The mean age of all the participants was 30.9 years (men: 29.4 years, women: 31.9 years). Mean weight and BMI were significant higher in men than women. Around 87.6% and 95.7% of participants were defined to have general obesity and abdominal obesity, respectively. The result of sensitivity analysis showed that no significant difference of baseline weight between all participants and dropout participants at 36 months ($P = 0.678$).

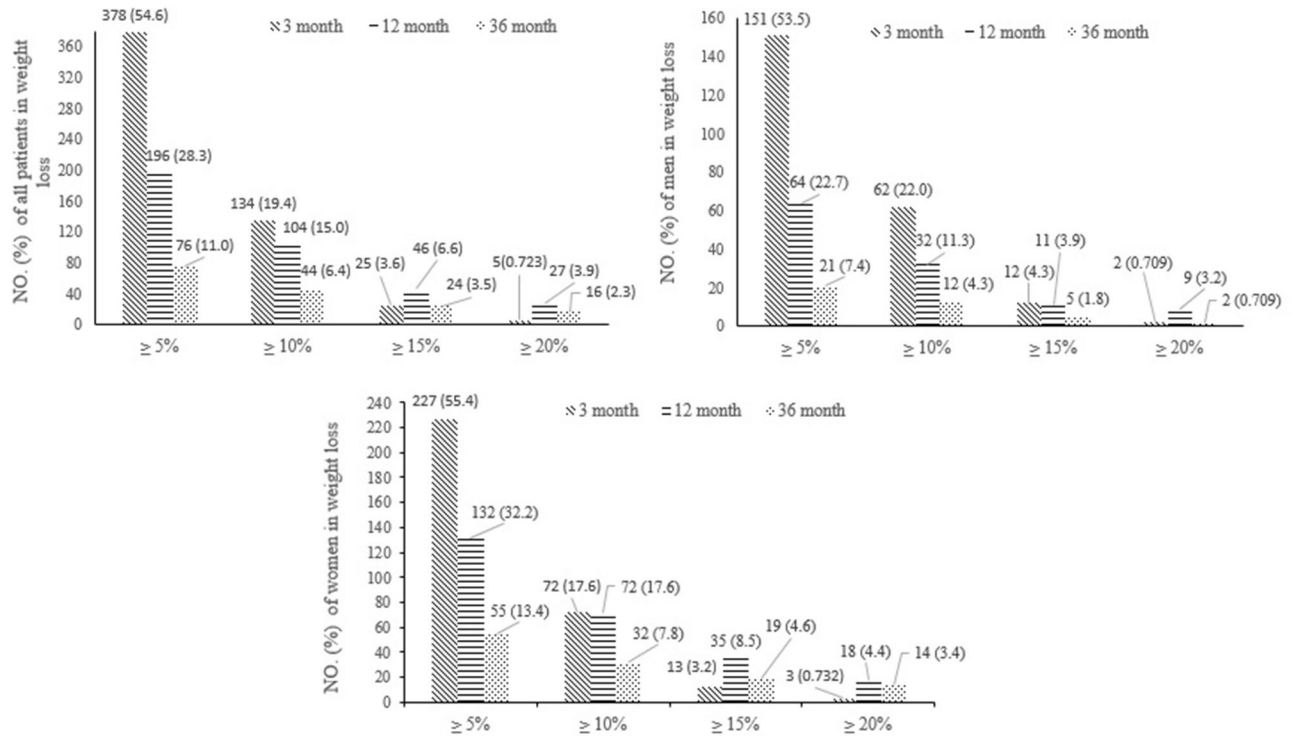

FIGURE 1 | Effects of interventions on weight loss in total 692 participants from the baseline weight at 3, 12, and 36-month follow-ups.

Weight Loss

Weight loss was evaluated across the entire 36-month programme (**Table 4**). Weight significantly reduced after 36 months in both sex with and without Bonferroni correction (adjusted difference, male: −7.0, $P < 0.001$; female: −7.4, $P < 0.001$). Participants had a significant initial weight loss of adjusted weight at 3-month follow-up in both sex. Mean weight at each follow-up was significant from mean baseline weight. However, adjusted weights were slightly regained in both sex (adjusted weight: men, −7.4 kg at 24 months and −7.0 kg at 36 months; women, −7.4 kg at 36 months).

A sizable proportion of participants sustained clinically significant weight loss at 3, 12, and 36-month follow-ups (**Figure 1**). Overall, at 36-month follow-up, 8.7% of all baseline participants (6.7% of men and 10.0% of women) reached the target goal of weight loss 5–15%. Moreover, 2.3% of all baseline participants (2 men and 14 women) reached ≥20% weight loss at 36 months, exceeding the originally target goal.

DISCUSSION

To all authors' knowledge, the present study was the first long-term comprehensive lifestyle intervention to evaluate the effect of weight management programme on weight loss and its maintenance in overweight and obese outpatients in Ningbo. Our weight managment programme, focusing on regulating dietary intakes and lifestyle, and promoting positive life attitude and behaviour, was to address reducing body weight and maintaining weight loss. The results after the 36-month programme demonstrated the significant benefits to weight loss in both sex.

In the present study, a mean adjusted weight of 7.0 kg and 7.4 kg was reduced in both men and women, respectively, after 36 months. In our previous feasibility study, BMI was observed to reduce by 2.4 kg/m^2 after 6 months (15). Lifestyle intervention including nutritional counselling and physical activity was evidenced to be more effective on weight loss in overweight and obese people (23–25). However, a big challenge in weight management of obesity is maintaining weight loss. Evidence stated that long-term success rates of lifestyle weight loss treatments are so low and may be fruitless (25, 26). In the present study, mean adjusted weight at 36 months was much lower than baseline weight. At the end of our programme, 6.7% of men and 10.0% of all participanting women maintained weight loss and reached the target goal of weight loss 5–15%. Even, 2 male and 14 female patients got weight loss ≥20%. Therefore, the weight management programme can be effective and clinical benefits to obese patients.

Most lifestyle intervention trials on overweight and obese adults failed due to rapid weight regain after an initial weight loss intervention period (25, 27). A 12-week weight reduction programme including dietary advice and physical activity regimes indicated a regain of 1.39 kg/m^2 BMI after initial 12-week weight loss (25). Weight regain was observed in our study as well. Nevertheless, an important difference is that, unlike other lifestyle intervention, weight regain was almost in the end of our study and weight regain was minor. This might be due to

intensive intervention programme (phase 2), keeping counselling sessions and frequent feedbacks via WeChat (phase 3). Personal solution and advice with psychological and social supports to our patients might be critical to contribute to maintenance of change in eating behaviour and positive lifestyle during 36-month period (28). Our previous feasibility study in line with our findings indicated to keep reducing BMI at 3 and 6-month follow-ups, respectively (15). While, a previous lifestyle intervention reported no significant difference between intensive counselling and short-term counselling interventions (28).

An important key to progress in weight loss is the effective method. In this regard, an individual and group strategy including face-to-face counselling and interactive technology-based intervention (e.g., WeChat group) was used in our intervention and 33-month follow-ups. Thus, this weight management strategy can enhance adherence in weight management programme through efficient and frequent communication, which can increase the success rate of this entire study. A recent systematic review and meta-analysis, supporting our weight management strategy, suggested an extended care is essential and efficacious to address long-term maintenance of lost weight (−3.2 kg) (29). Therefore, our intensive intervention can prevent weight regain after initial weight loss and our phase 3 can maintain long-term weight loss.

Comparing to one previous Trials of Hypertension Prevention Phase II (TOHP-II), our study and TOHP-II both used similar weight management strategy including individual counselling session and group meetings focusing on dietary intakes, physical activity, and social support (30). An additionally similar strategy for both studies is an intensive lifestyle intervention followed by less intensive intervention programme. The result of in TOHP-II showed that mean weight change from baseline was −0.2 kg at 36 months, which is far less than weight loss in our study. The significant difference is that our strategy included psychological counselling session to provide emotion, psychological and mental support. A meta-analysis including 36 randomised controlled trials indicated that psychological interventions that combined with dietary and physical activity strategies was more useful to enhance weight reduction (−4.9 kg) (31).

Women had a slight more weight loss at 36 months than men, although no significant difference was found. In addition, more almost 10% female patients reached our original weight loss target (5–15%) and 12 more women exceeded our target than men. Most weight management intervention studies were conducted to compare weight loss between intervention group and control group. The rate of weight loss success can be attribute to the different characteristics between men and women in our study. Physiological mechanisms including higher plasma leptin concentrations in women (32) and more percentage of muscle mass in men (33) may result in the different level of weight loss between men and women. Attendance in this study indicated that women were more eager to lose body weight for keeping healthy and desired body shape (34).

Strengths and Limitations

Our study is the first comprehensive lifestyle counselling intervention programme to evaluate the effect of our strategies on weight loss and maintenance of weight loss. Our progrmme strategies included individual counselling and group education, provided personal feedback through WeChat APP during the entire programme. However, this programme still has some limitations. First, the complicated intervention design with long-term follow-up resulted in high dropouts at 36 months indicating participants lost interests in this long-term programme. Relocation of our participants and switching hospitals caused high dropouts as well. Second, self-reported body weight used for their personal feedbacks via WeChat online sessions might not reflect the real body weight of overweight and obese patients due to psychological factor. The under-reported body weight cannot affect the accurate weight and patients could not gain appropriate feedbacks and advice resulting in the influence in weight control and weight loss maintenance. Third, due to the structure of our questionnaires, some basic information was not well-collected, thus, baseline study could not reflect more details on daily energy intake and physical activity level. The last but not least is that no control group can be compared to the intervention group because all the outpatients followed the same standard intervention programme in this ongoing real life study. In the future study, energy intake and physical activity should be well-collected to estimate the levels for total energy intake and physical activity, which may affect weight loss.

CONCLUSION

The results indicated that overweight and obese participants got significant initital weight loss after 3 months and maintained wight loss during 33-month follow-ups. Therefore, this comprehensive lifestyle intervention programme is suggested to benefit to long-term weight management in overweight and obese people. In the future, the effectiveness of individual interventions on overweight and obese people needs to be investigated to compare with control group in a randomised control trial.

DATA AVAILABILITY STATEMENT

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

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the Research Ethics Committee, Ningbo First Hospital. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

YL performed and interpreted statistical analysis and drafted manuscript writing. XY was responsible for data collection, quality control, and manuscript preparation. KC, RH, and J-LL supported manuscript writing. LL and YL contributed to the study design for the whole research. All authors read and approved the final manuscript.

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Sex-Related Difference in the Association Between Child Neglect and the Accuracy of Body Weight Perception Among Chinese Primary Schoolchildren

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Introduction: Body weight perception (BWP) directly determines weight management behaviors. Although child neglect is a well-established risk factor for managing body weight, little is known about its association with the accuracy of BWP. This study aimed to assess the cross-sectional and longitudinal associations between child neglect and BWP accuracy in primary schoolchildren, and explore how these differ based on the sex of the child.

Methods: The sample included 1,063 primary schoolchildren (557 boys and 506 girls, aged 8–10 years) from a two-wave observational study between 2018 and 2019 in Wuhan, China. Child neglect and BWP were investigated using self-administered questionnaires. The accuracy of BWP was defined by comparing the BWP and actual body weight, and it was categorized into three groups—consistent, underestimated, and overestimated. Multinomial logistic regression analysis was conducted with fitting child neglect as the independent variable and the accuracy of BWP as the dependent variable.

Results: The prevalence of weight misperception was ∼44% at baseline (underestimation 40%; overestimation 4%) in Chinese primary schoolchildren. In the cross-sectional analysis, children with a higher level of neglect were more likely to misperceive their body weight. Moreover, there was an apparent sex-related difference that boys who experienced a higher level of neglect significantly reported more underestimation, while girls reported more overestimation. There was no significant longitudinal association between child neglect and the change in BWP accuracy.

Conclusions: This study revealed that a higher level of neglect was significantly associated with underestimated BWP in boys and overestimated BWP in girls. The mechanisms of sex-related difference and whether child neglect is involved in the change in BWP, merit further investigations.

Keywords: child neglect, body weight perception, sex differences, children, multinomial logistic regression

INTRODUCTION

Body weight perception (BWP) is conceptualized as how people understand and perceive their body weight (1). It plays an important role in the management of body weight with consciousness and behaviors (2). Studies have revealed that BWP directly influences weight-control behaviors, including physical activities, and dietary behaviors (2–6). On the one hand, the misperception of body weight in those who are underweight, overweight, or obese may reduce the interest in or attempts at weight-control behaviors (5, 7). On the other hand, in those with normal weight, the misperception of body weight fuels the transition to unhealthy lifestyles (1). Given that the prevalence of childhood overweight and obesity is persistently high (over 20%) in China (8), improving the accuracy of BWP may be an effective strategy to control abnormal weight in children.

Body weight perception interacts with the actual body weight, and is affected by a range of social factors (9). Of these, child maltreatment is of particular interest, since it comprehensively reflects the child's growth environment (10). Several systematic reviews have indicated that childhood maltreatment contributed to a lifelong risk for obesity (11–13). However, little is known about the association between child maltreatment and BWP. To the best of our knowledge, only two studies assessed the relationship between childhood maltreatment and the discrepancy of BWP, but both in adults (14, 15). Late childhood to early adolescence is a critical window for physical and psychological development; children and adolescents begin to notice their own body shape and how peers perceive them (16). Therefore, an investigation into the association between child maltreatment and BWP during this period is warranted.

Additionally, sex was closely related to BWP, where underestimation of body weight is more common in boys, while overestimation is more common in girls (17, 18). Furthermore, there were differences in child maltreatment, in that boys were more likely to experience higher levels of emotional and physical neglect than girls (19). These findings suggested that the association between child maltreatment and BWP might differ depending on sex. Child maltreatment is a multidimensional concept that includes physical and sexual abuse, and neglect. Of these, child neglect is the most prevalent subtype, but received the least concern in the current study (20, 21). Given the high burden of child neglect (the prevalence was nearly 50%) (21) and inaccurate BWP (the prevalence of misperception was over 30%) (17, 22), we conducted a two-wave observational study to examine the cross-sectional and longitudinal associations between child neglect and the accuracy of BWP, and assess whether those vary by sex.

METHODS

Study Design

This study was originally designed to investigate the health outcomes of child neglect in a convenience sample in four public primary schools in Wuhan, China. All students from grades 3 to 4 were invited to participate in the baseline study in April 2018, and would be followed-up with annually until graduation from primary school (grade 6). Written informed consent was obtained from children and parents. This study was approved by the Medical Research Ethics Committee of Wuhan University.

Participants

A total of 1,340 children (aged 9.1 $\pm$ 0.6 years) were included at baseline following the inclusion criteria: (i) without preexisting congenital diseases and defects (e.g., diabetes, heart disease, hypertension, and disability); (ii) not being transfer students or the transfer period was over one semester; and (iii) did not suffer major family changes (e.g., parents' divorce and relative's death). This study used the data of baseline and the first wave of follow-up (2019) for data analysis. A total of 1,193 children completed the two-wave observation, and 147 children were lost to follow-up (attrition rate: 11%) because of the following reasons: sick/compassionate leave, school transfer, and refusal to partake in the follow-up investigation.

Measurements

Body weight: Children's height without shoes and with light clothes was measured using standard methods to calculate BMI, with weight (kg) divided by height squared (m^2) (23). The actual body weight was defined as severe underweight, underweight, normal weight, overweight, and obese, using the BMI reference values for Chinese school-age children (24).

Body weight perception: BWP was determined by asking "Which body shape do you think you have?" There were five possible responses: "too thin," "relatively thin," "all right," "relatively heavy," and "too heavy" (16). The accuracy of BWP was examined by comparing the actual body weight with the BWP. Children who were (severely) underweight but perceived themselves as "all right" and "relatively (too) heavy" and those with normal weight who perceived themselves as "relatively (too) heavy" were categorized as "overestimated." Conversely, children who were overweight or obese but perceived themselves as "all right" and "too (relatively) thin" and those with normal weight who perceived themselves as "relatively (too) thin" were categorized as "underestimated." Children who are (severely) underweight and perceived themselves as "relatively thin" or "too thin," who were normal weight and perceived themselves as "all right," and those who were overweight or obese and perceived themselves as "relatively heavy" or "too heavy," were categorized under "consistent" (25).

Child neglect: Child neglect was assessed using the Child Neglect Scale (CNS) developed by Yang et al. (26), which comprises 38 items in four dimensions: physical neglect (7 items); emotional neglect (14 items); security neglect (9 items); and communication neglect (8 items). Each item was evaluated using a four-point Likert scale: "never," "occasional," "usual," and "constant." The CNS has been validated in Chinese schoolchildren and has shown good internal consistency (Cronbach's $\alpha = 0.85$) and test-retest reliability (0.90) (27). The total score of the CNS ranges from 4 to 152, with a higher score indicating a higher level of neglect. This study used the tertiles of neglect for analysis.

Covariates: Age and sex were reported by children. Demographic characteristics, including monthly household

income, parental education, and single-child family were reported by parents. Monthly household income was classified as "<10,000," "10,000–20,000," and ">20,000" (*RMB*). Parental education was classified as "middle school or lower," "high school," and "university or higher." The single-child family was determined with a "yes" and "no." The pubertal stage was evaluated in a private room by trained investigators using the Tanner Stage Scale. The pubertal development was determined by comparing the external primary and secondary sex characteristics of children with the realistic color image of the Tanner Stage Scale (28).

Procedures

Body weight perception and child neglect were assessed in classrooms with the guidance of teachers, using self-administered questionnaires. All questionnaires were answered independently to protect privacy and were signed with real names for tracking during the follow-up. Trained investigators read and explained each item in the questionnaires to facilitate completion by the children. The children were then invited to attend the anthropometric test and pubertal stage evaluation in separate locations, according to sex. The demographic information was also collected using questionnaires, which were brought home by children.

Statistical Analysis

Among the 1,193 children who completed the baseline and follow-up surveys, 130 were excluded from the final analysis because of missing information in child neglect, actual body weight, BWP, or other covariates. Chi-square test was used to examine the difference in all variables between sex and between the included and excluded samples. All descriptive statistics of 1,063 children (557 boys and 506 girls) were categorical variables and presented as frequency (%). Multinomial logistical regression model regarding the consistent BWP as reference group was used to examine the cross-sectional and longitudinal association between child neglect, and the accuracy of BWP stratified by sex. For cross-sectional analyses, model 1 was adjusted for school, age, monthly household income, parental education, and single-child family at baseline, and model 2 was further adjusted for pubertal stage and BMI at baseline. For longitudinal analyses, BWP at baseline was further included in model 1. The threshold for the statistical significance was set at P-value < 0.05. Statistical Package for the Social Sciences (SPSS) software (version 20.0. Armonk, NY: IBM Corp.) was used to conduct all analyses.

RESULTS

As shown in **Table 1**, the children's age ranged from 8 to 10 years. Approximately 70% of the children lived in a household with a monthly income of over 10,000 yuan, or parents with a university degree or higher. More than half of the children had no siblings in the family. There were no significant differences in demographic characteristics between sex. Boys had a higher level of child neglect than girls (tertiles 2–3: 66.4 vs. 59.1%). The prevalence of underweight and overweight children was ∼3 and 20%, respectively, in all children at baseline, while the prevalence of overweight boys (23%) was much higher than overweight girls (15.6%). The prevalence of underweight and overweight children was 1.4 and 25.6%, respectively, in all children during follow-up, and the sex-related difference was still significant. Nearly half of the children perceived their body weight as too (relatively) thin/heavy at baseline and follow-up, with no significant sex-related difference. Approximately 40% of the children did not perceive their body weight accurately at baseline and follow-up. Among them, underestimation was more common than overestimation, regardless of sex. Sex-related difference in BWP accuracy was insignificant at baseline, but significant at follow-up. There were no significant differences in all variables between the included and excluded samples, except for a marginally significant lower level of neglect among children in the excluded sample (Supplementary Table 1).

Table 2 shows the cross-sectional analysis between child neglect and the accuracy of BWP in all children or stratified by sex. In the overall sample, children in the highest tertile of neglect were more likely to report underestimation (OR = 1.59, 95% CI: 1.17–2.17, $P = 0.003$) and overestimation (OR = 2.19, 95% CI: 1.01–4.74, $P = 0.047$) of their own body weight compared with those in the first tertile, even when adjusted for demographical characteristics, pubertal stage, and BMI. However, the sex-stratified analysis indicated that boys in the highest tertile of neglect showed increased odds of underestimating their body weight (OR = 1.80, 95% CI: 1.16–2.80, $P = 0.009$), while the association between child neglect and underestimated BWP was not significant in girls (OR = 1.35, 95% CI: 0.86–2.12, $P = 0.189$). Conversely, there was a significant association between child neglect and overestimated BWP in girls (OR = 3.36, 95% CI: 1.18–9.57, $P = 0.023$) for the highest tertile of child neglect, which was not significant in boys (OR = 1.01, 95% CI: 0.30–3.38, $P = 0.991$).

The accuracy of BWP at follow-up, with child neglect at baseline, was also examined (**Table 3**). However, child neglect at baseline was not associated with the misperception of body weight at follow-up, in both overall and sex-stratified analyses.

DISCUSSIONS

There was a high discrepancy between BWP and actual body weight in Chinese schoolchildren, with nearly 40% of the children reporting underestimation, and 5% reporting overestimation. This study revealed a significant cross-sectional association between child neglect and underestimated and overestimated BWP. Moreover, the association differed in sex that boys with higher neglect were more likely to report underestimated BWP, while girls with higher neglect were more likely to report overestimated BWP. However, longitudinal associations were not significant in both overall and sex-stratified analyses.

The prevalence of inaccurate BWP was nearly 45% in our study, which was slightly higher than that in previous studies among Chinese schoolchildren (17, 18, 29). Comparing those studies, the prevalence of the underestimated BWP was consistently much higher than that of the overestimated BWP (17, 18, 29), and the magnitude varied from ∼2 times higher

TABLE 1 | Descriptive characteristics in the sample of 1,063 primary schoolchildren.

Characteristics	Total (n = 1,063)	Boys (n = 557)	Girls (n = 506)	P[a]
Baseline				
Age, *years*				0.223
8	114 (10.7%)	55 (9.9%)	59 (11.7%)	
9	725 (68.2%)	374 (67.1%)	351 (69.4%)	
10	224 (21.1%)	128 (23%)	96 (19%)	
Monthly household income, *yuan*				0.326
<10,000	326 (30.7%)	176 (31.6%)	150 (29.6%)	
10,000∼20,000	457 (43%)	245 (44%)	212 (41.9%)	
>20,000	280 (26.3%)	136 (24.4%)	144 (28.5%)	
Parental education				0.952
Middle school or lower	95 (8.9%)	49 (8.8%)	46 (9.1%)	
High school	163 (15.3%)	84 (15.1%)	79 (15.6%)	
University or higher	805 (75.7%)	424 (76.1%)	381 (75.3%)	
Single-child family, *yes*	575 (54.1%)	312 (56.0%)	263 (52.0%)	0.187
Pubertal stage				0.554
Tanner 1	46 (4.3%)	26 (4.7%)	20 (4.0%)	
Tanner 2	565 (53.2%)	302 (54.2%)	263 (52%)	
Tanner 3	451 (42.4%)	228 (40.9%)	223 (44.1%)	
Tanner 4[b]	1 (0.1%)	1 (0.2%)	–	
Child neglect, tertiles				0.046
T1 (∼54)	394 (37.1%)	187 (33.6%)	207 (40.9%)	
T2 (54–69)	327 (30.8%)	182 (32.7%)	145 (28.7%)	
T3 (70∼)	342 (32.2%)	188 (33.8%)	154 (30.4%)	
Actual body weight				0.009
Underweight	32 (3%)	15 (2.7%)	17 (3.4%)	
Normal weight	824 (77.5%)	414 (74.3%)	410 (81.0%)	
Overweight	207 (19.5%)	128 (23.0%)	79 (15.6%)	
Self-perceived body weight				0.221
Too (relatively) thin	368 (34.6%)	194 (34.8%)	174 (34.4%)	
Normal	550 (51.7%)	278 (49.9%)	272 (53.8%)	
Too (relatively) heavy	145 (13.6%)	85 (15.3%)	60 (11.9%)	
The accuracy of body weight perception				0.090
Consistent	592 (55.7%)	312 (56%)	280 (55.3%)	
Underestimated	427 (40.2%)	229 (41.1%)	198 (39.1%)	
Overestimated	44 (4.1%)	16 (2.9%)	28 (5.5%)	
Follow-up				
Actual body weight				0.010
Underweight	15 (1.4%)	8 (1.4%)	7 (1.4%)	
Normal weight	776 (73%)	385 (69.1%)	391 (77.3%)	
Overweight	272 (25.6%)	164 (29.4%)	108 (21.3%)	
Self-perceived body weight				0.456
Too (relatively) thin	271 (25.5%)	150 (26.9%)	121 (23.9%)	
Normal	598 (56.3%)	304 (54.6%)	294 (58.1%)	
Too (relatively) heavy	194 (18.3%)	103 (18.5%)	91 (18%)	
The accuracy of body weight perception				0.007
Consistent	641 (60.3%)	327 (58.7%)	314 (62.1%)	
Underestimated	373 (35.1%)	213 (38.2%)	160 (31.6%)	
Overestimated	49 (4.6%)	17 (3.1%)	32 (6.3%)	

[a] *The sex difference was tested by* χ^2 *test.*
[b] *Tanner 4 was not included in the* χ^2 *test.*

TABLE 2 | Cross-sectional analysis for the association of child neglect with the accuracy of body weight perception at baseline.

Child neglect, tertiles	Underestimated vs. consistent						Overestimated vs. consistent					
	Total (n = 1,063)		Boys (n = 557)		Girls (n = 506)		Total (n = 1,063)		Boys (n = 557)		Girls (n = 506)	
	OR (95% CI)	*P*	OR (95% CI)	*P*	OR (95% CI)	*P*	OR (95% CI)	*P*	OR (95% CI)	*P*	OR (95% CI)	*P*
Model 1[a]												
T1 (∼54)	1.00		1.00		1.00		1.00		1.00		1.00	
T2 (54–69)	1.11 (0.81–1.51)	0.515	1.21 (0.78–1.88)	0.389	0.99 (0.63–1.56)	0.970	1.51 (0.68–3.38)	0.312	0.61 (0.16–2.33)	0.473	2.41 (0.83–6.99)	0.104
T3 (70∼)	1.63 (1.20–2.22)	**0.002**	1.79 (1.16–2.77)	**0.009**	1.41 (0.91–2.21)	0.127	2.25 (1.04–4.85)	**0.040**	0.99 (0.30–3.32)	0.992	3.51 (1.24–9.96)	**0.018**
Model 2[b]												
T1 (∼54)	1.00		1.00		1.00		1.00		1.00		1.00	
T2 (54–69)	1.11 (0.82–1.52)	0.500	1.23 (0.79–1.91)	0.355	1.00 (0.63–1.58)	0.990	1.53 (0.68–3.41)	0.304	0.60 (0.16–2.29)	0.453	2.44 (0.84–7.08)	0.101
T3 (70∼)	1.59 (1.17–2.17)	**0.003**	1.80 (1.16–2.80)	**0.009**	1.35 (0.86–2.12)	0.189	2.19 (1.01–4.74)	**0.047**	1.01 (0.30–3.38)	0.991	3.36 (1.18–9.57)	**0.023**

[a]*Model 1 adjusted for school, age, sex (sex stratified analysis did not include sex), monthly household income, parental education, and single-child family at baseline.*
[b]*Model 2 further adjusted for pubertal stage and body mass index at baseline. Bold values indicate statistical significance with P-value < 0.05.*

TABLE 3 | Longitudinal analysis for the association of child neglect with the accuracy of body weight perception at follow-up.

Child neglect, tertiles	Underestimated vs. consistent						Overestimated vs. consistent					
	Total (n = 1,063)		Boys (n = 557)		Girls (n = 506)		Total (n = 1,063)		Boys (n = 557)		Girls (n = 506)	
	OR (95% CI)	*P*	OR (95% CI)	*P*	OR (95% CI)	*P*	OR (95% CI)	*P*	OR (95% CI)	*P*	OR (95% CI)	*P*
Model 1[a]												
T1 (∼54)	1.00		1.00		1.00		1.00		1.00		1.00	
T2 (54–69)	1.09 (0.79–1.53)	0.596	1.50 (0.95–2.38)	0.085	0.75 (0.45–1.23)	0.250	1.12 (0.52–2.41)	0.783	0.81 (0.23–2.87)	0.740	1.16 (0.43–3.12)	0.765
T3 (70∼)	0.94 (0.67–1.31)	0.697	1.18 (0.74–1.88)	0.493	0.73 (0.45–1.19)	0.204	1.49 (0.73–3.07)	0.277	0.85 (0.25–2.94)	0.800	1.77 (0.70–4.44)	0.228
Model 2[b]												
T1 (∼54)	1.00		1.00		1.00		1.00		1.00		1.00	
T2 (54–69)	1.10 (0.78–1.53)	0.593	1.55 (0.97–2.47)	0.065	0.72 (0.43–1.18)	0.192	1.13 (0.52–2.44)	0.761	0.89 (0.25–3.21)	0.856	1.15 (0.43–3.09)	0.782
T3 (70∼)	0.90 (0.64–1.26)	0.524	1.15 (0.71–1.84)	0.578	0.68 (0.41–1.12)	0.131	1.46 (0.71–3.02)	0.306	0.87 (0.25–3.01)	0.822	1.75 (0.69–4.45)	0.239

[a]*Model 1 adjusted for school, age, sex (sex stratified analysis did not include sex), monthly household income, parental education, single-child family, and the accuracy of body weight perception at baseline.*
[b]*Model 2 further adjusted for pubertal stage and body mass index at baseline.*

(25.3% underestimated BWP vs. 13.1% overestimated BWP) in the study of Wang VH et al. (18) to 10 times higher than (about 40% underestimated BWP vs. 4% overestimated BWP) in our study. This was mainly due to the difference in the study setting that all children in our study lived in urban areas, while 63% of the children in a study by Wang Y et al. (17) and 47% of the children in a study by Wang (18) lived in rural areas. Therefore, rural-urban variation may affect the difference between the prevalence of the underestimated and overestimated BWP. Additionally, a similar significant sex-related difference was observed in a study by Wang Y et al. (17), while Wang VH et al. (18) reported an insignificant sex-related difference in children aged 6–11 years. They consistently explained that the sex-related difference may result from different beliefs of ideal body image, in that boys preferred masculinity and girls preferred femininity (17, 18). Furthermore, Wang infers that the prevalence of the underestimated and overestimated BWP may change a lot from childhood to adolescence in girls, and that a higher proportion of girls will overestimate their body weight (18). Therefore, future weight management programs for children and adolescence should consider the sex-related difference in the different growth and developmental stages.

Currently, no study examines the association between child neglect and inaccurate BWP in children, while two studies in adults consistently indicated that child maltreatment was associated with inaccurate BWP in adulthood (14, 15). These studies suggested that adults with higher child maltreatment may be more sensitive and vulnerable to subsequent stressors and consequently, easily misperceive their body weight (14, 15). In addition, as for children, the maltreatment experience directly leads to maladjustment, including depression and low self-esteem (30). In turn, the adverse psychological consequence was associated with inaccurate BWP (16, 31). Additionally, child neglect in families inherently results from parents/caregivers. The lack of supervision and communication between children and parents may lead to children's BWP is more likely influenced by peers and social media (17). On the other hand, the lack of attachment and security caused by neglect exacerbates the parent-child discrepancy in children's BWP. A study by Uccula et al. indicated that parents of children with insecurities had a tendency to underestimate the actual body weight of their children, particularly those who were overweight or obese (32). In this situation, parents believe that their children perceive themselves as more obese than the parents perceive them, and unconsciously construct an obesogenic family environment (32).

Importantly, our study highlighted the sex-related difference in the association between child neglect and misperception of body weight, which was also consistent with the findings of two studies in adults (14, 15). These studies consistently explained that females with a higher level of child maltreatment were more vulnerable to life stress (14, 15), and it might be fueled by maladaptive strategies that used body shape to determine self-worth (14). However, it was unclear whether the explanation could be applied to children. In addition, children's coping strategies with stress differ in sex, in that girls were more likely to suffer from depression after relational victimization (33). Moreover, a study by Wei et al. indicated that girls who experienced childhood trauma displayed a higher risk of depression than boys (34). Additionally, we failed to identify a longitudinal significant association between child neglect and the accuracy of BWP. We supposed that the measurement of body weight might have an influence on children's BWP and that the preface of the parents' questionnaire reminded them to focus on children's body weight.

Strengths and Limitations

To the best of our knowledge, our study was the first to investigate the association between child neglect and the accuracy of BWP using a longitudinal design. Our findings directly indicated the negative influence of child neglect on the accuracy of BWP, which indirectly emphasized that the development of BWP and the management of body weight required family support. Additionally, the identification of sex-related differences in their association will be helpful for explaining the sex-related difference in the prevalence of childhood obesity and the inaccuracy of BWP in children in China.

This study has several limitations. First, this study used a convenience sampling method, with a high proportion of children from high socioeconomic families. Second, four public schools were in the urban areas. Therefore, the generalizability of our results is limited by sample selection bias. Third, ∼11% of the children were excluded from the final analysis, which might also result in selection bias. However, the comparison of all variables between the included and excluded samples was insignificant. Fourth, child neglect was assessed using a self-reported questionnaire, making a recall bias inevitable. However, CNS has been validated and has shown good reliability in Chinese schoolchildren. Finally, other potential confounders to BWP, including exposure to social media and psychological factors, were not assessed in the analysis.

CONCLUSIONS

This study suggested that the prevalence of inaccurate BWP was common in Chinese primary schoolchildren, and largely consisted of underestimated BWP. Importantly, our study revealed that child neglect was significantly associated with inaccurate BWP. Moreover, a significant sex-related difference was identified that boys who experienced a higher level of neglect were more likely to report underestimated BWP, while girls who had been neglected were more likely to report overestimated BWP. The mechanisms of sex-related difference and whether child neglect is involved in the change in BWP merit further investigations.

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 Medical Research Ethics Committee of Wuhan

University. Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

AUTHOR CONTRIBUTIONS

H-jY: conceptualization, data curation, formal analysis, investigation, methodology, validation, visualization, writing—original draft, and writing—review and editing. XL: conceptualization, formal analysis, methodology, writing—original draft, and writing—review and editing. M-wL: investigation, project administration, and writing-review and editing. MZ: methodology and writing—review and editing. Q-qH: conceptualization, data curation, funding acquisition, investigation, methodology, project administration, resources, software, supervision, validation, and writing-review and editing. All authors have read and approved the final manuscript.

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A Spatial Analysis of Access to Physical Activity Infrastructure and Healthy Food in Regional Tasmania

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Prevalence of physical inactivity and obesity continues to increase in regional areas such as North-West (NW) Tasmania and show no signs of abating. It is possible that limited access to physical activity infrastructure (PAI) and healthier food options are exacerbating the low levels of habitual physical activity and obesity prevalence in these communities. Despite a burgeoning research base, concomitant exploration of both physical activity and food environments in rural and regional areas remain scarce. This research evaluated access (i.e., coverage, variety, density, and proximity) to physical activity resources and food outlets in relation to socioeconomic status (SES) in three NW Tasmanian communities. In all three study areas, the PAI and food outlets were largely concentrated in the main urban areas with most recreational tracks and natural amenities located along the coastline or river areas. Circular Head had the lowest total number of PAI ($n = 43$) but a greater proportion (30%) of free-to-access outdoor amenities. There was marked variation in accessibility to infrastructure across different areas of disadvantage within and between sites. For a considerable proportion of the population, free-to-access natural amenities/green spaces and recreational tracks (73 and 57%, respectively) were beyond 800 m from their households. In relation to food accessibility, only a small proportion of the food outlets across the region sells predominantly healthy (i.e., Tier 1) foods (∼6, 13, and 10% in Burnie, Circular Head and Devonport, respectively). Similarly, only a small proportion of the residents are within a reasonable walking distance (i.e., 5–10 min walk) from outlets. In contrast, a much larger proportion of residents lived close to food outlets selling predominantly energy-dense, highly processed food (i.e., Tier 2 outlets). Circular Head had at least twice as many Tier 1 food stores per capita than Devonport and Burnie (0.23 vs. 0.10 and 0.06; respectively) despite recording the highest average distance (4.35 and 5.66 km to Tier 2/Tier 1 stores) to a food outlet. As such, it is possible that both food and physical activity environment layouts in each site are contributing to the obesogenic nature of each community.

Keywords: obesity, physical activity, food environment, spatial analysis, regional area, NW Tasmania, Regional Australia

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INTRODUCTION

Physical inactivity and sub-optimal dietary practises are global public health concerns, and inexorably linked to poor health outcomes (1, 2). Sustained inactivity impacts short- and long-term health and quality of life, with substantial attendant economic costs (3). In Australia, as is the case in many developed nations, low levels of physical activity are very common; 55% of Australians aged 18 years and over do not engage in recommended levels of habitual physical activity (4). Similarly, consumption of fruit and vegetables—an important indicator of a healthy diet and lifestyle—is low, with the vast majority of Australian adults failing to meet national dietary recommendations. These patterns of low levels of physical activity and sub-optimal dietary practises are particularly acute in regional areas such as Northwest (NW) Tasmania which report some of the lowest levels of physical activity in the country (5). Moreover, only 3% of Tasmanian adults meet the National Health and Medical Research Council guidelines for fruit and vegetable consumption (5).

The built environment—broadly defined as major physical structures and facilities where people live, work, and play, such as buildings, stores, streets, homes, schools, parks, playgrounds, and other infrastructure (e.g., fitness and community centres)—have a significant impact on the physical activity and dietary patterns of individuals (6, 7). The built environment differs notably between urban and regional settings, with major downstream effects on health outcomes (8, 9). For instance, lack of physical activity resources and limited access to healthy food options in regional areas can manifest as higher prevalence of lifestyle-related chronic diseases (10–12). The significantly higher prevalence of obesity and associated chronic diseases in adults living in the NW of Tasmania is a good case in point.

Economic precarity in most regional locations further complicates the relationship between the built environment and health. There is strong evidence for the association between socioeconomic status (SES) and obesity (13–17). Regional NW Tasmania is a relatively disadvantaged area (18, 19), and this may partly explain the prevalence of obesity and associated chronic disease. Physical activity resources and access to healthy food may also be inequitably distributed in these locations and reinforce patterns of obesity. The links between the built environment and PA/PI are manifold and complex. Nevertheless, the availability of Geographic Information System (GIS) based measures such as population density, land-use mix, access to recreational facilities, and street connectivity etc., and a multitude of observational infrastructure assessment techniques in recent times, has demonstrably improved the ability to assess the capacity of the built environment and its effect on health and wellbeing (20–22).

A considerable body of empirical evidence illustrates associations between obesity, SES, and attributes of the built environment, including access to healthy food and physical activity resources (23–25). However, to date, most of this evidence has been generated in large urban areas. A better understanding of the local food and physical activity environment in regional NW Tasmania may elucidate some of the drivers of high rates of obesity and chronic disease in this and similar regional areas, and potential intervention points to improve health in these locations. Therefore, this research aimed to evaluate access (i.e., coverage, variety, density, and proximity) to physical activity resources and healthier food in NW Tasmania. Secondly, we evaluated the relationship between access to physical activity opportunities, healthier food, population density, and SES in the region.

MATERIALS AND METHODS

A visual representation of study procedure is presented in **Figure 1**.

Study Area

The study regions included three Local Government Areas (LGAs)—Burnie, Devonport, and Circular Head—in the NW of Tasmania. Briefly, the selected LGAs were classified as Remoteness Area 2 (Inner Regional Australia) and 3 (Outer Regional Australia), according to the Australian Statistical Geography Standard classification system and contained sufficiently demarcated administrative boundaries from neighbouring communities. SES was defined using Socio-Economic Indexes for Areas (SEIFA) Index of Relative Socio-economic Advantage and Disadvantage (IRSAD) scores for each Statistical Area 1 (SA1; ∼400 people) within each LGA, accessed via the Australian Bureau of Statistics (26).

Census of Physical Activity Resources and Food Outlets

Seven categories [based on previous literature (27)] of physical activity infrastructure/ resources (referred to herein as PAI) was generated using an extensive online search via Google, Yellow Pages, Facebook, Local Council and State Government web pages. Subsequently, two categories of PAI (Recreation track and Natural amenity/green space) were further classified as "free-to-access" based on them being accessible around the clock with no associated monetary costs.

1. Recreation track: free-to-access, purpose-built outdoor pathway, trail, or track for recreational physical activity.
2. Natural amenities, green space: free-to-access area of vegetation or a beach, set apart for recreational purposes. National parks were not included in this category as they require a permit to visit them.
3. Sporting venues: purpose-built outdoor sporting areas for organised sport.
4. Multi-purpose community centre: purpose-built structure for informal, formal, and social recreational and physical activities.
5. Gyms/fitness centres/dance studios: purpose-built structures for strength and conditioning activities and learning/rehearsing dance.
6. Religious venues (e.g., churches): purpose-built structures (primarily) for public religious activity with secondary usage for recreational pursuits.

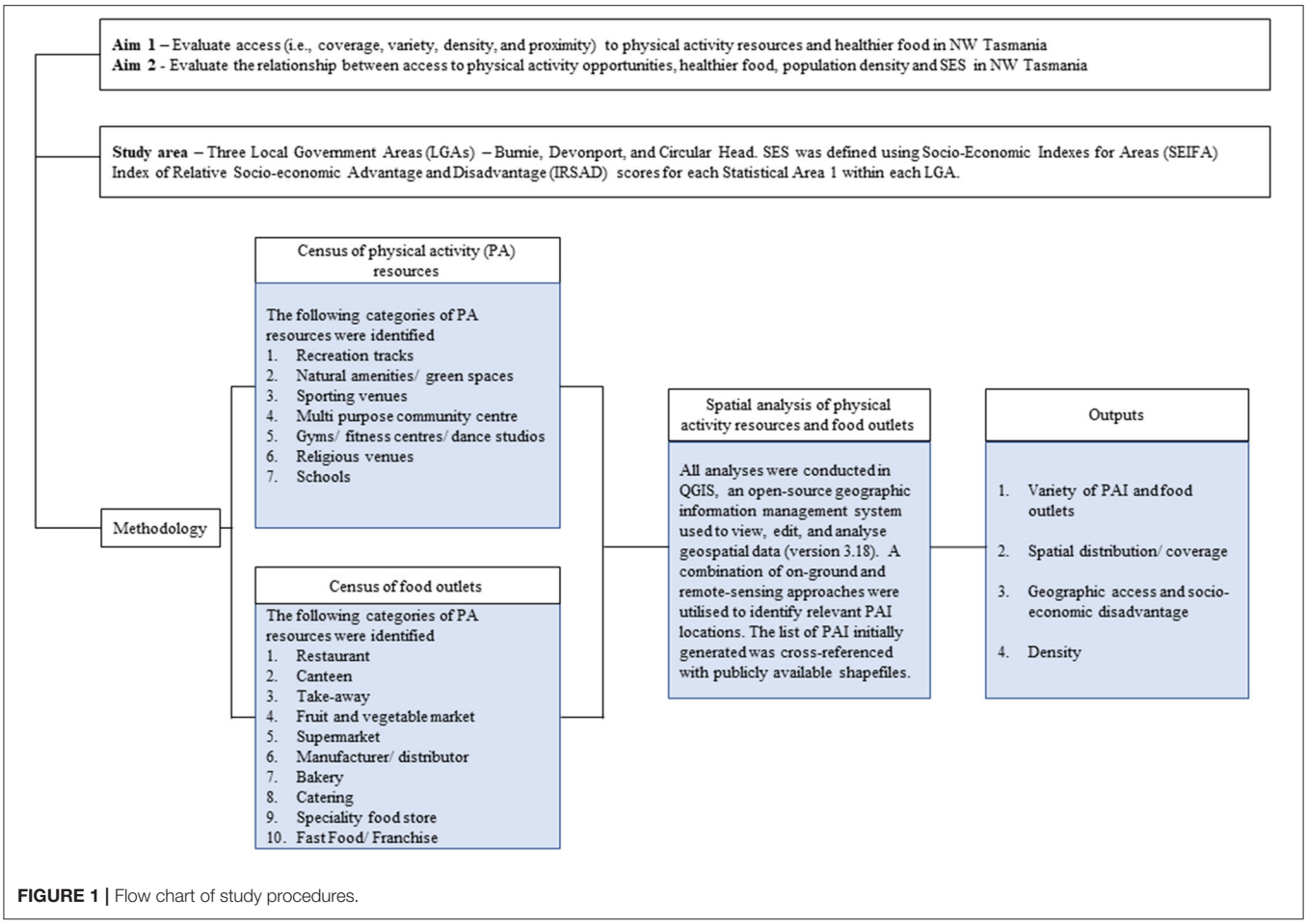

FIGURE 1 | Flow chart of study procedures.

7. Schools: purpose-built structures for educating children which also have outdoor play equipment.

Ten categories of food outlets were initially identified through business registration lists (obtained via LGA Environmental Health Officers) for each study site. These were subsequently cross-referenced and confirmed through online verification by trained research personnel.

1. Restaurant - Seated venue where food is purchased and primarily eaten onsite.
2. Canteen - Where food is prepared / served and associated with a school, aged care, or sporting facility site.
3. Take Away - Where food is prepared and purchased to take away.
4. Fruit & Vegetable Market - Primarily sells fruit and vegetables.
5. Supermarket - A primarily self-service shop selling foods and household goods.
6. Manufacturer/distributor - Manufacturers or processes food that is on sold mainly to other businesses for resale (could be home based or larger commercial operation).
7. Bakery - Produces baked goods / bakery products.
8. Catering -Mobile business that provides prepared food (e.g., food vans, caterers that cater for events, service /special interest clubs etc.).
9. Specialty food store - Butcher or fishmonger.
10. Fast Food/ Franchise - Business belong to franchise and sells fast food primarily to take away.

For analytical purposes, food outlets were stratified into "Tier 1" (green grocers, butchers, supermarkets and health food shops etc.), and "Tier 2" (chain and non-chain fast-food outlets, bakeries, sweet food retailers, and convenience stores, etc.) outlets (refer to **Table 2** for all categories and their designations) using previously published approaches (23, 28, 29). Briefly, a combination of visibility of fruit and vegetables in the outlet consumer view-space (as judged by research team members) and the level of "food processing" (defined as all methods and techniques utilised by food, drink, and associated industries to convert fresh foods into food products) was considered in the assignment of outlets to one of two categories.

Spatial Analysis

All analyses were conducted in QGIS, an open-source geographic information management system used to view, edit, and analyse geospatial data (version 3.18) (30). A combination of on-ground and remote-sensing approaches were utilised to identify relevant PAI locations. The list of PAI initially generated was cross-referenced with publicly available shapefiles (i.e., Public Land

Classification, Local Government Authority Reserves, Tasmanian Reserve Estates and Infrastructure and Utilities to identify Track and Ferry Routes) to further identify potentially relevant natural amenities/green space and recreational tracks and their spatial extents. Subsequently, the potentially relevant tracks and polygons (natural amenities) were "ground trothed" using local knowledge; irrelevant sites were removed, and spatial extents corrected as needed.

Once the final layers of relevant points, lines and polygons were formed, population-weighted centroids were created for each SA1/suburb in the area using the 2019 average annual night-time lights (31). Unpopulated SA1s were removed from all analyses ($n = 6$). Weighted centroids were used to calculate the average distance to the nearest PAI or Tier 1 food outlet using the point-to-point calculations tool (for points) and the NNjoin tool for distance to nearest polygon or line.

The number of points per LGA was calculated by "Count points in a polygon" tool for PAI points, healthy and Tier 2 food sites. Length of tracks/trails was calculated using the vector analysis "sum line lengths" tool. Buffers were created for each line, point and polygon by first converting these shapefiles into the Lambert projection system, and then adding the 400 and 800 m buffers—∼5 and 10 min of walking distance (32, 33)—for each geometry type. SA1s were intersected with the buffered areas and the percent of the area of the SA1 inside the buffer was used to calculate the percent of the population with access to that PAI. These values were calculated for each SA1 and averaged across IRSAD rankings or population density quintiles for each region of interest.

TABLE 1 | Proportion of physical activity infrastructure (PAI) in Burnie, Circular Head, and Devonport.

	Burnie % (*n*)	Circular Head % (*n*)	Devonport % (*n*)
Recreation track	5% (3)	7% (3)	14% (12)
Natural amenities/green space	16% (12)	23% (18)	12% (9)
Sporting venues	24% (14)	23% (8)	26% (16)
Multi-purpose community centre	2% (2)	7% (3)	4% (3)
Gyms/fitness centres/dance studios	21% (13)	5% (2)	14% (19)
Churches	8% (6)	16% (8)	13% (10)
PAI in schools	24% (15)	19% (8)	18% (14)
Total PAI	100% (*N* = 62)	100% (*N* = 43)	100% (*N* = 78)

TABLE 2 | Variety of Tier 1/Tier 2 food outlets in Burnie, Circular Head, and Devonport.

	Burnie *N* = 163	Circular Head *N* = 119	Devonport *N* = 248
Tier 1 food options			
Fruit and vegetable market	1	1	1
Supermarket	9	10	13
Specialty food store	0	0	8
Tier 1 manufacturer/distributor	0	5	4
Total Tier 1 food outlets	10	16	26
Tier 2 food options			
Restaurant	51	33	101
Canteen	37	28	40
Take away	35	11	18
Bakery	11	3	3
Catering	0	10	25
Fast food/Franchise	14	0	13
Tier 2 manufacturer/Processor	5	18	23
Total Tier 2 food outlets	153	103	222
Proportion of Tier 1 (*n*) from total food options	6% (10/163)	13% (16/119)	10% (26/248)

RESULTS

Variety of PAI and Food Outlets

All three study sites were found to have a variety of PAI food outlets (**Tables 1**, **2**). Circular Head had the lowest number of PAI ($n = 43$) although 30% were free-to-access outdoor amenities (i.e., natural amenities/green space and recreational tracks)—the highest proportion in the wider study region. Approximately one quarter of all PAI in the study sites are sporting venues (**Table 1**). It is also noteworthy that ∼20% of PAI are located within school premises (**Table 1**). Despite the variability, ∼6, 13, and 10% of the food outlets in Burnie, Circular Head and Devonport, respectively, were classified as "Tier 1" (**Table 2**). Further, there was a noticeable absence of "fast food outlets" in Circular Head and "speciality food stores" in Burnie and Devonport (**Table 2**).

Spatial Distribution/Coverage

Geographical locations of the identified PAI and food outlets in Burnie, Circular Head and Devonport are presented in **Figures 2A,B**. In all three study areas, the PAI (**Figure 2A**) and food (**Figure 2B**) were largely concentrated in the main urban areas (see insets) with most recreational tracks and natural amenities (e.g., beaches) located along the coastline or the riverine areas. In all locations, non-free-to-access PAI points (which included Categories 3–7) were more distributed throughout the urban area than the tracks or natural amenities; however, Burnie has several inland natural amenities/green spaces within the urban area and beyond (**Figure 2A**). The number of "Tier 2" food outlets vastly out-weigh the "Tier 1" food outlets in all 3 study areas (**Figure 2B**) with no distinct spatial distribution pattern observable. The availability of PAI points per 100 people ranged between 0.2 and 0.4 across the sites with Circular Head recording the highest PAI points per capita. The amount (in km^2) of natural amenities per 100 people was low across the three regions, with Devonport having <0.01 km^2 per 100 capita (**Table 3**). Further, length of walking track per capita is substantially lower in Burnie compared with the other 2 sites (**Table 3**). Devonport has the most accessible PAI (average distance <2 km) while residents in Circular Head were, on average, ∼8 km away from the nearest PAI (**Table 3**).

As for the food outlets, Circular Head had at least twice as many Tier 1 food stores per capita than Devonport and

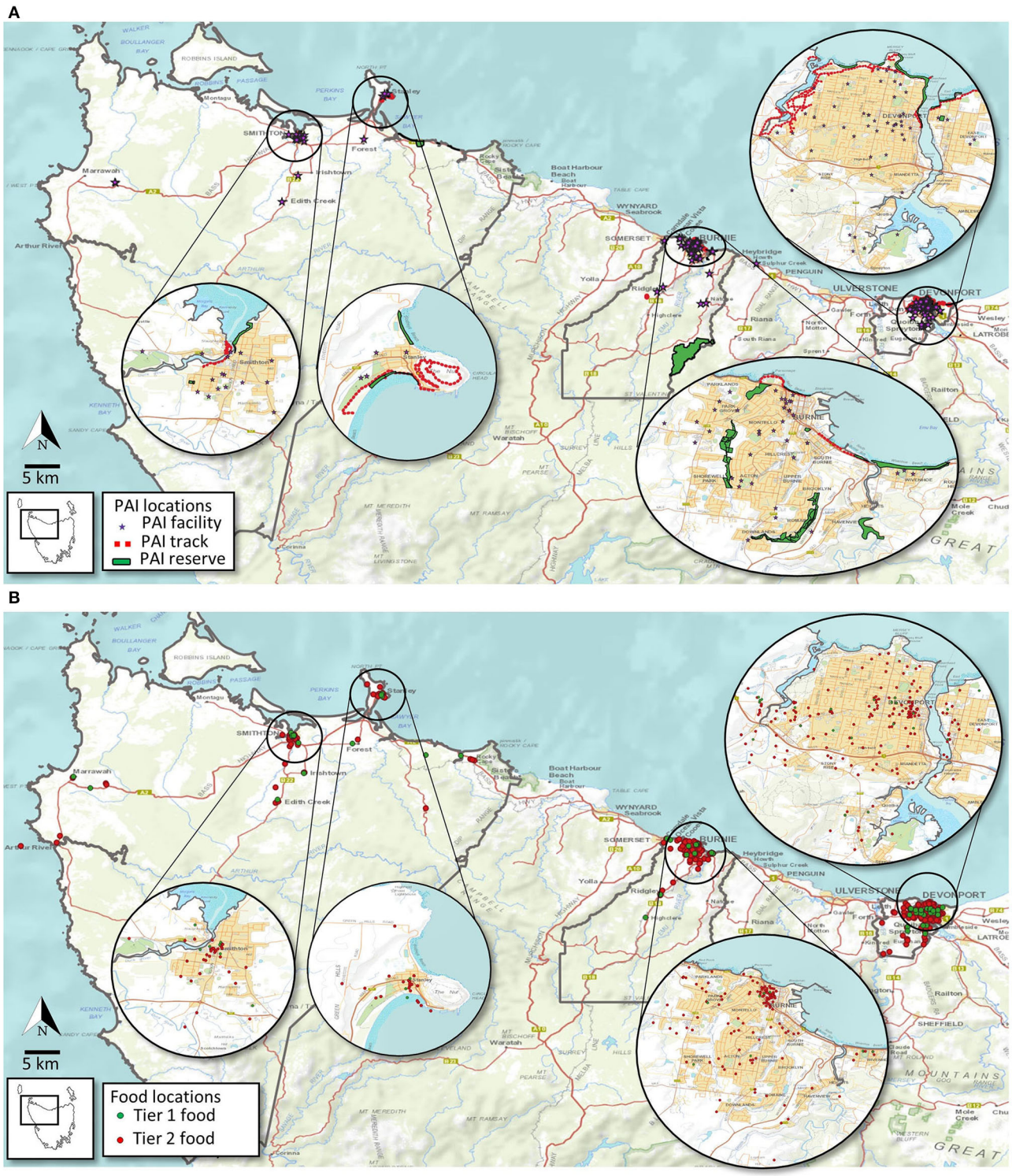

FIGURE 2 | Spatial distribution of PA infrastructure **(A)** and food outlets **(B)** across the study area.

Burnie (0.23 vs. 0.10 and 0.06; respectively) despite recording the highest average distance (4.35 and 5.66 km to Tier 2/Tier 1 stores) to a food outlet (**Table 3**) and the lowest number of food outlets overall (**Table 2**). Proximity to food outlets was highest in Devonport with a Tier 2 food outlet available in less than a kilometre from the average resident (**Table 3**).

TABLE 3 | Summary of the availability of physical activity infrastructure (PAI) and food outlets per region.

Region	Number of PAI points per 100 people	Area of natural amenity/green space per 100 people (km^2)	Length of recreational track per 100 people (km)	Healthy food outlets per 100 people	Avg distance to PAI point (km)	Avg distance to natural amenity/green space (km)	Avg distance to recreational track (km)	Avg distance to Tier 2 food outlet (km)	Avg distance to Tier 1 food outlet (km)
Burnie	0.26	0.11	0.16	0.06	3.88	4.27	6.10	4.14	4.48
Circular Head	0.39	0.03	1.09	0.23	8.79	8.04	11.79	4.35	5.66
Devonport	0.23	0.00	0.85	0.10	1.80	3.41	2.76	0.95	1.82
Study region	0.27	0.05	0.63	0.11	3.73	4.47	5.52	2.79	3.50

Geographic Access and Socio-Economic Disadvantage

As depicted in **Figures 3A,B**–in different shades of red and yellow—most of the study area contains suburbs that are socio-economically disadvantaged (≤6 IRSAD decile). Accessibility to PAI varies markedly amongst different IRSAD areas within and between the sites (**Table 4**) with pockets of high socio-economic disadvantage (darker shades of red) in all 3 sites having some degree of poor accessibility to PAI (**Figure 3A**). Overall, when any PAI is considered, only a small proportion (under 30%) of residents in these NW Tasmania sites have poor access (**Table 4**). However, for a considerable proportion of the population, free-to-access natural amenities/green space and recreational tracks (73 and 57%, respectively) are more than 800 m from their households (**Table 4**). Some of the suburbs with higher SES (>6 IRSAD percentile) in Burnie and Devonport have exceptionally poor access to natural amenities/green space and recreational tracks (**Table 4**). The interface between SES and accessibility to "Tier 1 food" also appears to be as varied and complex as PAI, with ∼50% (overall) of residents in Burnie, Circular Head and Devonport located >800 m from a healthier "Tier 1" food store. Similar to PAI accessibility, there are pockets of socioeconomically disadvantaged areas in all three study sites that have poor access to Tier 1 food outlets (**Figure 3B**). Furthermore, ∼25 and ∼30% of people across the sites have "limited access" (defined as 400–800 m) to PAI and Tier 1 food outlets (**Table 5**).

Density

Accessibility of PAI and Tier 1 food outlets by population density is depicted in **Figures 4A,B**. Areas with the highest population density (i.e., top population density quintiles) have the most access to PAI and Tier 1 food outlets in all three study sites (**Table 6** and **Figures 4A,B**). Nevertheless, accessibility to Tier 1 food outlets appear poor (i.e., >800 m) within some pockets of high population density areas in Burnie, Circular Head, and Devonport.

DISCUSSION

A considerable body of empirical evidence—with a biassed representation of urban environments—illustrates the associations between lifestyle factors that contribute to obesity (and related chronic diseases), SES, and attributes of the built environment (23–25, 34). Given the pivotal role of "the living environment" on disease incidence and progression, there is a need to better understand the local food and physical activity environment in regional areas where there is often higher obesity-related chronic disease prevalence, as seen in NW Tasmania. Accordingly, this research evaluated access (i.e., coverage, variety, density, and proximity) to physical activity resources and food outlets in relation to SES in three NW Tasmanian communities. Overall, a considerable variety of physical activity resources and food outlets were observed with variability in access across socioeconomic and population density categories.

In the Australian context, poor functionality in available PAI, lack of diverse opportunities to be active, and environmental limitations have been highlighted as pressing concerns leading to sub-optimal levels of physical activity in rural areas (35). Yet the abundance and diversity of PAI found in the study region—including ∼25% of them being natural amenities/recreational tracks, and ∼20% associated with schools—is intriguing. Perhaps what is lacking are intervention strategies to address barriers to physical activity participation and initiatives that enhance access to extant PAI. Such approaches have been successful in promoting physical activity and reducing sedentary behaviours equitably elsewhere (36). Inherent geographical, economic, and social challenges experienced by rural residents are likely to be significant factors that shape the availability of opportunities to maintain an active lifestyle, compared with those living in urban settings (37–39).

We observed a marked variation in accessibility to PAI amongst different areas of disadvantage within and between the sites with pockets of high socio-economic disadvantage in all three sites having some degree of poor accessibility to facilities. This is in line with previous research, where lack of accessibility/affordability of PAI and SES are intertwined. More disadvantaged neighbourhoods are disproportionately affected with residents less likely to be able to access or afford recreational facilities and engage in adequate levels of physical activity (14, 15, 40–42). However, in the current study patterns were variable across sites and did not follow a clear SES gradient (**Table 4**).

Our observations across the study region recorded 47 free-to-access PAI, more than anticipated given the overall SES is lower than the national average (26). Provision of natural amenities/green spaces and recreation tracks (collectively known as public open spaces in some instances), are critical for healthy,

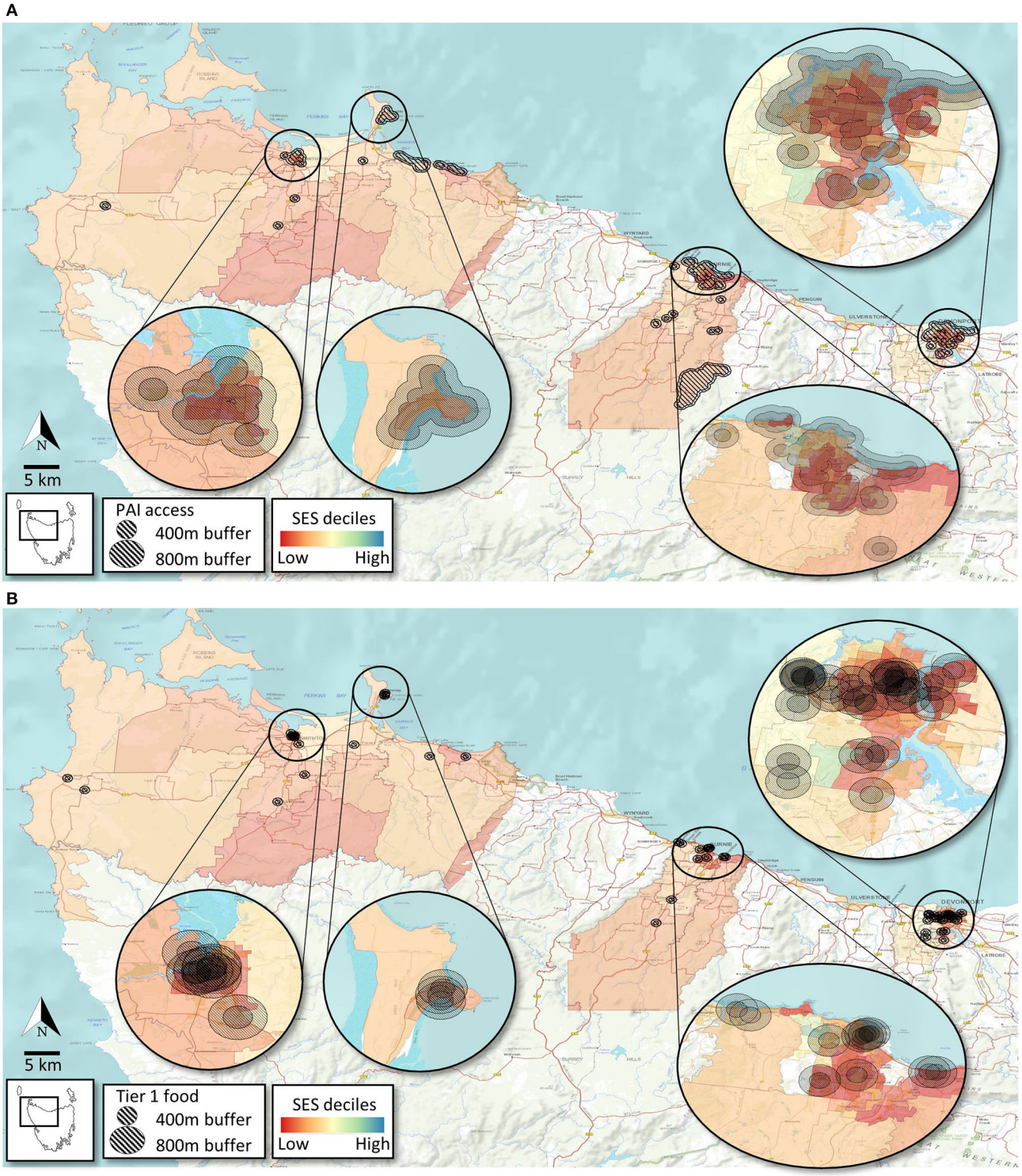

FIGURE 3 | Access to PA infrastructure **(A)** and Tier 1 food outlets **(B)** based on socioeconomic level of suburbs (SA1s) across the study area.

sustainable living as has been acknowledged in the United Nations Sustainable Development Goals (43). This is particularly important in the Australian context where housing footprints have increased and space for lawns and gardens have decreased consistently in the last few decades (44, 45). Town planners in Australia usually adhere to "park minimum standards" which

TABLE 4 | Proportion of the population in each region with poor access to PAI and food outlets based on socioeconomic disadvantage (IRSAD).

	PAI				Recreational tracks				Natural amenities and green space				Tier 1 Food outlets			
IRSAD Dec	**B**	**CH**	**D**	**SR**	**B**	**CH**	**D**	**SR**	**B**	**CH**	**D**	**SR**	**B**	**CH**	**D**	**SR**
1	15.34	0.00	11.62	12.42	97.35	9.98	60.60	72.57	12.70	13.40	68.45	42.02	39.24	5.92	13.97	23.88
2	22.53	51.42	1.94	15.91	86.23	81.76	70.70	76.57	19.29	69.00	80.34	62.97	56.11	62.42	32.28	43.63
3	43.90	68.02	6.05	38.82	95.09	73.61	45.20	70.03	46.15	70.41	64.83	61.12	75.37	74.24	70.85	73.38
4	40.12	98.14	54.21	57.48	65.65	99.18	59.54	71.84	43.50	98.38	100.00	71.55	48.97	98.48	43.25	59.00
5	0.00	98.08	62.47	44.19	80.88	99.99	81.13	82.04	0.00	99.28	85.59	58.69	55.49	99.24	92.16	80.70
6	0.00	NA	97.37	47.55	100.00	NA	97.53	98.80	69.55	NA	99.88	84.36	62.39	NA	74.80	68.45
7	0.78	NA	13.30	10.53	100.00	NA	6.13	26.87	47.21	NA	42.61	43.63	95.16	NA	57.40	65.75
8	NA	NA	84.95	84.95	NA	NA	100.00	100.00	NA	NA	100.00	100.00	NA	NA	79.80	79.80
9	5.75	NA	NA	5.75	100.00	NA	NA	100.00	60.22	NA	NA	60.22	38.58	NA	NA	38.58
Total	**23.72**	**61.53**	**18.66**	**27.48**	**88.98**	**72.73**	**62.31**	**73.59**	**27.17**	**68.54**	**75.05**	**56.79**	**52.24**	**67.72**	**40.27**	**49.05**

Poor access is defined as being >800 m from each infrastructure type or food outlet. NA is used when a given region does not have that IRSAD level (1 being the lowest socioeconomic level and 10 is the highest; no SA1s in the study region were in the 10th decile).
Burnie, B; Circular Head, CH; Devonport, D; Study region, SR.

TABLE 5 | Proportion of the population in each region with limited access to PAI and food outlets based on IRSAD.

	PAI				Recreational tracks				Natural amenities and green space				Tier 1 food outlets			
IRSAD Dec	**B**	**CH**	**D**	**SR**	**B**	**CH**	**D**	**SR**	**B**	**CH**	**D**	**SR**	**B**	**CH**	**D**	**SR**
1	32.12	3.63	25.44	26.83	2.62	52.71	23.11	16.52	52.45	42.52	21.93	35.80	46.76	57.72	47.37	47.77
2	34.64	8.52	31.74	28.34	8.01	13.59	21.03	16.43	37.79	21.66	11.27	19.78	24.80	24.63	35.65	30.96
3	25.70	17.92	37.60	27.23	4.17	8.93	20.90	11.73	8.86	11.06	19.95	13.54	16.74	15.38	20.24	17.51
4	15.62	1.37	9.14	10.55	17.76	0.67	13.12	12.52	20.16	1.07	0.00	10.27	20.80	1.17	24.83	17.30
5	31.13	1.78	25.25	25.91	15.58	0.01	1.68	6.08	9.26	0.57	8.19	8.13	30.54	0.63	7.79	14.75
6	29.86	NA	2.60	16.54	0.00	NA	1.67	0.82	30.45	NA	0.12	15.64	33.04	NA	17.29	25.35
7	69.72	NA	47.90	52.72	0.00	NA	15.35	11.96	45.89	NA	6.95	15.55	4.84	NA	16.94	14.26
8	NA	NA	15.05	15.05	NA	NA	0.00	0.00	NA	NA	0.00	0.00	NA	NA	14.08	14.08
9	48.63	NA	NA	48.63	0.00	NA	NA	0.00	39.78	NA	NA	39.78	51.59	NA	NA	51.59
Total	**29.23**	**10.61**	**27.88**	**25.54**	**6.96**	**13.85**	**18.56**	**13.63**	**33.26**	**15.53**	**14.85**	**21.57**	**31.86**	**20.05**	**32.89**	**30.42**

Limited access is defined as being between 400 and 800 m from each infrastructure type or food outlet. NA is used when a given region does not have that IRSAD level (1 being the lowest socioeconomic level and 10 is the highest; no SA1s in the study region were in the 10th decile).
Burnie, B; Circular Head, CH; Devonport, D; Study region, SR.

are based on population-ratio and/or maximum catchment (distances travelled to gain access) standards (46, 47). However, in all three study sites, the free PAI were more than 800 m (approximately a 10-min walk) from most residences, which may dissuade some residents from frequenting them. Although there is no consensus on the amount of green space required (both in terms of per capita as well as distance), existing literature indicates substantial health benefits (including lower prevalence of obesity) when residences are located within 300–400 metres of green space (48, 49). Our observation that some of the suburbs with higher SES (>6 IRSAD percentile in Burnie and Devonport) have exceptionally poor access to natural amenities/green space and recreational tracks, was unexpected. The spatial distribution of some of the wealthier suburbs (i.e., congregation in peri-urban areas of high real estate value but not necessarily proximate to amenities), may explain this pattern. It is widely acknowledged that availability/ accessibility of these facilities is positively related to recreational activity levels (50, 51), although for effective public health promotion and sustainable reduction of obesity prevalence, a better understanding of preferences and patterns of utilisation of open spaces is required (52).

In addition to providing children with a multitude of physical activity options, the substantial amount of PAI based in schools is a significant value-add to the overall communal PAI availability in the region. Most schools in the study region are centrally located within local neighbourhoods and have a range of gymnasia, playgrounds, sports fields, courts etc. that provide residents with invaluable opportunities (albeit restricted to out of school hours in some instances) to be physically and socially active. Participation in sporting pursuits and related benefits for

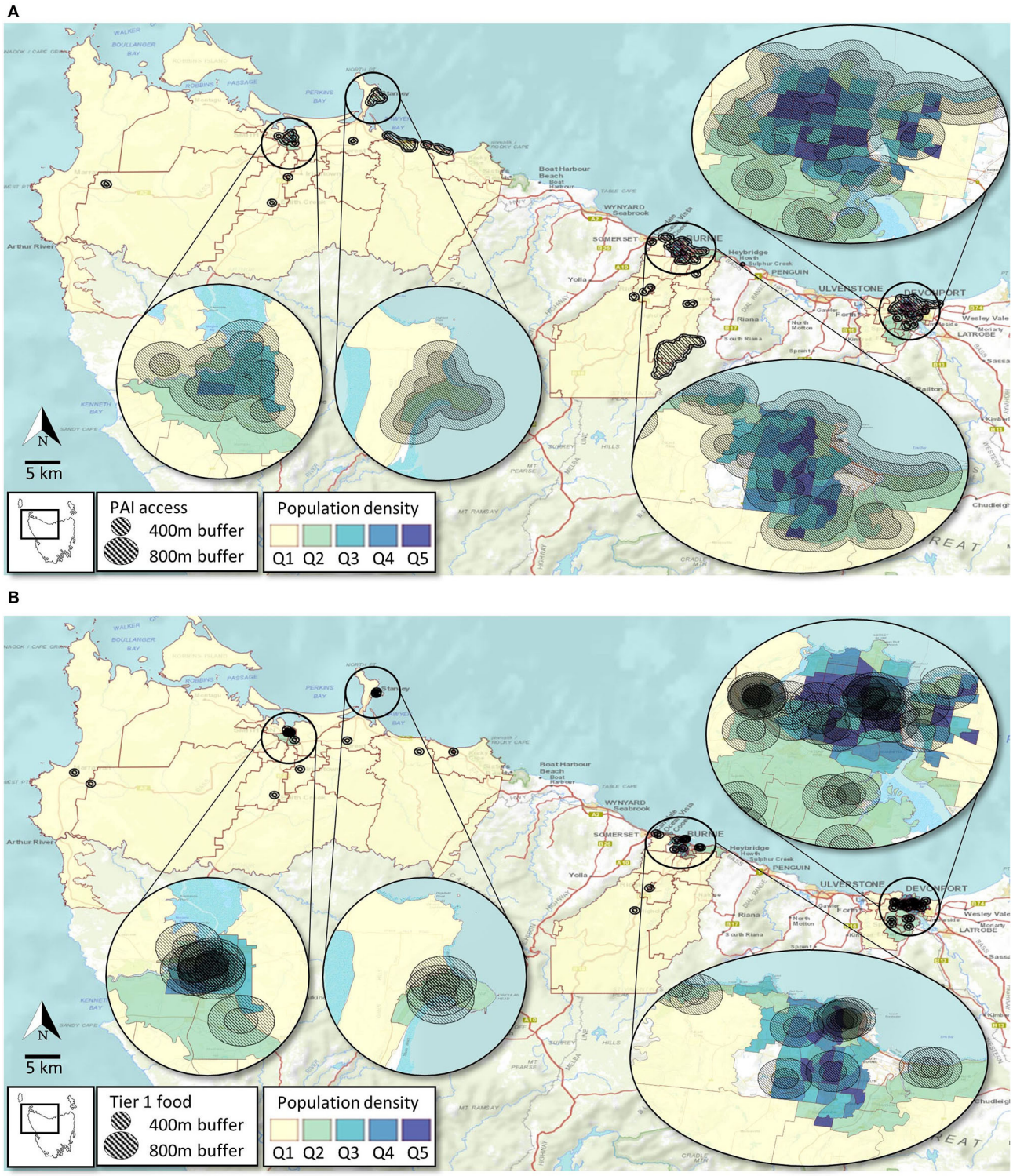

FIGURE 4 | Access to PA infrastructure **(A)** and Tier 1 food outlets **(B)** based on population density of suburbs (technically SA1s) across the study area.

health and well-being is well-known (53). Organised sport has a prominent place in the Australian identity and is an important element of the social fabric of NW Tasmania (54). As such, the availability of a vast array of sporting facilities (footy ovals, gyms, dance studios etc.) in the wider study area is a significant asset. Even so, based on existing Australian population data—which

TABLE 6 | Percent of the population with poor access (>800 m) to PAI and healthy food outlets based on population density quintiles across whole study area.

Population density (people/km^2)	PA facilities	PA tracks	PA reserves	Tier 1 food	Total area (km^2)
1–41	97.07	99.13	95.81	98.46	95663.49
41–613	47.52	76.58	65.97	63.37	27481.72
614–1,103	2.00	60.79	40.44	41.47	33156.60
1,104–1,631	9.99	70.28	34.21	38.72	15619.93
>1,631	3.31	68.14	58.65	20.66	7835.02
Total	**27.48**	**73.59**	**56.79**	**49.05**	**179756.75**

indicate significantly lower "sport and recreation" participation rates in rural/remote areas compared with inner regional (75.9 vs. 80.8%) and major cities (75.9 vs. 84%)—it is unclear whether availability of facilities translates to physical activity in a significant proportion of the local population (55, 56). Given the availability of substantial sport related infrastructure, there are ample cost-effective and safe opportunities for residents in Burnie, Circular Head, and Devonport to participate in a range of sporting activities in a social setting which could form the basis of health promoting public health initiatives.

In the current study, only a small proportion of the food outlets (∼6, 13, and 10% of outlets in Burnie, Circular Head and Devonport, respectively) sold predominantly healthier/perishable foods (i.e., Tier 1 outlets). Similarly, only a small proportion of residents are within a reasonable walking distance (i.e., 5–10 min walk) from them. Food outlets selling predominantly energy-dense, highly processed food (i.e., Tier 2 outlets) were considerably closer to individual dwellings. Accessibility to affordable, fresh, and good-quality food in local neighbourhoods can play an integral role in communal dietary habits (34, 57, 58). Importantly, proximity to perishable food options with high nutrient value (e.g., fresh fruit, vegetables, and lean meat) has been associated with healthier dietary patterns (59). Globally, disadvantaged communities (e.g., low SES or culturally diverse communities) have often been reported to have limited/poor access to these outlets (60–62). As extant evidence indicate, this lack of access (referred to as "food deserts" in some contexts) to healthy food can potentially manifest into obesity related debilitating chronic conditions (63, 64).

The link between low fruit and vegetable availability and increased risk for poor health outcomes is also well-documented (34). Although the precise mechanisms for this relationship are yet to be elucidated, previous reports (including some from Australia) have highlighted elements such as SES-driven purchase habits (e.g., wealthier regions having more purchasing power), demographic factors (e.g., proportion of females) and spatial patterning of food outlets (e.g., wealthier areas having more supermarkets and less fast food outlets) to be important mitigating factors (65–67). Recently, reports have suggested that long-term poverty and welfare dependency are significant contributors to dietary choices (e.g., increased purchase of imported cheap foods with low nutritional value over healthy perishables) of people living in rural Tasmania (68). Given the socio-demographic and geographical layout of NW Tasmania, it is likely that a combination of these factors is at play in different manifestations of the existing food environment.

CONCLUSION

Considering the well-established link between poor diet, inadequate physical activity, obesity, and non-communicable diseases in low SES communities, the observed spatial patterns in the current study (i.e., relative ease of access to unhealthier food and moderate access to natural amenities and green space), should be of concern. Overall, although a wide variety of PAI and food options are available to the residents in the study region, a substantial number are beyond an (approximately) 10-min walk from most households, a factor shown to reduce use/visitation rates (69–71). In fact, recent health metrics indicate that lifestyle risk factors such as PA, fruit/vegetable consumption, and sugary beverage consumption have been trending in the wrong direction in the past decade (5). As such, it is possible that the existing layout of food and physical activity environments of Burnie, Circular Head and Devonport are contributing to the obesogenic nature of these communities. Based on our observations, the following actionable strategies are recommended in the NW of Tasmania.

1. Increase public awareness of available PAI—particularly the free-to-access natural amenities and green space.
2. Increase connectivity between PAI resources through provision of better transport options.
3. Nutrition education and increased public awareness of Tier 1 food outlets.

Future public health initiatives geared toward generating environments that are conducive to regular physical activity and accessibility of healthy food will require action at strategic and policy levels involving multiple levels of government; findings from this spatial analysis may add significant value to such initiatives.

DATA AVAILABILITY STATEMENT

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

AUTHOR CONTRIBUTIONS

SJ, EF, DK, RS, and AH: conceptualisation, design of the study, formulating research questions, writing and editing draughts, data collection, and analysis. MK, KP, KA, RH, TH, and NB: conceptualisation, design of the study, review, and editing of the manuscript. All authors contributed to the article and approved the submitted version.

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REVIEW
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Shifting From Tokenism to Meaningful Adolescent Participation in Research for Obesity Prevention: A Systematic Scoping Review

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Background: Traditionally, adolescent participation in research has been tokenistic. Adolescents are rarely afforded the opportunity to influence decision-making in research designed to prevent obesity. Engaging adolescents in meaningful decision-making may enhance research translation. This review aimed to analyze the current modes and nature of adolescent participation in obesity prevention research decision-making.

Methods: A systematic scoping review was conducted using Arksey and O'Malley's six-stage framework. Six major databases were searched for peer-reviewed primary research studies with adolescent participation related to obesity, physical activity, and diet. Modes of adolescent participation were categorized based on the Lansdown-UNICEF conceptual framework for measuring outcomes of adolescent participation. The framework outlines three modes of meaningful participation: (i) consultative, which involves taking opinions and needs into consideration; (ii) collaborative, where adolescents are partners in the decision-making process; and (iii) adolescent-led participation where adolescents have the capacity to influence the process and outcomes. The degree of involvement in research cycles was classified based on the National Health and Medical Research Council consumer engagement framework. Five stages of the research cycle were determined: identify, design and develop, conduct, analyze and disseminate.

Results: In total, 126 papers describing 71 unique studies were identified. Of these, 69% (49/71) took place in the USA, and 85% (52/61) were conducted in minority or underserved communities, while males were more likely to be under-represented. In 49% (35/71) of studies, participation was consultative and 9% (6/71) of studies involved an adolescent-led approach. Furthermore, 87% (62/71) of studies incorporated adolescent participation in one or more of the research cycle's formative phases, which involve eliciting views, opinions and idea generation. Only 11% of studies engaged adolescents

in all five stages of the research cycle where adolescents could have more influence over the research process.

Conclusion: Meaningful adolescent participation in the obesity prevention research cycle is limited. Empowering and mobilizing equal partnership with adolescents should be at the forefront of all adolescent-related obesity prevention research.

Keywords: adolescent, youth, participation, engagement, decision-making, obesity, overweight, prevention

INTRODUCTION

Overweight and obesity is a global health crisis affecting 340 million young people (5–19 years) worldwide (1). Despite common misconceptions and gender-based stereotypes, obesity is more likely to affect adolescent boys than girls in 60% of countries, with this trend most apparent in high and upper-middle-income nations (2). The prevalence of overweight and obesity in young people continues to increase and has quadrupled in this cohort from 4 to 18% in the last three decades (3). The incidence of overweight and obesity has plateaued in several high-income countries while simultaneously escalating at a 10-fold rate in lower-income countries across Asia and Africa (4). Overweight and obesity are significant risk factors for developing lifestyle-related chronic diseases such as cardiovascular disease, diabetes mellitus, hypertension, some cancers, muscular-skeletal, and mental health disorders (5).

An unhealthy diet and insufficient physical activity are modifiable risk factors for obesity. Social equity challenges, such as income, education, and food insecurity strongly influence these risk factors (6, 7). An increasing body of evidence demonstrates the relationship between diet and physical activity behaviors in adolescence and the association between obesity and chronic disease development in adulthood (8–11). Yet, globally, there is inconsistent evidence regarding the effectiveness of diet or physical activity interventions or a combination of both to reduce the risk of obesity and its related co-morbidities in adolescents (12–14). Obesity prevention research is further complicated by ethical and psychosocial health concerns such as weight stigmatization, eating disorder risk, low self-esteem, body dissatisfaction, anxiety, and depression (15–18). Emerging research demonstrates how supervised obesity treatment can improve psychosocial health for adolescents; however, there is limited research regarding obesity prevention initiatives (19). Engaging adolescents in the design and development of obesity prevention interventions can address social equity challenges and ethical and psychosocial health concerns (20). It is therefore crucial that adolescents from all backgrounds are engaged in obesity prevention research (21).

Current evidence syntheses have focused on determining the efficacy and effectiveness of obesity prevention interventions (12, 14); the conclusions are limited mainly to factors related to intervention outcomes (22). This finding suggests little attention has been given to understanding meaningful adolescent participation in the research decision-making process beyond passive engagement as research participants. Currently, no review has focused on understanding adolescents' engagement in the research cycle and relationships to intervention efficacy and effectiveness.

In recent years, there has been a growing call to prioritize the voice of adolescents in societal decision-making (23). Meaningful adolescent participation is a fundamental human right as articulated in the Convention on the Rights of the Child (24). The importance of adolescent participation is further expanded on in the Lansdown-UNICEF framework for adolescent participation (25). The framework acknowledges that meaningful participation involves adolescents articulating their views and being involved in the decision-making process to impact matters of importance to them. Meaningful participation varies in mode and is subject to the evolving capacity of adolescents as they transition from early adolescence through to young adulthood.

Theoretical youth engagement models such as UNICEFs Adolescent and Youth Engagement Strategic Framework (26), Hart's Ladder (27), and Shier's pathway (28), among others, have been developed to guide organizations on the components of effective and ethical consumer or stakeholder engagement. Such models aim to amplify adolescent voices and improve their confidence and feelings of empowerment, which are fundamental to meaningful participation and decision-making in research and ultimately to research translation (25, 26).

Additionally, practical and transparent frameworks allow researchers to monitor meaningful participation where stakeholders and consumers can be involved effectively throughout the research process. Examples of such are the United Kingdom's National Institute for Health Research (NIHR) INVOLVE Public and Patient Involvement Framework (29, 30), and the Australian National Health and Medical Research Council (NHMRC) Consumer Engagement Framework (31), which provide a detailed outline of the stages and strategies necessary to achieve meaningful participation. Such frameworks offer foundational measures for researchers to assess the degree of engagement expected throughout the research cycle.

Despite the increasing call to effectively engage adolescents in society and consumers in research, there is yet to be

Abbreviations: USA, United States of America; UNICEF, United Nations Children's Fund; NIHR, National Institute for Health Research; NHMRC, National Health and Medical Research Council; PAR, Participatory Action Research; PE, Patient Engagement; CBPR, Community Based Participatory Research; PRISMA-ScR, Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for Scoping Reviews; MeSH, Medical Subject Headings; CINAHL, Cumulative Index of Nursing and Allied Health Literature; CENTRAL, Cochrane Controlled Register of Trials; RCT, Randomized Control Trial; SES, Socioeconomic Status; BMI, Body Mass Index; WHO, World Health Organization; SDGs, Sustainable Development Goals; YAG, Youth Advisory Group; LMICs, Low- and Middle-Income Countries.

meaningful convergence. To date, reviews in the field of participatory research have tended to focus specifically on specific methodological approaches such as Participatory Action Research (PAR) (32, 33), Youth advisory (34), Patient Engagement (PE) (35), or Community Based Participatory Research (CBPR) (36). The demographic of interest also varies significantly between published reviews with researchers specifically investigating children (37) or children grouped with adolescents, youth, or young people and results for such populations analyzed together despite their significantly different needs and abilities (32, 33, 36, 38). Moreover, current evidence syntheses are looking broadly at participatory approaches (32, 33, 36), how they influence social determinants (32), general health and well-being (34, 35, 38), or health policy (39). Currently, comprehensive evidence syntheses are lacking to evaluate the participatory approaches for adolescent consumers in obesity prevention research.

Mental health researchers have recognized that engaging adolescents in meaningful participation is a crucial component of effective research and intervention development (40, 41). Adolescents have unique insight into their own lived experiences and needs; therefore meaningful participation involving adolescent consumers in the decision-making is a potentially vital link to tailor obesity and chronic disease prevention interventions to this demographic. In this scoping review, we aim to address this gap in the literature by broadly assessing how and to what extent adolescents are meaningfully participating in the co-design and decision-making in research studies that target overweight, obesity, physical activity, and dietary interventions specifically for adolescents. Secondly, we aim to provide recommendations on optimal modes of participation in obesity and chronic disease prevention research.

The following research questions guided this scoping review:

i) Is there evidence of the effectiveness of adolescent participation in peer-reviewed primary research studies?
ii) What are the components, processes, or conceptual frameworks of effective peer-reviewed primary research studies involving adolescent participation?
iii) Are there any identified barriers or facilitators, or evidence gaps for adolescent participation?

METHODS

A scoping review was determined to be the most suitable form of evidence synthesis for the research question as it allowed for a broad and thorough examination of the existing literature (42). The scoping review methodology was informed by the Arksey and O'Malley six-stage framework (43), Levac et al.'s (44) recommendations, and the Joanna Briggs Institute (45–47) guidelines for scoping reviews. The review was reported based on the Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR) checklist (see **Supplementary File 1**) (48). As per scoping review guidelines, no quality assessment is required (47, 48). The research questions were formulated, followed by the identification of criteria for the inclusion of relevant studies. Next, studies were selected based on the pre-defined criteria, and relevant data from the included studies were extracted. Collating, summarizing, and reporting the results followed. The scoping review protocol contains full details of the study methodology and search strategy (49). The protocol is registered with Joanna Briggs Institute and Open Science Framework, doi: 10.17605/OSF.IO/E3S64. A brief description of the methods is provided below.

Key Definitions

The term "adolescent" is defined by the World Health Organization (WHO) as a person aged 10–19 years old, and "youth" as one between the age of 15–24 years old (50). However, within the published peer-reviewed literature, these terms are used synonymously. To broadly examine the literature and in line with the Lancet Child and Adolescent health definition of an adolescent (51), this scoping review assessed published peer-reviewed literature engaging adolescents or youth aged 10–24 years.

Meaningful participation refers to participation in which adolescents have some level of influence over the research and development decision-making. The mode of meaningful participation is dependent on the degree of influence adolescents impart on the research process (**Table 1**). Furthermore, meaningful participation is dependent on the methods and strategies used at various points within the research cycle (31). All modes of participation can be valid and effective if conducted within an enabling environment where participatory outcomes are based on empowerment and the degree of influence is measured and achieved (25).

Search Strategy and Study Selection

Based on key concepts emerging from the research questions, the research team developed a search strategy in consultation with an academic liaison librarian. All qualitative and quantitative peer-reviewed primary research studies published from 1995 to December 2020 were considered for inclusion; reviews were excluded. Peer-reviewed papers of all languages with an abstract in English were considered. Studies involved participants aged 10–24 years involved in obesity or chronic disease prevention, nutrition or physical activity research decision-making. Youth participation was the primary outcome sought hence inclusion of broad search terminologies such as Youth-PAR, CBPR, youth involvement, and youth engagement. Medical subject heading (MeSH) terms were selected accordingly. An example search strategy is presented in **Supplementary Table 1**.

Systematic searches of six scientific databases, Medline (PubMed), Embase, CINAHL, Scopus, Global health, and CENTRAL, were conducted. Publications identified up to the first of December 2020 were considered. Additional sources were identified through hand searching, reference list examination, and citation chaining. Results were pooled and duplicates removed, remaining results were uploaded to the Covidence systematic review software. A two-part study selection process followed, first a title and abstract review by one reviewer (MM) and secondly a full-text review by two reviewers (MM and

TABLE 1 | Working definitions to classify mode and degree of adolescent participation.

Mode of adolescent participation	
Consultative	Adolescents contribute opinions, perspectives, knowledge, and experience
Collaborative	Adolescents are involved as partners in the decision-making process
Adolescent-led	Adolescents identify the issues and control the process and outcomes
Other	Adolescents are involved in an important role, but their opinions are not considered, they play no part in the decision-making and have no influence over the research process or outcomes
Adolescent participation in stages of the research cycle	
Identification of topic	The consumers views, opinions or aspirations are sought. Consumers are involved in the identification and development of the research idea and/or topic
Design and Development	The consumer is engaged in methods selection and development
Conduct	Consumers lead or facilitate research methods and gather data
Analyses	Consumers are involved in consolidating and reporting the findings
Dissemination	Consumers are involved in presenting and/ or circulating the findings. Consumers are involved in implementing findings by developing strategies to translate research findings

Definitions adapted from the Lansdown-UNICEF conceptual framework for measuring outcomes of adolescent participation (25) and Australia's National Health and Medical Research Council (NHMRC) framework for effective consumer and community engagement in research (31).

SRP). Any discrepancies were resolved by consensus with a third reviewer (JR).

Data Extraction

Data extraction table variables were iteratively developed to broadly encompass the scope of adolescent participation in the obesity and chronic disease research cycle. Relevant data were extracted and tabulated by one reviewer (MM) (see **Supplementary Table 2**). Key outcomes extracted included social and environmental variables, the degree of adolescent participation in the research cycle, modes of participation, participatory outcomes, and chronic disease-associated outcomes. Corresponding authors were contacted *via* email where necessary data was missing or not reported. A second reviewer (SRP) cross-checked 20% of studies for consistency in data extraction.

Synthesis and Analysis of the Results

Data presented were based on active (meaningful) adolescent participation in the research and decision-making process, where adolescents were engaged as consumers rather than passive study participants. Data were assessed based on key modes of participation (consultative, collaborative and, adolescent-led) and alignment with participatory outcomes from the Lansdown-UNICEF conceptual framework for adolescent participation (25). After the protocol publication, the NHMRC framework for effective consumer and community engagement in research was selected to contextualize the data within the phases of the research cycle (31). The framework was deemed necessary for data analysis and was the only protocol deviation.

Chronic disease outcomes associated with improved health status or obesity and chronic disease risk factor prevention were established based on emerging categories founded on preliminary searching. Reported chronic disease outcomes were classified into the following categories: (i) increased awareness of family, peers and adolescents; (ii) program or intervention development; (iii) policy change; (iv) environmental change, relating to changes in the physical surroundings in which adolescents live; (v) behavior change specifically changes in diet and physical activity behaviors; and (iv) health status or risk factor change, including but not limited to change in body mass index, weight status, waist circumference, and blood pressure. Qualitative analysis of the data revealed emerging trends and themes. Data were reported by descriptive numerical analysis and in narrative form.

RESULTS

Descriptive Numerical Analysis

The search strategy generated a total of 1,212 results, including an additional 53 papers through hand searching, which were subsequently pooled, and duplicates removed, leaving 902 unique papers (**Figure 1**). The 902 papers were assessed by title and abstract screening for inclusion; 736 were excluded. The full text of the remaining 166 papers were reviewed, and a further 40 papers were excluded and reasons documented. In total, 126 full-text peer-reviewed papers (52–175) describing 71 unique studies were included in the review.

Study Characteristics

The studies identified varied broadly in their target demographic and scope. Various socioeconomic and ecological characteristics were analyzed (**Table 2**).

Study Design

Of the 71 unique studies identified, 65% (46/71) were qualitative, and a further 30% (21/71) employed a mixed-methods approach. Thirteen studies (18%, 13/71) were randomized controlled trials (RCT).

Year of Publication and Study Duration

Publication dates ranged from 2003 to 2020, with >50% (n = 36) of studies publishing their first paper between 2015 and 2020. Studies varied in duration from 30-min to 6 years, the mean study duration being 3 months or less in duration (23/71), followed by intervention durations >12 months (12/71).

Country of Origin

Most studies (76%, 54/71) were conducted in North America, with a total of 49 in the USA and five in Canada. Eight studies took place in Europe (Netherlands, United Kingdom, Belgium, Spain, France) and five studies in Australia. Furthermore, two studies were conducted in Asia (Republic of Korea, Vietnam), one

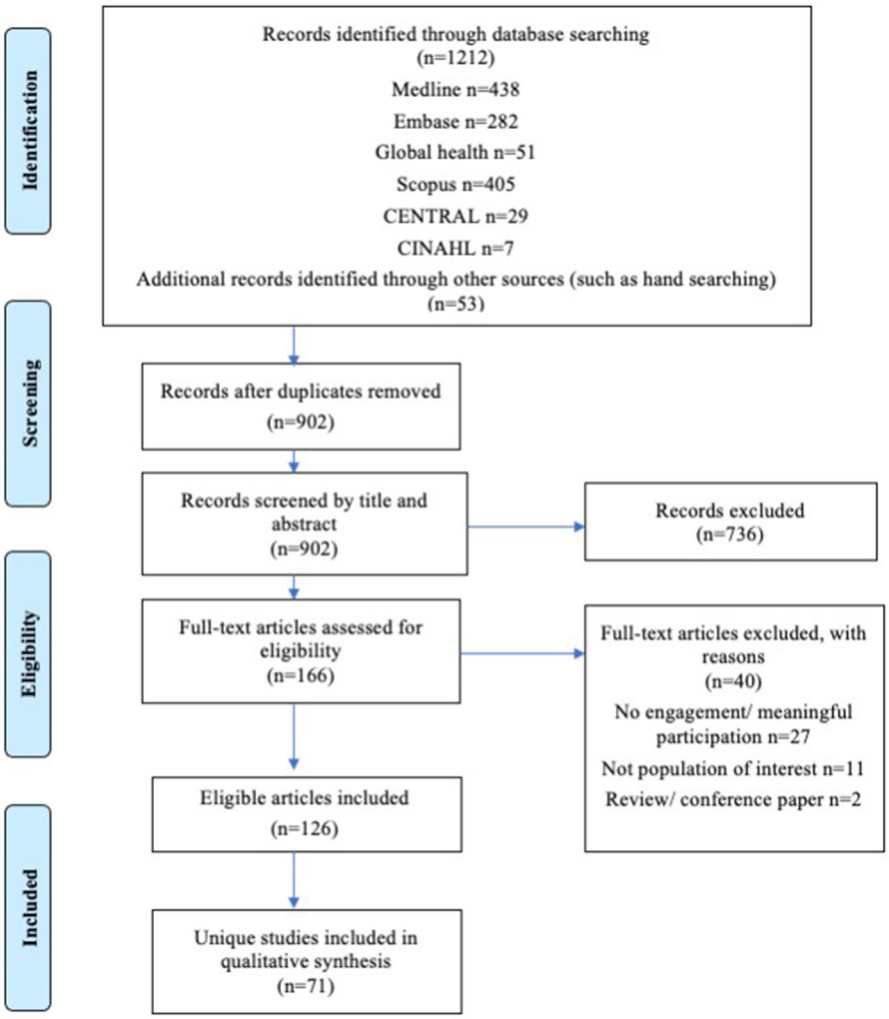

FIGURE 1 | Prisma flow diagram: adolescent participation in research for obesity prevention.

in South America (Peru), and one multi-country (Australia, New Zealand, Fiji, and Tonga) study.

Socioecological Setting

The most common socioecological setting targeted was the local community (54%, 38/71), followed by secondary education institutions (30%, 21/71). Eight studies targeted the adolescent (individual), and one study specifically targeted the family unit. Peer leadership, mentoring, or education were components of 18 studies, with six targeting the local community and 12 targeting secondary education institutions. Similarly, youth or peer advocacy was a component of nine studies, eight of which targeted the local community and one targeting a secondary education institution.

Socioeconomic status (SES) was described in 61/71 studies (86%), of those reporting SES, 52 studies (85%) were conducted in a minority or underserved community, and one study took place in an affluent (high SES) setting.

Study Purpose

Overweight and obesity was the most common chronic disease or chronic disease risk factor targeted in the included studies, with 89% (63/71) of studies reporting this to be the main purpose for the study. The remaining eight studies investigated the prevention of obesity-related co-morbidities such as type 2 diabetes and cardiovascular disease.

Participants

Of the 71 studies, the total number of participants involved in a meaningful participatory method ranged from 5 to 14,000 participants (**Supplementary Table 2**), with a median of 43 participants. Thirty-one studies (46%) had between 11 and 50 participants; three studies did not report the number of adolescent participants. The gender of adolescent participants was not reported in 24% of studies (17/71). In 26 (48%) of the studies which reported gender, gender was evenly distributed. Still, in the studies that remained, males were more likely to be

TABLE 2 | Summary of study characteristics.

	Sub-category of study characteristics	*N* (%)
Study design *n* (%)	Mixed methods*	21 (30%)
	Qualitative	46 (65%)
	RCT only	4 (6%)
Publication year** *n* (%)	2001–2005	2 (3%)
	2006–2009	8 (11%)
	2010–2014	25 (35%)
	2015–2020	36 (51%)
Duration of intervention *n* (%)	≤3 months	23 (37%)
	>3 to <6 months	2 (3%)
	6 to <12 months	7 (11%)
	12 to <18 months	9 (15%)
	18–24 months	9 (15%)
	>24 months	12 (19%)
	Not reported	9 (13%)
Continent/country *n* (%)	USA	49 (69%)
	Canada	5 (7%)
	Europe/United Kingdom	8 (11%)
	Other***	9 (13%)
Socio-ecological setting *n* (%)	Local community *n* (%)	38 (54%)
	Institution's total (schools, hospitals, courts, workplaces) *n* (%)	24 (34%)
	Secondary education *n* (%)	21 (30%)
	Tertiary education	2 (3%)
	Hospital	1 (1%)
	Family	1 (1%)
	Peers**** (alone)	0
	Youth/peer leadership/mentoring or education total	18 (25%)
	Local community	6 (8%)
	Institution (secondary school)	12 (18%)
	Youth/peer advocacy/activism total	9 (13%)
	Local community	8 (11%)
	Institution (secondary school)	1 (1%)
	Adolescent (Individual)	8 (11%)
Main chronic disease or risk factor of interest	Overweight/obesity	63 (89%)
	Type 2 Diabetes	3 (4%)
	Cardiovascular disease	1 (1%)
	Wellness/determinants of health/NCD***** prevention	3 (4%)
	Physical inactivity	1 (1%)
Number of participants *n* (%)	1–10	6 (9%)
	11–50	31 (46%)
	51–100	11 (16%)
	>100	20 (29%)
	Not reported	3 (4%)
	Total number	39079
	Mean	575
	Median	43
	Range	5–14000
Gender	Majority female (>60%)	24 (44%)
	Majority male (>60%)	4 (7%)
	Mixed (almost equally)	26 (48%)
	All female	6 (11%)
	All male	2 (4%)
	Not reported	17 (24%)
Socioeconomic status (SES)/participant representation	Minority/underserved community/low-income	52 (85%)
	Mixed high and low SES	8 (13%)
	High SES	1 (2%)
	Not reported	10 (14%)

(Continued)

TABLE 2 | Continued

**Nine studies were RCT's with qualitative components.*
***Year of publication of the first paper if multiple papers published regarding the same study.*
****Five studies in Australia, two in Asia, One in South America and One Multi-country.*
*****Peer mentoring which took place within an institutional or local community setting was classified under those categories.*
******Non-Communicable Disease (NCD).*

under-represented [24 (44%) or not represented at all six (11%), while females were under-represented in four (7%) studies and not represented in a further three (4%)].

Adolescent Participation

Degree and Mode of Participation

In 87% (62/71) of studies, adolescents participated in at least one of the two formative phases of the research cycle (identification of the topic or design or development), and in 11% (8/71) of studies, participation took place in all five stages of the research process (**Table 3**). The mode of participation was almost equally distributed between consultative (49%, 35/71) and collaborative (41%, 29/71) approaches. An adolescent-led mode of participation was identified in six studies (9%).

Participatory Methods

The number and type of participatory methods used by researchers in the included studies significantly varied. Results revealed that a combination of methods was commonly employed in each study. Approaches ranged from one participatory method per study to a maximum of four methods, with a mean of two participatory methods per study. Adolescent-led participatory approaches were more likely to employ a greater number of participatory methods (mean of three methods per study) to achieve their outcomes.

Components of Participatory Methods

Overall, the most common single method used was focus groups in 55% (39/71) of studies, followed by questionnaires and surveys (38%, 27/71) and interviews (38%, 27/71). These were more

TABLE 3 | Adolescent participation, theoretical frameworks used and outcomes of participation in the research cycle.

		N (%)
Adolescent participation in the research cycle *n* (%)	1. Identification of topic (building relationships or developing research idea)	49 (69%)
	2. Design or development	45 (63%)
	3. Conduct	35 (49%)
	4. Analyses	10 (14%)
	5. Dissemination	28 (39%)
	Participation in at least one of the two formative stages (stages 1 or 2)	62 (87%)
	Participation in all 5 stages	8 (11%)
Mode of participation	Consultative	35 (49%)
	Collaborative	29 (41%)
	Adolescent-led	6 (9%)
	Other*	1 (1%)
Participatory outcomes (PO) measured	Sense of self-worth or self-esteem or efficacy	5 (7%)
	Being taken seriously	2 (3%)
	Making decisions	2 (3%)
	Public civic engagement	0%
	No. of studies which measured at least one PO	5 (7%)
	No. of studies which measured all four PO	1 (1%)
Chronic disease related outcomes (CDO)**	Increased Awareness	49 (69%)
	Program or intervention development	45 (63%)
	Policy change	8 (11%)
	Environmental change	16 (23%)
	Behavior change (diet and physical activity)	18 (25%)
	Health status or risk factors change*** (wt. = 6, BP = 1)	7 (10%)
	No. of studies which reported four or more CDO	10 (16%)
Models, theories or conceptual frameworks n (%)	Participatory****	34/71 (48%)
	Social*****	34/71 (48%)
	Complex models or multiple theories	35/71 (49%)
	Other******	21/71 (30%)
	Not reported	9/71 (13%)

**Adolescents played a key role as facilitators, however they did not play any part in decision-making or influencing the process.*

***These were not always reported or aimed for.*

****Six studies reported change in weight, one study reported a change in blood pressure.*

*****Participatory alone (13), participatory included in multi-theory (21).*

******Social theory alone (5), Socio-ecological theory (7), Socio-cognitive theory (22, 31%).*

*******Behavioral (3), Ecological (8), Environmental (1), Psychological (2), Empowerment (7).*

commonly employed in consultative studies either alone or combination with other methods. Furthermore, other methods such as photovoice ($n = 10$), needs and community assessments ($n = 5$), discussion groups, and community forums ($n = 3$) were also used in a smaller proportion of studies. These methods have in common that they elicit views, opinions and uncover the needs of adolescents and their community which is a fundamental element of formative work. Youth advisory groups ($n = 2$) and peer leadership and advocacy activities were a component of 25% of studies (18/71). The studies that used these approaches were typically studies that employed a collaborative ($n = 13$) or adolescent-led ($n = 3$) mode of participation. A social marketing approach was used in six studies (8%), four of which were collaborative, and two were adolescent-led. Additionally, co-design or co-creation activities (sessions) were specified in 7% ($n = 5$) of studies; these were a component of one consultative study and four studies that used a collaborative approach.

Models, Theories, and Conceptual Frameworks

Overall, studies varied significantly in their theoretical basis, with 9 theoretical models and 15 complex models and frameworks reported. **Table 3** presents the most common models, theories and frameworks used. A significant number of studies used multiple theories or models (49%, 35/71). Overall, 48% (34/71) of studies reported a participatory design, of which 74% (25/34) used CBPR principles to guide their project. Moreover, other theories which complement but do not explicitly promote a participatory approach were identified. Thirty-four (48%) studies reported a social component, with social-cognitive theory reported to inform 22/71 (31%) of studies, and socio-ecological theories informed seven studies. Of the multi-theory models employed, which did specifically involve a participatory component, the transtheoretical model of behavior change ($n = 5$) and the PRECEDE-PROCEED model ($n = 4$) were the most reported. Empowerment theory was used in seven studies; however, participatory outcomes which measure empowerment and influence were only measured in five studies. Of the studies labeled participatory, 32% (11/34) involved adolescents in at least four research cycle stages. A collaborative approach was employed in more than half (18/34, 53%) of participatory studies.

Chronic Disease Outcomes

Chronic disease outcomes were largely based on outcomes of obesity prevention research. The most common chronic disease-related outcomes of adolescent participation were "increased awareness among family and peers" (49/71, 69%) and "program or intervention development" (45/71, 63%). It is also important to note that two studies (69, 135) were in progress, and therefore, information on outcomes was not available or incomplete.

Characteristics of Studies Reporting Four or More Chronic Disease Outcomes

Overall, 12 studies (17%, 12/71) reported four or more chronic disease outcomes; these studies tended to be 12 months or longer in duration, and five of these studies (41%) involved adolescents in four or more stages of the research cycle. Nine of the 12 studies (75%) used a mixed-methods interventional design, with seven studies (58%) involving an RCT component and another two (17%) studies using a quasi-experimental design. Of these 12 studies, 11 (92%) employed a collaborative mode of adolescent participation. Moreover, seven studies (58%) were

supported by multiple theoretical frameworks, and six (50%) had a participatory agenda. While 8/12 (67%) studies used youth or peer leadership or advocacy practice, only 33% (4/12) were also described as participatory. In contrast, all seven RCTs involved youth or peer-leadership or advocacy regardless of whether they declared the usage of a participatory model or not. Overall, participatory outcomes were measured in 5/71 (7%) studies but were more likely to be reported in studies with four or more chronic disease outcomes measured 3/12 (25%).

Characteristics of Studies Reporting Three or Fewer Chronic Disease Outcomes

Due to the broad range of study designs and aims, chronic disease outcomes as per the established categories were not within the aim or scope of many of the studies reviewed and, as such, were not reported. This was particularly the case in qualitative studies that employed a consultative participatory mode, usually focus groups, discussion groups, questionnaires, surveys, or interviews. In these instances, the researchers were seeking opinions and preferences. Therefore changes in weight, diet, or physical activity levels were not measured as they would be outside the scope of the study. A total of 91% (29/32) of consultative studies described <3 chronic disease outcomes. Similarly, all six studies (82, 86, 114, 133, 173) that used an adolescent-led participation mode achieved no more than three chronic disease outcomes despite all except one (145) meeting the aims of their respective projects. Furthermore, adolescent-led studies described outcomes related to increased awareness (82, 86, 133, 173), program/intervention development (86, 114, 133, 173), or environmental changes (86, 133) and did not report anthropometric, behavioral changes, or changes in health status associated with obesity and chronic disease development.

Effectiveness of Studies Involving Adolescent Participation in Improving Obesity and Chronic Disease Risk Factors

Differences in the study designs and methodologies of the studies analyzed meant that data reporting differed. Quantitative measures were often not measured/ or sought in many studies included within this review. Still, 22 studies (31%) reported an improvement in one or more obesity risk factors. Data on anthropometric measures as well as behavioral measures such as physical activity and dietary intake were analyzed.

Anthropometric Measures

Eight studies (11%) reported an improvement in one or more anthropometric measures such as BMI (57, 62, 76, 91, 158, 169), weight (161), waist circumference (158), or adiposity (142) albeit not always statistically significant (161, 169). Methodological components which were common between these studies included use of an RCT (57, 62, 76, 91, 142, 169) in 75% (6/8) of studies, a collaborative (62, 76, 91, 158, 161, 169) mode of adolescent participation in 75% (6/8) of studies and inclusion of a peer-component (57, 62, 76, 91, 169) in 63% (5/8) of studies.

Physical Activity and Fitness

Improvements in physical activity and fitness behaviors were reported in 12 studies (54, 93, 96, 101, 105, 126, 142, 149, 161, 164, 165, 169), five of these involved an RCT (101, 142, 164, 165, 169), seven employed a collaborative (54, 93, 96, 105, 161, 165, 169) mode of adolescent participation and seven involved a peer-component (93, 96, 105, 126, 149, 164, 169).

Dietary Behaviors

Encouraging changes in dietary behaviors were reported in 17 studies, as an improvement in dietary intake or nutrition behaviors (61, 91, 96, 101, 105, 112, 126, 149, 161, 164, 165, 169), increased fruit (93) and vegetable consumption (121), reduced caloric intake (99), reduction in sugar sweetened beverage intake (108) or an increase in water consumption (54). Overall studies involving improvements in dietary behaviors had in common that they were more likely to be collaborative (9/17) (54, 91, 93, 96, 105, 108, 161, 165, 169) and involve a peer-component (10/17) (61, 91, 93, 96, 105, 108, 126, 149, 164, 169). Studies which reported an improvement in dietary behaviors were almost evenly of qualitative (7/17) (54, 93, 105, 112, 121, 126, 149) or RCT (6/17) design (91, 101, 108, 164, 165, 169).

Barriers and Facilitators to Adolescent Engagement

Understanding barriers and facilitators to adolescent engagement are essential in improving meaningful adolescent participation in the obesity prevention research cycle. Of the studies analyzed, school, family, and work commitments were the most common barriers suggested. Facilitators to participation included compensation for the time spent participating, peer-support, leaderships opportunities, and adolescent-led participatory methods (such as photovoice and youth advisory groups), which gave the youth a voice and influence. Furthermore, incorporating meaningful participation into supportive and trusted environments such as the local community or school setting was suggested to facilitate engagement.

Overall, barriers and facilitators to adolescent participation when documented were usually reported as general observations rather than concrete data. Barriers and facilitators to participation were seldom an outcome measured in the studies reviewed and is in line with lacking measurements of participatory outcomes in general.

DISCUSSION

This is the first review investigating adolescent participation in the obesity prevention literature to the best of our knowledge. Overall, findings from our review indicate that adolescent participation in research is a complex yet adaptable construct that may be a vital link between obesity prevention research and practice.

Our review detailed the new and emerging field of adolescent participatory research in obesity prevention, with more than 50% of the studies identified having published their first paper in the last 5 years. We found that despite obesity and its associated co-morbidities affecting populations broadly

(176), the use of participatory research methods were not equitably deployed. Of the studies which reported socioeconomic characteristics, we found that 85% targeted minority or underserved communities in mostly affluent western nations. Only four studies took place in middle-income nations, where adolescents represent a greater proportion of the total population (177) and where obesity has surpassed undernutrition as a leading cause of morbidity (4). The lack of participatory research for adolescents in LMICs may be attributable to low resources and challenges in health research allocation and implementation. Funders and the global community often expect LMICs to direct research and funds to the most acute public health challenges (178). Furthermore, our finding suggests adolescent participation in obesity prevention research appears to be gender-biased with studies involving predominantly adolescents identifying as female. Adolescents identifying as male were either not represented at all or underrepresented in 55% of the included studies, while "no representation" or underrepresentation of adolescents identifying as female-only occurred in only 11% of studies. This finding may be explained by sociocultural factors and gender-based ideals, particularly in higher-income countries, with females more likely to be concerned with weight compared to their male counterparts (2). Girls are also more likely to partake in disordered eating behaviors and calls for further public health attention (179).

Our review revealed that over the last decade there has been a gradual increase in the awareness of the need to involve adolescents in the dialogue and decision-making processes to make progress on matters affecting youth, such as the global obesity crisis. This finding is consistent with the WHO-UNICEF-*Lancet* commission report (180), which recommends that youth be placed at the center of Sustainable Development Goals (SDGs). The commission states that "children should be given high-level platforms to share their concerns and ideas and to claim their rights to a healthy future" (180). Insights from our review indicate that meaningful participation not only upholds adolescents' fundamental right to participation but also allows for the development of interventions that are tailored to the unique needs of this demographic.

Results of our review suggest that meaningful adolescent participation is limited within obesity and chronic disease prevention research. Our results indicate that when adolescents are engaged, they are more likely to be involved in the formative stages of the research cycle in activities such as relationship building, needs assessment, research idea development, and project design (34). Nevertheless, only 11% of the included studies reported meaningful participation in all stages of the research cycle. Further, our review determined that to date, participatory research with young people has been predominantly consultative in nature, using methods such as surveys, focus groups, and interviews to elicit views and opinions. At the same time, an adolescent-led mode of participation was described in only 9% of the 71 studies examined. We found that methods that engage adolescents more meaningfully in research such as YAGs, youth advocacy, and peer leadership were a common component of the few adolescent-led participatory studies. Furthermore, studies that involved a youth-led component reported improvements in capacity building markers of empowerment and influence, enhanced confidence, and gave adolescents a voice in research that concerns their lives. The use of YAGs exemplifies a novel (181) yet practical and effective strategy to meaningfully engage adolescents in an adolescent-led approach throughout the entirety of the research cycle (114, 130). Similarly, in a recent scoping review investigating the use of YAGs in health research, Sellars et al. determined that YAGs are a valuable yet underutilized method of involving young people in effective research development and translation globally (34). Moreover, Sellars et al. also found an underutilization of YAGs was more apparent in research conducted in low and middle-income countries (LMICs), where socioeconomic and cultural factors such as lack of resources and age discrimination limited the use of such engagement strategies (34). This finding is consistent with the findings of our review, which found few participatory-focused research studies for adolescent obesity prevention in LMICs.

Findings from our review indicate significant variability in the scope of reported outcomes of meaningful adolescent participation. We found that participatory outcomes are rarely evaluated, and chronic disease outcomes are inconsistently reported. Nevertheless, similarly to Larsson et al. (38), our review provided evidence that increasing adolescent involvement in the advisory, co-design, and decision-making processes contributed to more meaningful obesity and chronic disease prevention associated outcomes. Chronic disease outcomes described within the studies analyzed included increased awareness of obesity, its risk factors and prevention, obesity prevention interventions and program development, environmental modifications to promote healthier lifestyle habits, behavioral changes including diet and physical activity, and improvements in anthropometric measures such as BMI and weight. Furthermore, we identified that meaningful participation contributes to the development of research and leadership skills as well participatory outcomes of empowerment and influence (82, 86). Although participatory outcomes were rarely evaluated in the 71 studies included within this review, there were reports of improved outcomes for the participating youth (97) and their peers (57, 62, 96). Additionally, DeBar et al. reported in their multi-center RCT, that meaningful participation alone (regardless of the amount) was the main factor driving a positive effect on outcomes, with peer-leadership and commitment contributing to a significant improvement in dietary behavior outcomes as well as a reduction in BMI compared to controls (76).

Our review revealed that current research is failing to take into consideration the dynamic context in which adolescents live, participate and the associated social, economic, cultural, political and health policy influences (182). Most included studies in our scoping review (87%) involved adolescent participation within a single socio-ecological setting, namely, local communities and secondary education institutions. However, studies that also included a "peer" context component in the form of YAGs, leadership, advocacy, or peer education were found to

be more likely to achieve a wider range of positive chronic disease outcomes. Moreover, findings from our review reinforced that adolescents as individuals live within a complex and intertwined socio-ecological sphere, which often impacts their opportunity for health equity (6, 25). In each context, adolescents experienced barriers and facilitators to their diet and lifestyle choices, and decision-making (183). Engaging adolescents in meaningful obesity prevention research across socio-ecological domains may allow for more efficient identification of risk factors that contribute to global adolescent health inequalities resulting in more dynamic intervention development and implementation (184–186). A study by Livingood et al. provided an exemplar model of how to engage adolescents in meaningful participation in research (114). Youth were engaged in a multi-method adolescent-led approach throughout the entirety of the research cycle. Youth developed and facilitated a youth advisory board and used methods such as photovoice and focus groups to identify needs, concerns and preferences. Youth analyzed and presented their findings, which ultimately led to the development of a digital communication (mHealth) obesity prevention intervention that was tailored to the specific needs of youth. However, although obesity prevention was indicated as an objective of the aforementioned study, chronic disease-related outcomes such as anthropometric measures were not taken and hence it is unclear what impact the development of this youth-led intervention will have on obesity incidence within the community (114).

Limitations

Despite our best efforts, this scoping review has several limitations and challenges to note. Overall, it was recognized that due to the lack of standardized measures and reporting, measuring and documenting participatory and chronic disease outcomes were predominantly subjective in nature. Furthermore, the term "participation" is routinely used to refer to participants taking part in a study and not necessarily participating in a meaningful way as per participatory frameworks (25). This made it difficult to decipher if meaningful participation was a component of the research processes. Additionally, participatory approaches were often included in methodology sections of reported studies and hence were often not components of the outcomes measured.

Furthermore, scoping reviews have innate limitations of importance to consider. By design scoping reviews are broad in scope and aim to map the literature therefore, the included studies were heterogenous in range of study methodologies and designs. This made direct comparisons between studies challenging. Furthermore, although search terms used were broad and the search strategy was systematic, as with any review, it is possible that some studies were missed. Moreover, studies were limited to those with abstracts published in English; this self-selection limitation may have inadvertently excluded perspectives from non-English speaking countries. Finally, as per the scoping review guidelines, it is not necessary to rate the quality of the data or conduct a critical appraisal of the evidence used in scoping reviews; this may have implications for practice (47).

Recommendations

For research to translate effectively into practice and to address health equity challenges faced by minority and underserved communities, more effort needs to be placed on making participatory research gender-balanced and inclusive. Future research should endeavor to identify why high-risk groups such as males in high and high-middle-income countries are underrepresented in obesity prevention participatory research and work toward facilitating equal representation between genders. Furthermore, future participatory obesity prevention research should aim for a broad representation of young people from different socio-economic backgrounds as well as cultural and social groups. Additionally, funding bodies and researchers should direct attention and resources to the growing adolescent obesity concerns in LMICs, where meaningful adolescent participation in obesity prevention research is remarkably lacking. Also, for participatory research to truly capture the voice and needs of adolescents, it is necessary for researchers to engage young people in an increasingly collaborative or adolescent-led capacity throughout all stages of research and development processes. Researchers should also take into consideration the diverse and dynamic socio-ecological settings in which adolescents and their peers connect. Finally, to adequately measure participatory outcomes and make comparisons between studies we recommend standardized and universal tools to measure participatory outcomes in adolescent obesity-related participatory research.

CONCLUSION

Findings from our review indicate that adolescents globally are not being engaged sufficiently in obesity prevention research decision-making to uphold the recommendations of the WHO-UNICEF-Lancet commission. The limited number of studies identified from this review that engaged adolescents to a greater capacity within the research process highlights a key opportunity for enhancing obesity prevention research and practice. Meaningful engagement of adolescents in an inclusive and fair manner builds their capacity to contribute throughout the obesity prevention research process. Addressing the unique needs of adolescents requires adolescents to be afforded increased opportunities to collaborate and lead stages of the decision-making, research and translation process.

AUTHOR CONTRIBUTIONS

MM, SM, HC, PP, JR, and SP: conceptualization, methodology, investigation, and writing—review and editing. MM: writing—original draft preparation. JR and SP: supervision. All authors have read and agreed to the published version of the manuscript.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpubh.2021.789535/full#supplementary-material

Supplementary File 1 | Prisma Scoping Review Checklist.

Supplementary Table 1 | Medline Search Strategy.

Supplementary Table 2 | Data extraction table of included studies.

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Gender Difference and Correlates of Physical Activity Among Urban Children and Adolescents in Ethiopia: A Cross-Sectional Study

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Background: Studies indicate that children and adolescent populations in most countries show a low level of physical activity (PA) and an increasing prevalence of obesity. Addressing gender disparity in PA is the main element of public health programs. There is currently a paucity of studies, particularly, in developing countries that investigate gender differences and correlates of PA among children and adolescents.

Objective: The study is aimed to assess the gender difference and correlates of PA among children and adolescents in Ethiopia.

Methods: An observational population-based cross-sectional study was conducted in representative samples of children and adolescents in the capital city of Ethiopia, Addis Ababa. Multivariable logistic regression models with robust estimation of SEs were fitted to predict the odds ratios (ORs) and 95% CIs.

Results: A total of 632 children and adolescents-parent dyads were included in the study. More boys than girls (17.0 and 11.7%) were engaged in moderate intensity PA 3 days a week or more ($p = 0.057$). Age, mothers working in a private business, attending public schools, longer sleep duration, and being taught the benefits of PA were positively associated with meeting moderate-to-vigorous PA (MVPA) in both sexes combined and in a sub-sample of boys. Furthermore, an inverse association was found between overweight/obesity and MVPA in the overall children and girls as well. For moderate PA (MPA); the age of the children, maternal education and occupation, school type, overweight/obesity, and sleep duration on school nights were significant correlates among the studied children.

Conclusions: The present study provided evidence of several correlates identified associated with meeting MVPA and MPA in both sexes combined. Girls are less likely than boys to engage in PA. Therefore, there is a need to take into perspectives the provision of a comprehensive multifaceted health behavior modification and interventions, such as focused and regular physical education in schools.

Keywords: physical activity and exercise, childhood, overweight/obesity, Ethiopia, gender difference

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INTRODUCTION

Globally, the prevalence of insufficient physical activity (PA) among school-attending adolescents was 78.4% for boys and 84.4% for girls aged 11–17 years (1). Studies also indicate that children and adolescent populations in most of the developing countries exhibit a low prevalence of overall PA levels and a rising prevalence of obesity (1). PA for children includes active play, walking or biking, exercising, school-based activities, recreational activities, etc. Identifying and addressing gender disparity in PA is the main element of public health programs (2). The health benefits of being physically active during adolescence are well-documented (3). PA is associated with a marked reduction in premature mortality and reduces risks of more than 24 chronic diseases, such as cardiovascular diseases, diabetes, and cancers (4, 5).

Different literature found out that girls were lower perceived competence in physical education (6) and were less active than boys and less physically fit compared to boys (1, 6–9). In a large scale, about 219,803 participants from 33 out of 47 Latin-American countries from 5 to 17 years study, in general, boys showed a higher prevalence of meeting PA guidelines in comparison with girls (10) and from 2009 to 2010 Health Behavior in School-Aged Children study included 36 countries indicate that boys reported more PA than girls, but the magnitude of these sex differences varied greatly between countries (11).

There is evidence to suggest that many children and adolescents do not engage in healthy behaviors at the recommended levels with multiple obesity risk behaviors (12). Findings from a review suggest that obesogenic cluster patterns are complex with a mixed PA/sedentary behaviur cluster observed most frequently. The tendency for older children/adolescents, particularly, girls to comprise clusters defined by low PA was also a robust finding (13).

In recent years, there are increased opportunities for children to become sedentary in their leisure time. Particularly, technology has offered more opportunities to play video games, watch TV, and browse the internet that are shown to be positively related with overweight and time spent on sedentary behaviors is inversely associated with physical exercise among adolescents (14, 15). The reduced level of PA in children is greatly associated with unfavorable metabolic and cardiovascular outcomes (16), reduced well-being, and cognitive function (17). Hence, this entails there is a need to promote PA in children across a spectrum of environmental settings (18, 19).

According to a recent review by Martin et al. (20), there is a growing body of literature that shows the influence of lifestyle interventions with modified forms of PA and dietary management that can impact the body's energy balance and metabolic system. School physical education is recognized as a key opportunity for improving PA by providing children and adolescents fundamental knowledge, movement skills, and active attitude for lifetime PA (12, 13, 21).

In Ethiopia, to address the problem of obesity, the National Nutrition Program incorporated the importance of PA to reduce obesity and its complications (22). However, the efforts do not target children and adolescents well. Although studies on PA have been conducted in Ethiopia, the risk factors for physical inactivity among children and adolescents have not been addressed. Hence, a paucity of studies among children and adolescents in Ethiopia necessitates investigating contextual factors to predict PA and genders disparity. This study, therefore, is aimed at assessing correlates of and gender differences in the level of PA among children and adolescents.

METHODS AND MATERIALS

Study Setting and Sample

This was an observational population-based cross-sectional study conducted in representative samples of school-aged children and adolescents in Addis Ababa between May 2017 and July 2017. The study was conducted in selected sub-cities in Addis Ababa; namely, Bole, Gulele, Kolfe Keranio, Niffasilk Lafto, and Yeka. Hosting 30% of the urban population of Ethiopia, Addis Ababa is considered to be the diplomatic capital of Africa and is one of the fastest growing cities on the continent. All Ethiopian population groups are represented within Addis Ababa due to its position as the capital of the country (23).

The source of data, sample size, and sampling procedure for this study are described and discussed in detail elsewhere (24). Here, we briefly discussed the parameters as follows. The source population was mother-child pairs at the household level living in each sub-city during the study period. The study population was paired sample school-aged children with their mothers present during the data collection period in the selected sub-cities with the inclusion criteria of those children who are living with their mothers, children who are of school age (5–18 years old), mothers who can respond to the interviewer, and school-aged children with their mothers who lived in each of the sub-cities for at least 5 years.

The sample size was calculated using single proportions sample size formula by using Epi Info (Centers for Disease Control and Prevention, Atlanta, GA, USA, 2010) statistical package. The following parameters were used to calculate the sample size: the proportion of children who were overweight in the population (P) is 9.5% (25), 95% CI [the standard normal value at (100%–α) confidence level], d- 3% of Margin of error for sampling and 80% power. This gave a sample size of 367. Then, by including 15% for non-response rate and design effect of 1.5, the total sample size calculated was 634. Multi-stage sampling techniques were carried out to identify the study participants from selected sub-cites. From each sub-city, the proportion to population sampling was applied to obtain the sample size. A simple random sampling method was used to select districts in each sub-city. One child was selected from single-child households, and in some instances, random selection of one child was done when the number of children in the household is greater than one. In this case, a child was selected randomly using the lottery method. In case of the absence of a qualified child in the selected household, the next household was considered.

Variables and Measurements

The outcome variables used for analysis in this study met the recommended moderate PA (MPA) and moderate-to-vigorous PA (MVPA) in children and adolescents. MPA is described as 60 min or more per day of either moderate or vigorous intensity aerobic PA and includes vigorously intense PA on at least 3 days a week and muscle-strengthening PA (MSPA) as part of 60 min or more of daily PA. Children and adolescents should include muscle-strengthening PA at least 3 days a week (26).

The independent variables in this study were the age group of the children and adolescents, sex of household head, maternal education, maternal occupation, family size, availability of vehicle for family transport, and the type of school where the children attend. Other covariates include the presence of PA sessions and plans and physical education in the school and lifestyle/habit-related factors that are linked with the outcome variable. Sleep duration is categorized as follows: <9, 9–10, and ≥10 h (27), based on the amount of sleep a child gets on a typical school night.

Data Collection Procedure

Data were collected using a structured questionnaire developed after an in-depth review of literature and adoption of standardized scales (28). The questionnaire, originally prepared in English, was translated into Amharic and retranslated back to English to check and maintain its consistency. Trained data collectors collected the data after it was pre-tested.

A team of interviewers was assigned to each selected sub-city, which consisted of one team supervisor, two female and two male interviewers. Two interviewers were assigned per household, and the supervisors oversaw the coordination aspect of data collection. Data were collected at the household level in

TABLE 1 | Socio-demographic, economic, and household characteristics of participants by gender in Ethiopia.

Characteristics/variables	Categories	Boy *n* (%)	Girl *n* (%)	*P*-value
Age group of the children and adolescent, years	5–9	64 (20.92)	61 (18.71)	0.725
	10–14	152 (49.67)	152 (52.45)	
	15–18	90 (29.41)	94 (28.83)	
Sex of household head	Male	242 (79.08)	242 (73.31)	0.089
	Female	64 (20.92)	87 (26.69)	
Maternal education	No-formal education	119 (38.89)	124 (38.04)	0.826
	Formal education	187 (61.11)	202 (61.96)	
Maternal occupation	Unemployed	103 (33.66)	108 (33.13)	0.658
	Private business	65 (21.24)	61 (18.71)	
	Employed	138 (45.10)	157 (48.16)	
Family size	<5	159 (52.13)	161 (49.39)	0.491
	≥5	146 (47.87)	165 (50.61)	
Presence of vehicle for family transport	Yes	76 (24.84)	83 (25.46)	0.857
	No	230 (75.16)	243 (74.54)	
Type of school where the child attend	Private	163 (53.27)	175 (53.68)	0.917
	Public	143 (46.73)	151 (46.32)	
Childhood overweight and/or obesity	Normal weight	221 (72.22)	229 (70.25)	0.583
	Overweight or obesity	85 (27.78)	97 (29.75)	
Muscle strengthening physical activity (MSPA)	<3 days/week	262 (85.62)	291 (89.54)	0.135
	≥3 days/week	44 (10.46)	34 (10.46)	
Moderate physical activity (MPA)	<3 days/week	254 (83.01)	287 (88.31)	0.057
	≥3 days/week	52 (16.99)	38 (11.69)	
Reported hours of sleep on a typical night	<9 h/day	176 (59.86)	186 (59.81)	0.983
	9–10 h/day	100 (34.01)	107 (34.41)	
	≥10 h/day	18 (6.12)	18 (5.79)	
Reported hours of sleep on a school night	<9 h/day	190 (62.09)	209 (64.31)	0.210
	9–10 h/day	71 (23.20)	83 (25.54)	
	≥10 h/day	45 (14.71)	33 (10.15)	
Received education on how to develop a physical fitness plan	Yes	198 (64.71)	208 (64.00)	0.853
	No	108 (35.29)	117 (36.00)	
Received education about benefits of Physical activity	Yes	220 (71.90)	235 (72.31)	0.908
	No	86 (28.10)	90 (27.69)	
Child participated in physical education in school	Yes	252 (82.35)	263 (80.67)	0.587
	No	54 (17.65)	63 (19.33)	

the attendance of mothers and children together at their place of residence.

Data Analysis and Processing

Data were entered using SPSS version 21, and analysis was carried out using STATA 15.0 (Stata Corporation, College Station, TX, USA) and WHO AnthroPlus software v1.02 (WHO, Geneva, Switzerland). Descriptive statistics were used to describe the relationship between meeting the recommended MPA and MVPA with background, household, child, and maternal characteristics of participants. Variables that showed significant association using a liberal $p < 0.2$ in the univariable analysis were included in the multivariable regression. Stepwise multivariable logistic regression models with robust estimation of standard errors were fitted to determine the association. At the final parsimonious model, those variables that retained a $p < 0.05$ were considered to be statistically significant and used to interpret the study findings.

RESULTS

A total of 632 children and adolescent-parent dyads were included in the study. About 48% were boys and the mean (SD) of the children's age was 12.5 (±2.96) years. Around three-quarters of children and adolescents live in a male-headed household in which the majority of their mothers had formal education, and almost two-thirds were either employed or engaged in a private business. Moreover, around half of the children reside in a household with ≥5 members (**Table 1**).

Although, no disparity was observed with regard to muscle-strengthening activities between boys and girls (10.5% vs. 10.5%, $p = 0.135$), more boys than girls (17.0 and 11.7%) had moderate intensity PA 3 days a week or more ($p =$

TABLE 2 | Final model of correlates associated with meeting the moderate-to-vigorous physical activity (MVPA) in children and adolescents in Ethiopia.

Characteristics/variables	Categories	Both		Boys		Girls	
		Adjusted odd ratio	*P*-value	Adjusted odd ratio	*P*-value	Adjusted odd ratio	*P*-value
Age group of the children and adolescent (in years)	5–9	Ref		Ref		Ref	
	10–14	2.78 (0.89; 8.74)	0.079	5.39 (1.01; 28.7)	0.048	1.32 (0.25; 6.85)	0.741
	15–18	9.32 (2.93; 29.6)	<0.0001	28.5 (4.96; 164.2)	<0.0001	3.84 (0.74; 19.9)	0.109
Sex of household head	Male	Ref					
	Female	0.80 (0.40; 1.62)	0.539				
Maternal education	No-formal education	Ref					
	Formal education	2.26 (1.13; 4.48)	0.020				
Maternal occupation	Unemployed	Ref		Ref		Ref	
	Private business	3.65 (1.56; 8.53)	0.003	3.24 (1.10; 9.51)	0.032	2.42 (0.55; 10.6)	0.242
	Employed	1.29 (0.59; 2.83)	0.516	0.83 (0.29; 2.34)	0.719	2.97 (0.86; 10.2)	0.085
Family size	<5	Ref		Ref		Ref	
	≥5	0.55 (0.30;1.02)	0.058	0.45 (0.19; 1.05)	0.065	0.66 (0.25; 1.73)	0.400
Type of school where the child attend	Private	Ref		Ref		Ref	
	Public	3.30 (1.71; 6.35)	<0.0001	2.47 (1.03; 5.92)	0.043	3.99 (1.41; 11.3)	0.009
Childhood overweight and/or obesity	Normal weight	Ref		Ref		Ref	
	Overweight or obesity	0.38 (0.17;0.87)	0.023	0.79 (0.27; 2.29)	0.660	0.14 (0.03; 0.63)	0.011
Reported hours of sleep on a typical night	<9 h/day	Ref		Ref		Ref	
	9–10 h/day	0.44 (0.21;0.92)	0.030	0.71 (0.27; 1.89)	0.495	0.33 (0.10; 1.10)	0.072
	≥10 h/day	0.08 (0.01;0.48)	0.006	0.04 (0.003; 0.49)	0.013	0.11 (0.01; 1.42)	0.091
Reported hours of sleep during school night	<9 h/day	Ref		Ref		Ref	
	9–10 h/day	0.54 (0.24; 1.22)	0.141	0.36 (0.10; 1.26)	0.109	0.81 (0.25; 2.68)	0.736
	≥10 h/day	2.59 (1.08; 6.26)	0.034	2.83 (0.88; 9.09)	0.081	3.12 (0.72; 14.1)	0.127
Received education about benefits of Physical activity	Yes	Ref		Ref		Ref	
	No	0.12 (0.03;0.52)	0.005	0.08 (0.01; 0.47)	0.006	0.35 (0.02; 5.43)	0.453
Child participate in physical education in school	Yes	Ref		Ref		Ref	
	No	0.55 (0.21; 1.45)	0.230	0.43 (0.10; 1.78)	0.243		

0.057). Regarding physical education lessons, more than a quarter and one-third of children were not taught in any of their classes about the benefit of PA and to develop physical fitness plans for themselves, respectively. Further, a significant proportion of the children (39.9% boys and 37.2% girls) was not taught about PA opportunities in their community (**Table 1**).

The current study found that attending public schools was positively associated with MVPA in girls (adjusted odds ratio [AOR] (95% CI) 3.99 (1.41; 11.3)). Furthermore, an inverse association was found between overweight/obesity and MVPA in the overall children [AOR 95% CI = 0.38 (0.17; 0.87)] and also in sub-samples of girls [AOR (95% CI) 0.14 (0.03; 0.63)]. For MPA, the age of the children, maternal education and occupation, school type, overweight/obesity, and sleep duration on school nights were significant correlates in the studied children.

After adjusting for confounding in the final parsimonious multivariate analysis, late age of children and adolescents, mothers working in a private business, attending public schools, longer sleep duration on school nights, and being taught the benefits of PA were positively associated with meeting MVPA in both sexes combined and in a sub-sample of boys (**Table 2**). Regarding correlates of MVPA, combined participants in both sexes, adolescents with the age of 15–18 had significantly higher odds of meeting the MVPA than younger children aged 5–9 years [AOR (95% CI) = 9.32 (2.93, 29.6)]. Similarly, children whose mothers had formal education and work in a private business had a significantly higher chance of meeting the MVPA. On the other hand, children who attended public schools also had 3.3 times higher odds of meeting the MVPA, $p < 0.05$. Conversely, overweight/obese children and those who were not taught the benefits of PA had a lesser chance of meeting the MVPA than those who had normal weight and took the lesson, respectively (**Table 2**).

Among the sub-sample of boys, adolescents aged 10–14 and 15–18 years had significantly higher odds of meeting the MVPA than the younger ones (5–9 years). Parallel to the results of both sexes combined, those whose mothers work in a private business and who attended public schools have higher odds of meeting the MVPA. Besides, those who were sleeping ≥10 h on a typical night and who were not taught the benefits of PA were less likely to meet the MVPA compared to their counterparts (**Table 2**). On the other hand, among the sub-sample of girl's children, only those attending public schools and overweight/obese children were more likely to meet the MVPA than private school and normal weight children. Age, maternal occupation, and being taught the benefits of PA did not significantly predict MVPA unlike the results in boys (**Table 2**). Regarding MPA; age, maternal education and occupation, school type, overweight/obesity, and sleep duration on school nights were significant correlates in the studied participants. Age, school type attended, and overweight/obesity were also significant correlates of MPA in boys. Furthermore, family size and school type attended were the significant correlates of MPA in girls. Children who were living in families ≥5 members were less likely to meet the MPA than those in families <5 members (**Table 3**).

DISCUSSION

Our study revealed that most children did not meet the daily recommended PA. In agreement with our finding, a pooled analysis conducted in 146 low-income countries found that among children aged 11–17 years insufficient PA was observed in about 85% of the participants (1). Similarly, another study in Ethiopia showed a comparable proportion; only 17.2% children were physically active (29). Our study strongly supports that boys were more active than boys in which there was a 5.3% difference in the proportion of MPA ≥ 3 days a week. This finding seemed to be consistent with most of the studies reviewed (1, 13, 29–35). Though the criteria of classifying as active/in-active differed across studies; Regina et al. and Gerson et al. reported 7.1 up to 38.8 percentage point increment in boys MVPA than girls (1, 30). Likewise, 20.6% of more boys also participated in PA ≥5 days/week in a study in the US (31). Further, another study in Brazilian children and a review paper using cluster analysis also showed that boys spend significantly higher time in PA than girls (13, 32). As reported in the review paper mentioned before (13), girls tended to engage more in homework and/or socializing through the phone which could be one reason and they were also more likely to report the feeling that they did not enjoy PA (33). Other studies also indicated that the lowest prevalence in female insufficient activity can be potentially explained by societal factors, such as girls being required to support activity and domestic chores around the home in south Asia countries (1), which is a similar feature with this study. The constant finding that boys engage more in both moderate and vigorous PA underlines the need for PA intervention programs to target girls of all ages.

In contrary to previous studies, in both sexes combined, and sub-sample of boys alone, we observed that older children (15–18) significantly engage in MVPA and MPA than younger ones (5–9 years). A review by Rebecca revealed that older children tend to be in clusters defined by low levels of PA. It was gender specific in two of the studies reviewed that older boys in one study and older girls in the other were observed with low levels of PA (13). Other studies in Nigeria and Ethiopia also evidenced MPA, MVPA, and total PA were lower in older adolescents and PA level decreased as age increased among girls in a study in Senegal (29, 34, 36). The disagreement could be attributed to the fact that most of the studies included older children (9–21, 14–19, 12–18, and 13–16 years, respectively) and one is conducted among girls only in whom no association was found between girls' age and PA in our study. Though it is conducted among young children, Dias et al. reported that older ones spent more time in MVPA than younger children similar to the current study (37). However, the association between age and PA may not be conclusive.

The present study also found that children whose mothers worked in a private business had higher odds of meeting both the MVPA and MPA compared to children with unemployed mothers. In line with our finding, Ferrari et al. found that children whose mothers worked full-time had more MVPA than those whose mothers worked part-time in Brazil (30). Another study also mentioned that screen time of children increased when

TABLE 3 | Final model of correlates associated with meeting the moderate physical activity (MPA) in children and adolescents in Ethiopia.

Characteristics/variables	Categories	Both		Boys		Girls	
		Adjusted odd ratio	*P*-value	Adjusted odd ratio	*P*-value	Adjusted odd ratio	*P*-value
Age group of the children and adolescent (in years)	5–9	Ref		Ref		Ref	
	10–14	2.91 (1.05; 8.04)	0.039	5.35 (1.09; 26.3)	0.039	1.74 (0.42; 7.29)	0.447
	15–18	5.99 (2.12; 16.9)	0.001	14.0 (2.82; 69.5)	0.001	2.47 (0.56; 10.8)	0.231
Sex of household head	Male						
	Female						
Maternal education	No-formal education	Ref				Ref	
	Formal education	1.96 (1.06; 3.64)	0.033			2.20 (0.73; 6.60)	0.159
Maternal occupation	Unemployed	Ref		Ref		Ref	
	Private business	2.51 (1.11; 5.69)	0.027	2.52 (0.91; 6.95)	0.075	2.28 (0.46; 11.4)	0.316
	Employed	1.72 (0.84; 3.50)	0.134	1.30 (0.53; 3.22)	0.569	3.25 (0.91; 11.7)	0.070
Family size	<5	Ref				Ref	
	≥5	0.60 (0.35; 1.06)	0.077			0.28 (0.10; 0.75)	0.011
Presence of vehicle for family transport	Yes	Ref				Ref	
	No	1.22 (0.60; 2.51)	0.580			1.15 (0.35; 3.76)	0.814
Type of school where the child attend	Private	Ref		Ref		Ref	
	Public	3.76 (1.95; 7.25)	<0.0001	3.73 (1.69; 8.22)	0.001	3.85 (1.33; 11.1)	0.013
Childhood overweight and/or obesity	Normal weight	Ref		Ref		Ref	
	Overweight or obesity	0.33 (0.16; 0.70)	0.004	0.28 (0.09; 0.83)	0.021	0.35 (0.12; 1.04)	0.059
Reported hours of sleep on a typical night	<9 h/day	Ref		Ref		Ref	
	9–10 h/day	0.42 (0.21;0.84)	0.014	0.52 (0.21; 1.29)	0.160	0.45 (0.16; 1.26)	0.129
	≥10 h/day	0.30 (0.08; 1.16)	0.082	0.49 (0.08; 3.00)	0.444	0.10 (0.01; 1.24)	0.073
Reported hours of sleep during school night	<9 h/day	Ref		Ref		Ref	
	9–10 h/day	0.54 (0.25; 1.15)	0.111	0.54 (0.19; 1.54)	0.249	0.47 (0.15; 1.48)	0.197
	≥10 h/day	2.35 (1.02; 5.41)	0.045	2.53 (0.81; 7.89)	0.109	2.24 (0.57; 8.87)	0.249
Received education on how to develop a physical fitness plan	Yes	Ref		Ref		Ref	
	No	1.67 (0.48; 5.73)	0.417	1.03 (0.20; 5.24)	0.969	4.15 (0.38; 45.4)	0.244
Received education on benefits of physical activity	Yes	Ref		Ref		Ref	
	No	0.43 (0.14; 1.35)	0.149	0.34 (0.08; 1.47)	0.149	1.45 (0.13; 15.8)	0.761
Child participates in physical education in school	Yes	Ref		Ref		Ref	
	No	0.47 (0.19; 1.14)	0.095	0.39 (0.10; 1.50)	0.169	0.72 (0.21; 2.55)	0.616

mothers were unemployed (20) but there was no association with PA (20, 38). Though it is a distal indicator, practical family support, such as providing the necessary sports facilities and transportation to get to a place where children can do PA, was associated with a higher level of PA (38) in which mothers working in a private business can do better than unemployed ones. However, a better understanding is needed on how a mother's employment affects PA.

The present study also found that children attending public schools were more likely to meet both MVPA and MPA than children in private schools. This finding is supported by other studies in India, Brazil, and Addis Ababa, which reported higher PA level among government school children (39–41). No association was also reported by Ferrari et al. (30). The results in the current study could be explained as, in Ethiopia, children in private schools tend to be from families of higher socio-economic status and spend their time in more sedentary activities, such as longer screen time and a better access to transport facilities. In the other way, public school children, who mostly are from lower socio-economic status families, also tend to involve in household chores that increase their level of PA than children in private schools (42).

In this study, in both sexes combined, overweight/obesity was inversely associated with both MVPA and MPA. Further MVPA is associated with girls and MPA with boys. Though it is not possible to convey causality because of the cross-sectional nature of the current and most reviewed studies, comparably, anthropometric variables (waist circumference, BMI, and body fat percent) have negative association with MVPA and MPA in the studied participants (30, 32, 43). Similarly, MPA and VPA were also negatively associated with body composition variables (BMI and body fat percent) in boys and girls, respectively (32). Studies that did not consider the intensity of PA also found similar results. A review with cluster analysis study mentioned that low PA characterized clusters showed a positive association with overweight and another study reported those in low PA cluster had the highest odds of being overweight (13). Moreover, substantial associations between overweight/obesity and low levels of PA also showed among studies in Africa and Ethiopia as PA burns off body fat and hence prevents obesity (44–47).

Moderate-to-vigorous physical activity and MPA were associated with sleep duration on typical and school nights negatively and positively in both sexes combined, respectively. A similar association was also found for MVPA in boys. Consistent findings are available in other studies as longer sleep contributes to an increase in PA level in both sexes combined (48). Lindsay et al. also found early onset and longer sleep duration were associated with increased MVPA (49). This could also explain the negative association on typical nights that may be attributed to late onset. Insufficient sleep duration has been shown to be associated with excessive TV watching, morning tiredness, and reduced odds of participating in PA in both boys and girls (50). Conversely, Sleep quantity was found not to be associated with PA (30). Studies reviewed considered the sleep duration in any nights, however, most of the nights of children are supposed to be school nights.

Physical education has become convenient and inexpensive way of fostering PA and fitness, which can reach large numbers of children across various demographic groups. In this study, being taught the benefits of PA was associated with higher odds of meeting the MVPA in both sexes combined and boys only. An intervention study showed that the mean PA score of the students significantly increased after a 1-month of educational intervention in terms of knowledge (51). Another review in secondary school physical education classes also reported that adolescents were least active when physical education lesson context was knowledge which may result in the small amount of MVPA time (21). The differences demonstrated that teachers, parents, and coaches need to consider gender differences in mixed physical education and sports settings because activities that focus on physical performance are likely to favor boys and teachers, in particular, need to know how to conduct PE and sports that provides boys and girls with equal opportunities for sustained engagement, development of competency and enjoyment of PA (6). However, it included secondary school students in which behavioral change may be less likely than younger children and adolescents. Moreover, in the current study, being taught the benefits of PA did not necessarily mean children spend PE classes with knowledge context only.

The strengths of this study include the inclusion of a wide range of the children age group and a large number of analyzed covariates, considering gender differences for MVPA and MPA levels. In addition, the study may be one of the few similar studies conducted in Ethiopia, which can be considered as added strength. The results of this study may have been influenced by recall bias since the results are based on self-reported PA level. Using reported PA levels, rather than objective measurement, may have limited validity in measuring PA to some extent. Furthermore, there may be information bias in the reporting of PA and sleep duration by the parent for the children. The cross-sectional design of the study precludes us from conclusively making causal inferences and not covering a wide geographic area is also worth mentioning.

CONCLUSION

The present study revealed that older age of children and adolescents, mothers working in a private business, attending public schools, longer sleep duration on school nights, and being taught the benefits of PA were positively associated with meeting MVPA in both sexes combined. Furthermore, the age of the children, maternal education and occupation, school type, overweight/obesity, and sleep duration on school nights were significant correlates in both sexes combined for MPA. Our study found that girls are less likely than boys to engage in PA with more than 5 percentage point difference Comprehensive multifaceted health behavior modification and interventions, such as facilities for PA through the provision of conducive school environment that includes sport and recreational services would encourage children to engage in PA more, and hence reduce the risks at later ages associated with overweight and obesity. Regular physical education on the benefits of PA in school needs to be strengthened as well. Future studies should focus on objective PA measurement in a larger and more diverse representative samples. The cross-sectional nature of this study precludes our ability to conclusively decide on correlates of PA. As a result, longitudinal studies with a long follow-up period would also provide more evidence on correlates of PA.

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/s.

ETHICS STATEMENT

Ethical approval was obtained from the Department of Health Studies, University of South Africa Ethical Clearance Committee for Research on Human Subjects (HSHDC/ 575/2016) and Addis Ababa City Administration Health Bureau (A/A/H/B/3542/227). Information about the study was given to the participants including purposes as well as potential risks and benefits

rendered. Official letters of co-operation from the above organizations were given to respective sub-cities and District administrators. Informed consent was obtained from the participants' parents. For those children under the age of 18 years, a letter of assent form was developed for participation and obtained from their parents. Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

AUTHOR CONTRIBUTIONS

SB conceived the idea, wrote and designed the protocol, data management and analysis, drafted the manuscript, and participated in the critical revision of the manuscript. BG, TM, and AA analysis and interpretation of data, drafted the manuscript, and participated in the critical revision of the manuscript. All authors read and approved the final manuscript.

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Forecasting Obesity and Type 2 Diabetes Incidence and Burden: The ViLA-Obesity Simulation Model

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Background: Obesity is a major public health problem affecting millions of Americans and is considered one of the most potent risk factors for type 2 diabetes. Assessing future disease burden is important for informing policy-decision making for population health and healthcare.

Objective: The aim of this study was to develop a computer model of a cohort of children born in Los Angeles County to study the life course incidence and trends of obesity and its effect on type 2 diabetes mellitus.

Methods: We built the Virtual Los Angeles cohort—ViLA, an agent-based model calibrated to the population of Los Angeles County. In particular, we developed the ViLA-Obesity model, a simulation suite within our ViLA platform that integrated trends in the causes and consequences of obesity, focusing on diabetes as a key obesity consequence during the life course. Each agent within the model exhibited obesity- and diabetes-related healthy and unhealthy behaviors such as sugar-sweetened beverage consumption, physical activity, fast-food consumption, fresh fruits, and vegetable consumption. In addition, agents could gain or lose weight and develop type 2 diabetes mellitus with a certain probability dependent on the agent's socio-demographics, past behaviors and past weight or type 2 diabetes status. We simulated 98,230 inhabitants from birth to age 65 years, living in 235 neighborhoods.

Results: The age-specific incidence of obesity generally increased from 10 to 30% across the life span with two notable peaks at age 6–12 and 30–39 years, while that of type 2 diabetes mellitus generally increased from <2% at age 18–24 to reach a peak of 25% at age 40–49. The 16-year risks of obesity were 32.1% (95% CI: 31.8%, 32.4%) for children aged 2–17 and 81% (95% CI: 80.8%, 81.3%) for adults aged 18–65. The 48-year risk of type 2 diabetes mellitus was 53.4% (95% CI: 53.1%, 53.7%) for adults aged 18–65.

Conclusion: This ViLA-Obesity model provides an insight into the future burden of obesity and type 2 diabetes mellitus in Los Angeles County, one of the most diverse places in the United States. It serves as a platform for conducting experiments for informing evidence-based policy-making.

Keywords: agent-based model, obesity, type 2 diabetes, simulation, prediction

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INTRODUCTION

Obesity is a major public health problem affecting millions of Americans with two in three adults and one in three children considered overweight or obese (1). This condition disproportionately affects lower-income minority and disadvantaged groups (1) giving rise to health disparities. Obesity has been on the rise for the past few decades (1, 2) despite ongoing prevention efforts warranting its description as a pervasive and complex phenomenon (3, 4). As a result, the obesity epidemic has been suggested to result from the complex interplay between individual and environmental factors and behaviors (3, 4). This complexity is clearly seen when considering the socio-ecological framework (5) and exemplified by the fact that our individual behaviors can be influenced by our past behaviors (6), the neighborhood we live in (7) and the people around us (8).

Obesity (and overweight) is considered one of the most potent risk factors for type 2 diabetes (9). Almost 80–90% of type 2 diabetes patients are overweight or obese. This is alarming as type 2 diabetes is a disabling disease that imposes considerable burden on individuals, families, communities and the health system. The total direct medical and indirect expenditures attributable to diabetes in the U.S. amounted to ∼$245 billion in 2012 (10).

To model obesity and forecast its future, researchers have suggested using complex methods (3, 4). One such method is an agent-based model—a computer representation of the real world (11, 12) where researchers and policymakers can run experiments *in silico* to evaluate the impact of potential interventions by simulating counterfactual scenarios (13). An example of such a virtual world is represented by the Coronary Heart Disease Policy Model developed to forecast and address coronary heart disease incidence, mortality and cost (14). Another prominent model is the Archimedes diabetes model (15), which was built to address clinical problems and questions around diabetes and modeled after several randomized controlled trials. In the present study, we chose to model our virtual world after that of Los Angeles County, California, for its high population density, its ethnic diversity (16), its rising rates of obesity and its marked racial/ethnic disparities in obesity (17).

In addition, modeling approaches that provide different and complementary insights on how changes in individual and environmental risk factors could affect disease rates in the future in a recent birth cohort are needed. Therefore, we set up a discrete-time modeling approach that will incorporate trends in individual and environmental risk factors in the hopes of evaluating their joint effects, at critical life stages, on future obesity or diabetes status in a recent birth cohort (13).

The overarching goal of this study was to develop an agent-based simulation model of a cohort of children born in Los Angeles County and followed into adulthood to study the life-course development of obesity and of its effects on diabetes mellitus. Specifically, we aimed to forecast and study the life course incidence and trends of obesity and its effect on type 2 diabetes mellitus risk. This synthetic cohort could serve as a platform for conducting *in silico* experiments and testing hypothetical public health interventions to inform evidence-based clinical and population-health decision- and policy-making (13, 18).

METHODS

We developed the ViLA–Obesity model, a stochastic, dynamic, discrete-time, agent-based model informed by various data sources and calibrated to the population of Los Angeles County in California to explore the incidence and trends in obesity and type 2 diabetes.

Description of the ViLA Simulated Population and Overview of the ViLA-Obesity Simulation Model

According to the 2010 US Census, Los Angeles County was inhabited by 9,818,605 individuals who lived in 2,346 census tracts (19). In this model, as it is the case in some other studies (20), we considered a census tract to represent a neighborhood. We simulated 235 neighborhoods with 418 inhabitants per neighborhood for a total simulated population of 98,230, which represented a 100th of the Los Angeles County (LAC) total population (**Supplementary Table 1**). Simulated individuals in the model are referred to as agents. In this closed cohort, each agent was born in a specific neighborhood and was simulated from birth (aged 0–1 year, i.e., $time = 0$) to middle adulthood (aged 60–65 years, i.e., $time = 9$) in 10 discrete time steps representing critical life stages (**Supplementary Table 2**). At each time step the agent's age is simulated using a uniform distribution bounded within the specific critical life stages (**Supplementary Table 2**).

ViLA-Obesity represents a simulation model or suite within our ViLA platform. It integrates trends in the causes and consequences of obesity, focusing on diabetes as a key obesity consequence during the life course. During the simulation, each agent exhibited obesity- and diabetes-related healthy and unhealthy behaviors [e.g., sugar-sweetened beverage consumption (SSB), physical activity, smoking], gained/lost weight and developed type 2 diabetes with a certain probability dependent on the agent's current state (**Figures 1**–**3**). We calculated and reported age-specific incidence, cumulative incidence, prevalence and average incidence rate of obesity and diabetes. To calculate the incidence measures, we considered the first-time diagnosis of obesity or type 2 diabetes among at-risk individuals. All data preparation and analysis and Monte Carlo simulation were also done in SAS 9.4 software (Cary, NC).

Data Sources and Parameters

- Proportions, means and standard deviations:

The parameters for the individual-level socio-demographics and those of the neighborhood-level socio-demographics were obtained from the American Community Survey (ACS) (**Supplementary Table 4**). The individual-level race and income group were derived respectively from the neighborhood-specific race percentage and percent below federal poverty level (FPL). The proportions, means and standard deviations of the

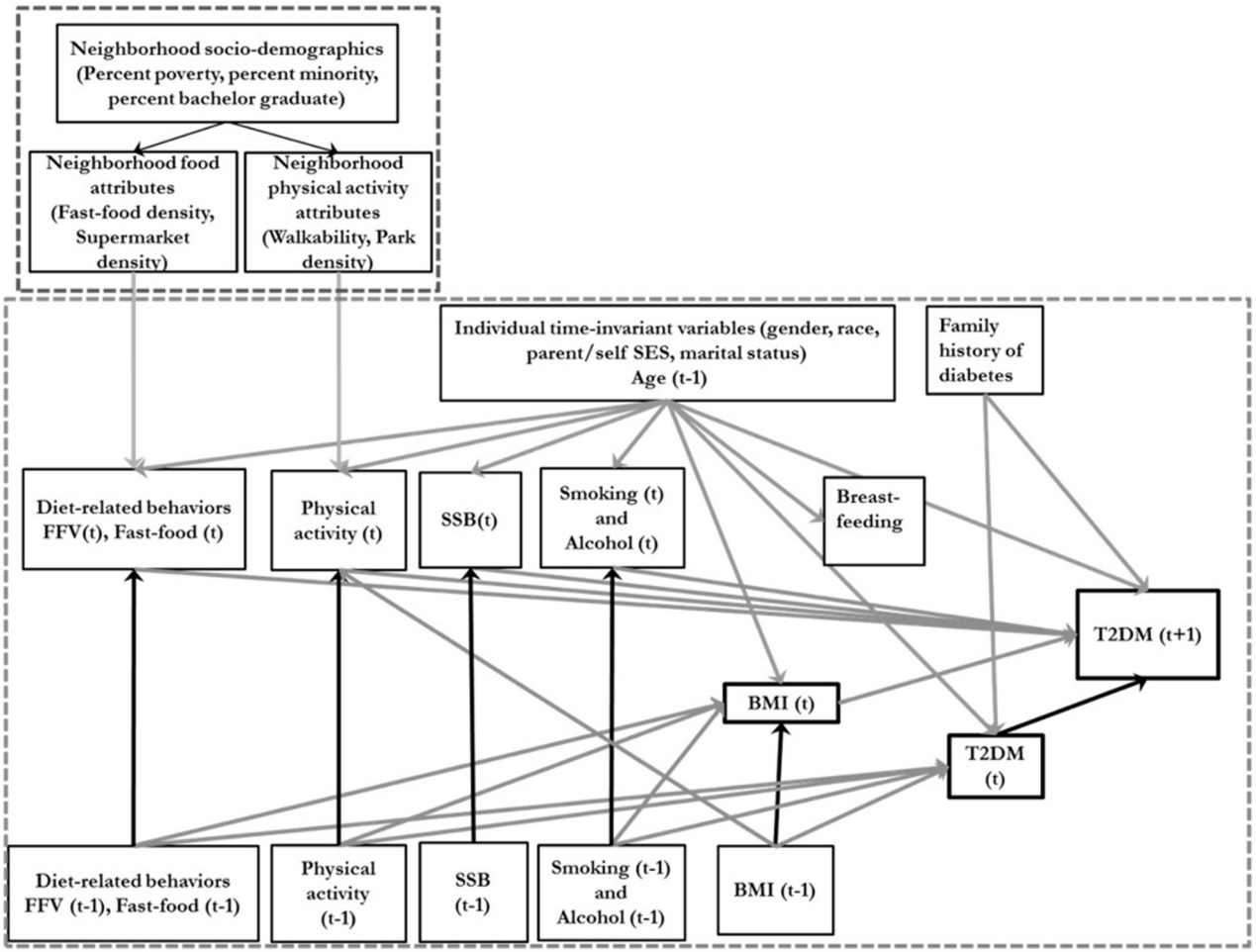

FIGURE 1 | Conceptual directed acyclic diagram underlying the data-generating process. SSB, sugar-sweetened beverage consumption; BMI, body mass index; FFV, Fresh fruit and vegetable consumption; T2DM, type 2 diabetes; Ado, Adolescence. T is an index of time. The smaller dotted square represents the neighborhood variables and the larger dotted square represents the individual level variables.

individual-level exposures and outcomes [breastfeeding, SSB, physical activity, fast-food consumption and fruit and vegetable consumption, smoking, alcohol consumption, body mass index (BMI), type 2 diabetes] were obtained from the California Health Interview Survey (CHIS) (21), the Centers for Disease Control and Prevention (CDC) (22), the World Health Organization (WHO) (**Supplementary Table 5**).

- Parameters for effect and association measures:

These regression coefficients were taken from various sources detailed in the **Supplementary Table 3**. For clarity, we defined three levels of evidence. "Evidence level 1" parameters are directly taken, in this order of preference, from published systematic reviews and meta-analyses, randomized control trial studies or cohort studies. "Evidence level 2" parameters are directly taken from cross-sectional studies from the peer-reviewed literature. "Evidence level 3" parameters are computed (indirectly obtained) by our research team using merged publicly and privately available data [e.g., American Community Survey, National Establishment Time-Series (NETS), Walkscore.com, WHO, National Health and Nutrition Examination Survey (NHANES) and the Los Angeles County Health and Nutrition Examination Survey (LAHANES) (21–25). Ideally, all parameters would be coming from "evidence level 1" but because most studies do not report on the relationships between covariates such as age, sex, race, socio-economic status [SES], and the outcome and between the covariates and the exposures, we identified other sources of evidence (**Supplementary Tables 6–10**).

Model Specification

Agent

Each simulated agent had three domains of attributes. The first domain was the agent's socio-demographics [i.e., age, sex, socio-economic status (SES), race/ethnicity and marital status] representing the individual's inherent susceptibility which was not allowed to change (i.e., time-invariant variables)

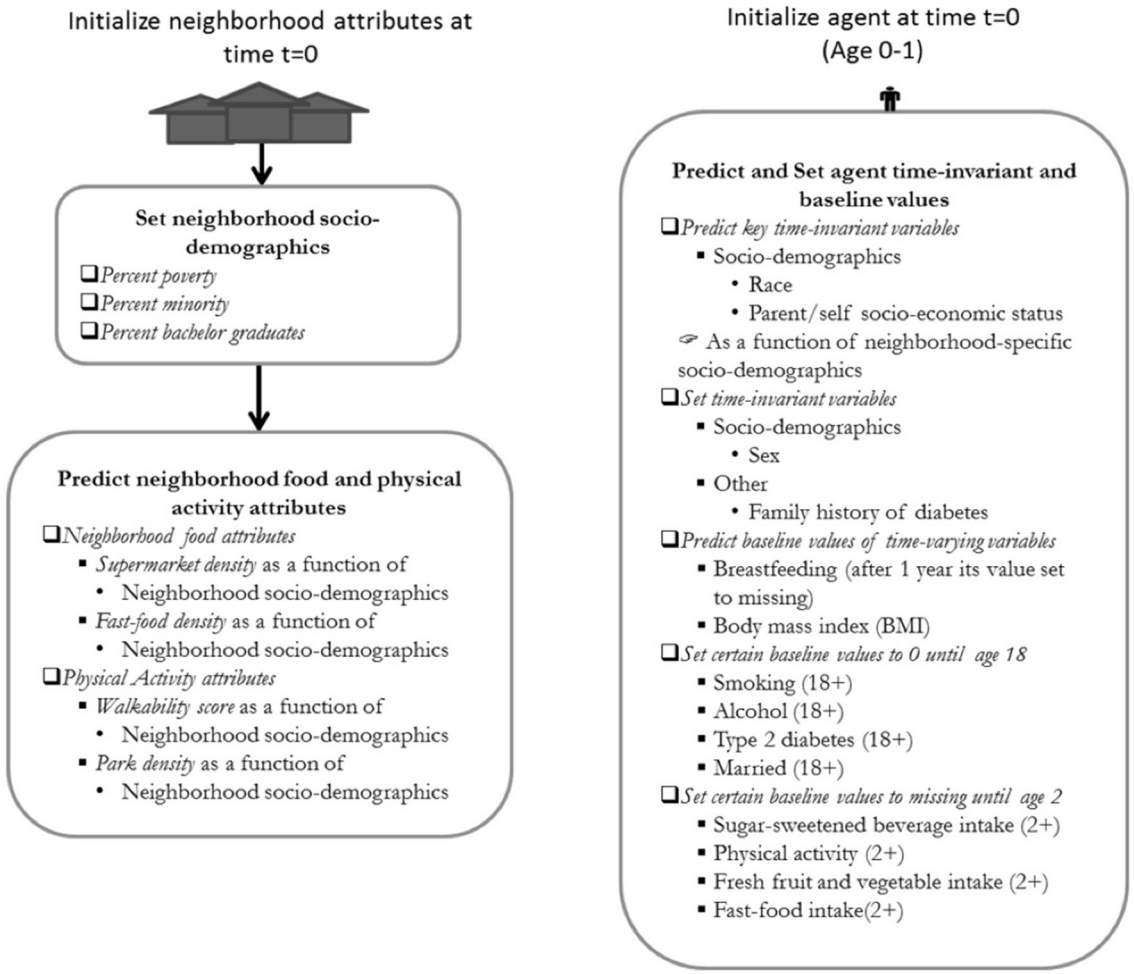

FIGURE 2 | Model initialization diagram of the ViLA-Obesity model. The neighborhood attributes are first initialized at time t=0 and subsequently followed by the initialization of the agent. The neighborhood food and physical activity attributes are predicted as a function of neighborhood socio-demographics. The individual time-invariant variables are set to their baseline values or predicted from socio-demographic variables.

with the exception of age. We assumed that individuals born in a certain SES group will remain in that group until the end of the simulation (i.e., inherit their parents' SES) and that agents could only get married after their 18th birthday (**Supplementary Table 4**). The second domain was the agent's behaviors and was divided into: (i) dietary behaviors (breastfeeding, fast-food consumption, SSB, fresh fruit, and vegetable consumption); (ii) physical activity behaviors (moderate-to-vigorous physical activity) and (iii) other behaviors (smoking, alcohol consumption) (**Supplementary Table 5**). The last domain was the agent's outcomes (BMI, and type 2 diabetes status).

Agents were only allowed to engage in smoking, alcohol consumption and develop type 2 diabetes after their 18th birthday. Both behavior and outcome domains were considered time-varying variables. For children aged 0–19, we defined overweight and obesity using the WHO BMI Z-score international child cutoffs (26). We calculated BMI Z-scores using CDC's SAS codes (27). Based on the WHO growth charts, a child with a BMI Z-score (BMIz) <-2 was classified as underweight; a BMIz ≥ -2 but <1 was classified as normal-weight; a BMIz ≥ 1 but $< +2$ was classified as overweight and a BMIz ≥ 2 was classified as obese (28).

Similarly, an adult with a BMI < 18.5 was classified as underweight; a BMI ≥ 18.5 but <25 was classified as normal-weight; a BMI ≥ 25 but <30 was classified as overweight and a BMI ≥ 30 was classified as obese (29).

Neighborhood Environment

The neighborhood where the agents dwelled had three domains. The first domain was the neighborhood socio-demographics encompassing the proportion of individuals who self-identified as non-White, the proportion of individuals living below the federal poverty level (FPL) and the proportion of individuals who had a bachelor's degree or higher. The data for this domain were obtained from the American Community Survey

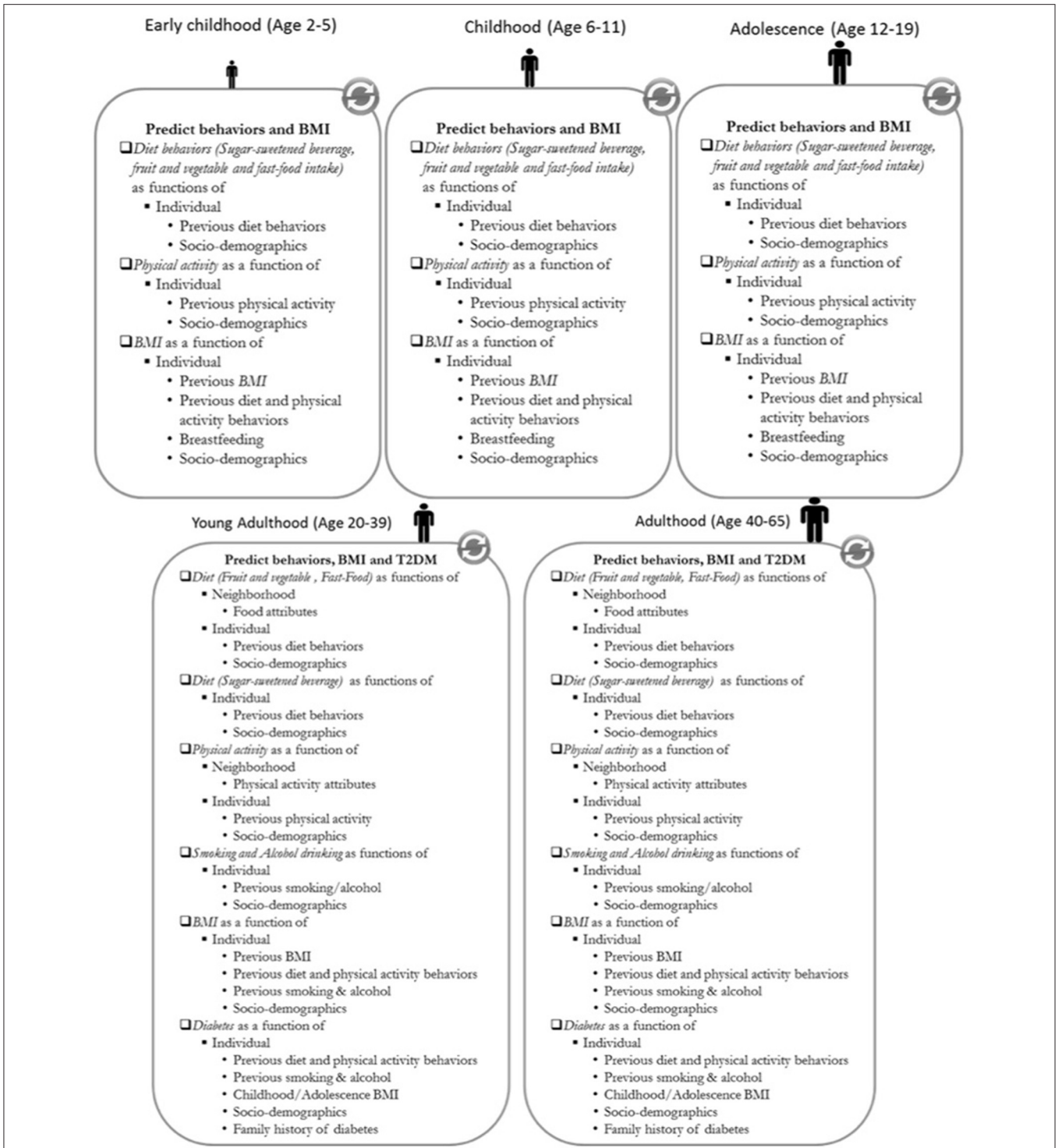

FIGURE 3 | Model execution diagram of the ViLA-Obesity model. BMI, body mass index; T2DM, type 2 diabetes; SES, Socio-economic status. Individual behaviors are predicted based on the agent's socio-demographics, previous behavior and depending on the behavior neighborhood characteristics. The body mass index and type 2 diabetes are predicted based on the agent's socio-demographics, previous behaviors, and previous body mass index in the case of body mass index.

[ACS] (19). The second domain was the neighborhood physical activity opportunities that comprise the neighborhood walkability and access to parks. The data for the second domain were obtained from Walkscore.com (30), the National Establishment Time-Series (NETS) (31) and Wolch et al. (30). The third domain was the neighborhood food environment

comprising the supermarket and the fast-food density. The data for the third domain were obtained from NETS (31) (see **Supplementary Table 4** for more details).

Conceptual Model, Equations, and Decision Rules

The decision rules underlying this model were mainly based on mathematical equations. Completely exogenous variables in this model were few and limited to individual- and neighborhood-level socio-demographics. Except at birth (time $t = 0$), all behavior equations (e.g., SSB, physical activity) had a common form whereby the dependent variable would be a function of the following: intercept, lagged version of the dependent variables and socio-demographics. Likewise, the outcome equations (e.g., BMI, type 2 diabetes) had in addition to the previous ones listed all age-specific behaviors (e.g., SSB, physical activity, and smoking). Linear and logistic regressions were used for modeling continuous and binary dependent variables, respectively. Accordingly, the inverse of the link functions used in the regression modeling were used for simulation (i.e., identity and expit functions respectively). The neighborhood environment and its attributes are first simulated, then agents with their attributes by time period are simulated within neighborhoods. These will engender a change in BMI and will subsequently affect diabetes risk. Most endogenous variables allow for time-dependency (i.e., previous behavior affecting future behavior). Features of feedback were also allowed. For instance, when BMI changed, it affected subsequent ability to exercise which subsequently affected future BMI and so on (32). A detailed description of the equation structure are presented in the **Supplementary Table 11**.

Model Calibration, Verification, and Validation

We undertook several iterative steps to build the ViLA-Obesity model. These included calibration, validation, and verification. Of note, *calibration* is the process through which we assign input parameters within the model and ensure that the predicted model output is close to that of the observed data (ideally using training data if available or the entire data if not). Evaluating whether calibration worked within one's own data could also be seen as an internal validation procedure. *Validation (*or sometimes external validation), on the other hand, strives to ensure that the predicted model output (ideally using a training data if available or using the entire data if not) is close that of the observed data (ideally using a test data or using observed data from a different period if not). *Verification* is a process that involves different techniques such as structured code walk-throughs to check for model consistency and errors and makes sure that the model does what it is intended to do (33, 34).

Model Verification

In the model verification step, we used structured code walk-through to check for model consistency and errors throughout the modeling process in an iterative fashion.

Model Calibration and Internal Validation

We first obtained parameters (i.e., proportions, means, standard deviations of each variable, and the regression coefficients relating any two variables) from multiple studies and datasets. Many commonly used external validation techniques (35) could not be used here because we did not have a base cohort in Los Angeles that followed individuals from birth to adulthood and which studied our exposures and outcomes of interests. In other words, we could not externally validate our model. Nevertheless, we used a "calibration-in-the-large" technique to calibrate and internally validate our model (35). In brief, the "calibration-in-the-large" is a calibration whereby one ensures that the mean predicted outcome equals the mean observed outcome [i.e., $\text{mean}(Y_{predicted}) = \text{mean}(Y_{observed})$] through the fine tuning of the intercept (35), or other coefficient. The finding of the equality $\text{mean}(Y_{predicted}) = \text{mean}(Y_{observed})$ ensured the internal validity of the model testifying that there was agreement between the observed data and our model predictions (i.e., internal validation). From a practical standpoint, after we have assigned the parameters in our equation models (see **Supplementary Table 11**, e.g., relative risks obtained from the three levels of evidence, etc.), we sought to find and finetune the remaining parameters, that is, those that could not be otherwise obtained directly from the literature. There were two such parameters: intercepts and feedback parameters (i.e., coefficients reflecting the relationship between current behavior or outcome to previous behavior and outcome, all else equal). As such, we defined a calibration objective function as the Mean Absolute Error (MAE) between the predicted and observed variable mean or prevalence. Once the objective function has been defined, we used a grid search strategy to find the appropriate parameters of interest. Parameter values that minimized the objective function were selected to parametrize the model. This was done sequentially starting from birth (aged 0–1 year, i.e., $time = 0$) to middle adulthood (aged 60–65 years, i.e., $time = 9$) in 10 discrete time steps. Furthermore, after the whole model parametrization, we evaluated whether our calibration (internal validation) was successful by (1) plotting our simulated and observed outcome means and proportions over time for each behavior [e.g., sugar-sweetened beverage (SSB)] and outcome (e.g., body mass index) and (2) computing the variance explained, R^2, between the simulated and observed data for each behavior and outcome over time. As such, we internally validated our model on the basis of its ability to the predict observed outcomes. To extend the model to other populations, we could adjust our intercepts to match the site-specific observed prevalence (35).

RESULTS

Calibration and Internal Validation

Figure 4 shows the simulated and observed means and proportions by age groups. Our simulation results broadly matched the age-specific means and proportions from CHIS 2009. However, there were some small but notable departures from the observed data for physical activity, fresh fruit and vegetable consumption, smoking and diabetes prevalence. This can also be seen with the computed R^2 which was

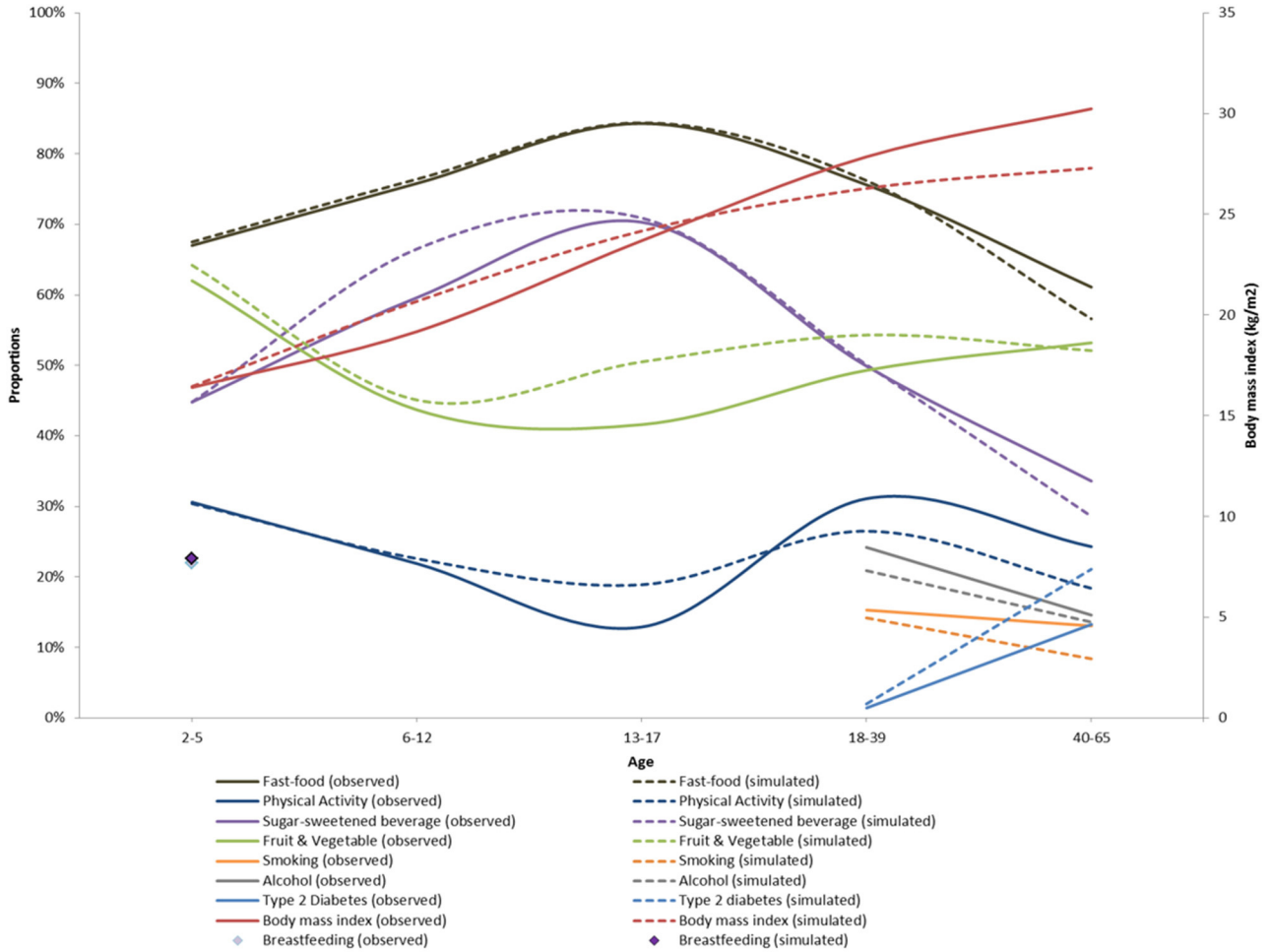

FIGURE 4 | Calibration of the ViLA-Obesity model. This figure depicts the results of the model calibration. It compares the observed (plain lines) to the simulated data (dotted lines).

high (>0.9) for body mass index, sugar sweetened beverage, fresh fruits and fast-food consumption and moderate (>0.6) for fresh fruits and vegetables and physical activity. The R^2 for exclusive breastfeeding, smoking, alcohol and type 2 diabetes could not be computed because of the low number of data points available (see **Supplementary Table 12** for details).

Trends in Obesity and Type 2 Diabetes

Figure 5 depicts the overall and racial subgroup trends (incidence and prevalence) in obesity and type 2 diabetes over time in the ViLA-Obesity model.

We found that the obesity age-specific incidence proportion was generally increasing from about 10% to about 30% across the individual life span with two notable peaks at age 6–12 and 30–39. Likewise, the age-specific incidence proportion of type 2 diabetes increases from <2% at age 18–24 to reach a peak of about 25% at age 40–49.

The prevalence of obesity was highest in childhood with about 25% of children considered obese between the age of 6 and 12 years. During adulthood, the prevalence of obesity rose to reach a maximum of 40% at the end of follow-up at age 60–65 years.

Compared to Whites, the incidence and prevalence of obesity and type 2 diabetes were generally higher among the non-White subpopulation. There were marked disparities in the prevalence of type 2 diabetes compared to that of obesity. The racial disparity gap in the prevalence of type 2 diabetes was greatest during middle adulthood but that in the prevalence of obesity was small but more uniform across ages.

Trends in Drivers of Health Behaviors

Figure 6 shows the overall and racial subgroup trends in key health behaviors. The consumption of fast-food was generally high and decreasing with age. It was highest during

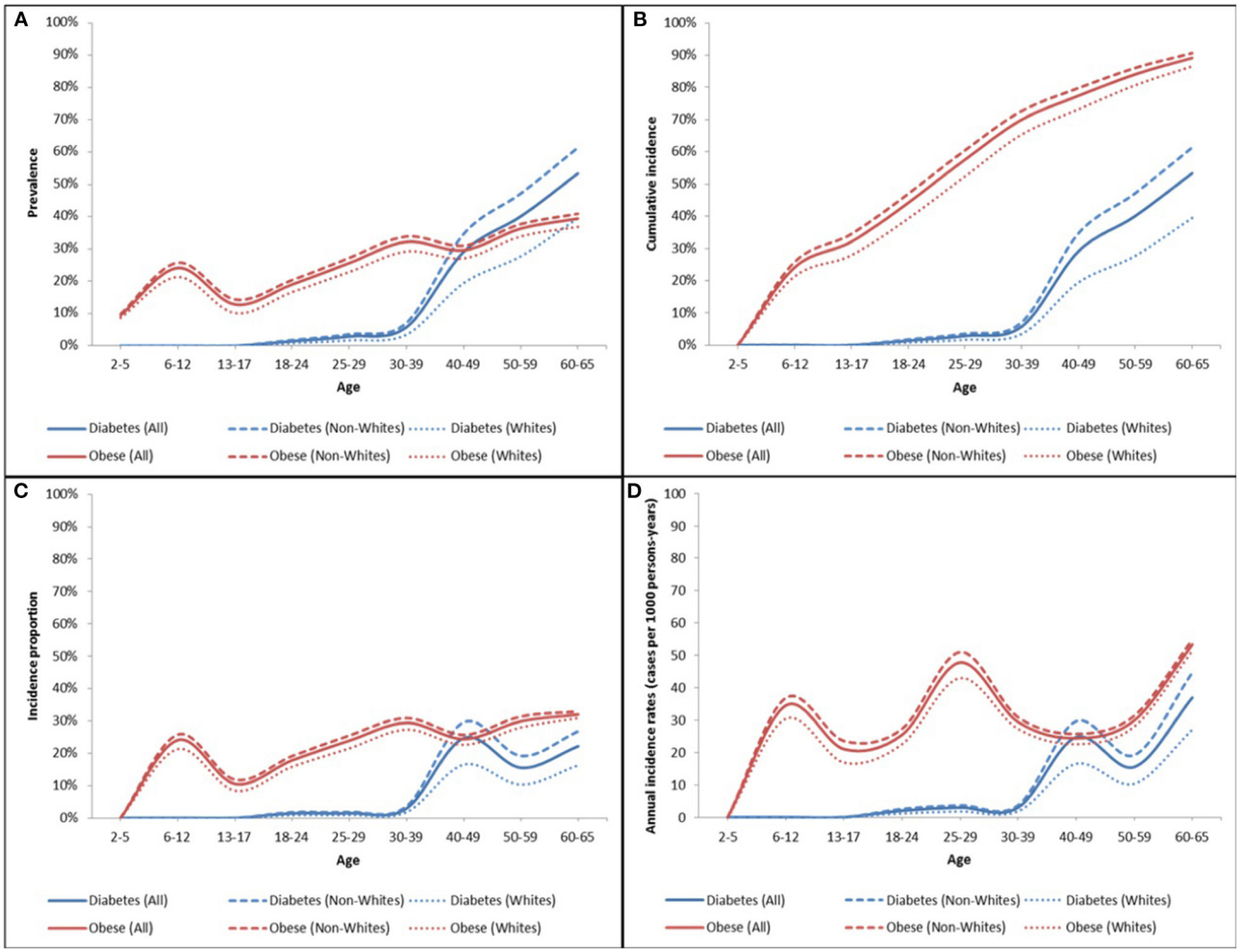

FIGURE 5 | Obesity and type 2 diabetes prevalence **(A)**, cumulative incidence **(B)**, age-specific incidence proportion **(C)**, and annual incidence rates **(D)** in the ViLA-Obesity model. The incidence measures were calculated for first-time diagnosis of obesity or type 2 diabetes among at-risk individuals (i.e., without the diagnosis).

childhood and adolescence with ∼75–85% of children and adolescents consuming fast-foods more than one time per week. The consumption of sugar-sweetened beverage was also generally high and decreasing with age. It was highest during childhood and adolescence with ∼60–70% of children and adolescents consuming more than one 12-oz drink of SSB per day. Engaging in moderate-to-vigorous physical activity was generally low and decreasing with age. It was lowest during adolescence with only about 20% of adolescents engaging in moderate-to-vigorous physical activity. The consumption of fresh fruits and vegetables was fairly constant over time. It was lowest during childhood with only about 40–50% of children aged 6–12 consuming more than five servings of fruit and vegetables per day. About one out of five individuals were breastfed for 6 months or longer during their 1st year of life.

Cumulative Incidence and Average Incidence Rate of Obesity and Type 2 Diabetes in the ViLA-Obesity Model

Table 1 presents the cumulative incidence and average incidence rates of obesity and type 2 diabetes in the ViLA-Obesity model.

Type 2 Diabetes

The 48-year risk or cumulative incidence of type 2 diabetes in the ViLA-Obesity model was 53.4% (95% CI: 0.53.1%, 0.53.7%) and the average incidence rate of type 2 diabetes was about 13 cases per 1,000 person-years (95% CI: 12.7, 12.9) for adults aged 18–65 years.

Obesity

The 16-year risk or cumulative incidence of obesity was 32.1% (95% CI: 31.8%, 32.4%) and the average incidence rate of obesity

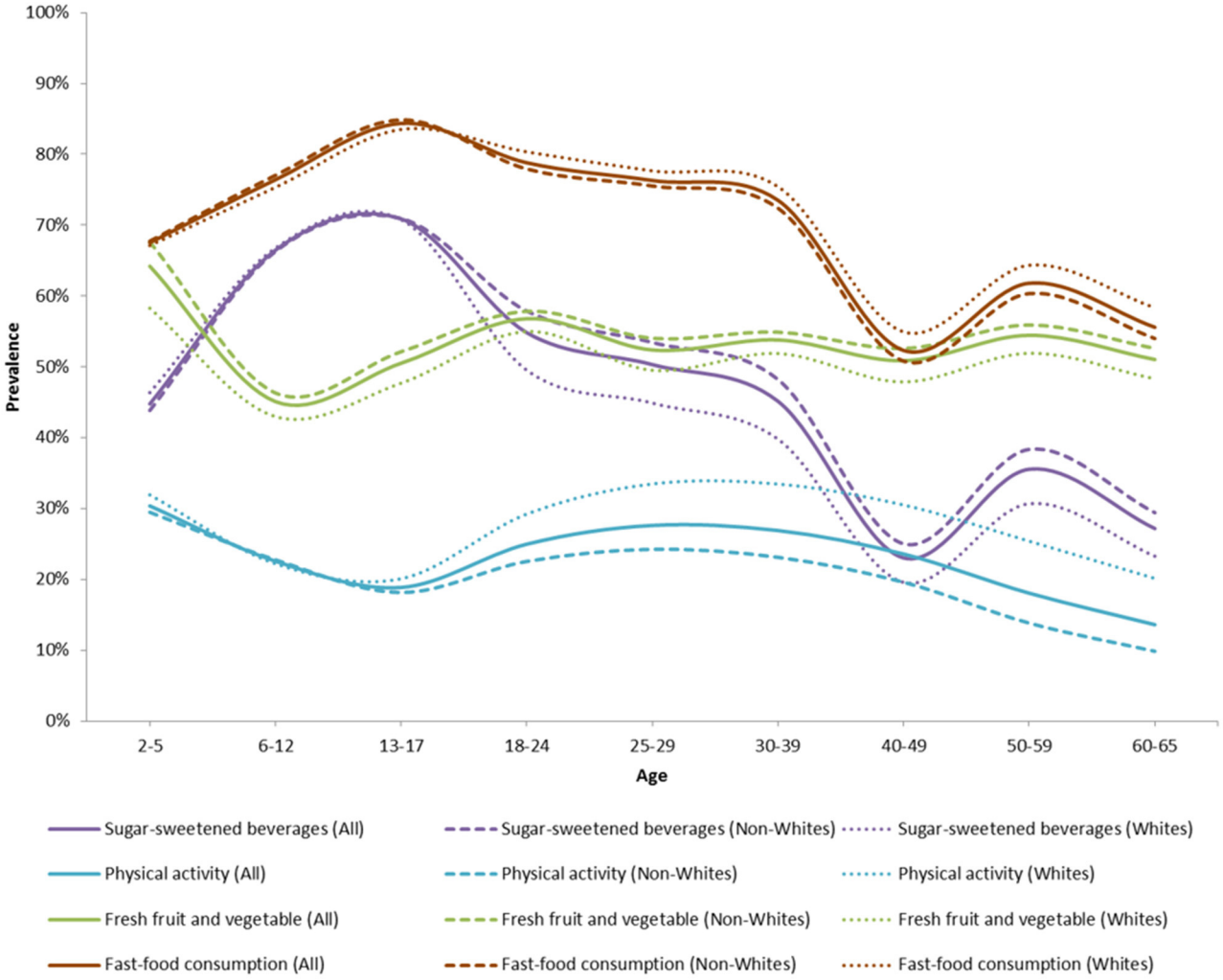

FIGURE 6 | Proportion of obesity- and type 2 diabetes-related health behaviors over time in the ViLA-Obesity model. This figure highlights the health behaviors prevalence across the population.

was about 22 cases per 1,000 person-years (95% CI: 22.0, 22.5) for children aged 2–17 years. The 48-year risk or cumulative incidence of obesity was 81% (95% CI: 80.8%, 81.3%) and the average incidence rate of obesity was about 28 cases per 1,000 person-years (95% CI: 27.8, 28.2) for adults aged 18–65 years.

DISCUSSION

The purpose of this study was to build an agent-based model of a cohort of children born in Los Angeles County and followed from birth into adulthood in order to study the life course development of obesity and of its effects on diabetes mellitus. This virtual cohort would then serve as a platform for conducting *in silico* experiments and testing hypothetical public health interventions to inform evidence-based clinical decision- and policy-making (13, 18).

Our findings suggest that the incidence and prevalence of obesity and type 2 diabetes within the ViLA-Obesity model were generally high and increasing during the life span. The prevalence of obesity was highest during childhood and among individuals in their 30's while the prevalence of type 2 diabetes started rising among individuals in their 40's. In addition, one in three children and adolescents and four in five adults will become obese before age 65 and one in two adults will develop type 2 diabetes before age 65 in the simulated cohort. There were some racial differences in the prevalence and incidence of obesity and type 2 diabetes. The non-White subpopulation experienced higher proportions of individuals who became obese or developed type 2 diabetes at any point in time throughout the 64-year follow-up compared their White counterparts. The presence of such racial disparities in obesity and type 2 diabetes has been well-documented in Los Angeles (17, 36).

TABLE 1 | Incidence rates and cumulative incidence of obesity and type 2 diabetes in the ViLA-Obesity model ($n = 98,230$).

	ALL			
	Obesity (2–65)	**Obesity childhood (2–17)**	**Obesity adulthood (18–65)**	**Type 2 diabetes adulthood (18–65)**
Total number	98,230	98,230	98,230	98,230
Events	87,625	31,544	79,606	52,426
Person-years (py)	3,183,963	1,415,891	2,847,196	4,099,783
Incidence rate (per 1,000 py)	27.5 (27.3, 27.7)	22.3 (22.0, 22.5)	28.0 (27.8, 28.2)	12.8 (12.7, 12.9)
Cumulative incidence	89.2% (89.0%, 89.4%)	32.1% (31.8%, 32.4%)	81.0% (80.8%, 81.3%)	53.4% (53.1%, 53.7%)
	Whites			
Total number	35,862	35,862	35,862	35,862
Events	31,072	10,023	28,067	14,162
Person-years (py)	1,245,482	523,022	1,090,448	1,571,629
Incidence rate (per 1,000 py)	25.0 (24.7, 25.2)	19.2 (18.8, 19.5)	25.7 (25.4, 26.0)	9.0 (8.9, 9.2)
Cumulative incidence	86.6% (86.3%, 87.0%)	28.0% (27.5%, 28.4%)	78.3% (77.8%, 78.7%)	39.5% (38.9%, 40.0%)
	Non-whites			
Total number	62,368	62,368	62,368	62,368
Events	56,553	21,521	51,539	38,264
Person-years (py)	1,938,481	892,869	1,756,748	2,528,154
Incidence rate (per 1,000 py)	29.2 (28.9, 29.4)	24.1 (23.8, 24.4)	29.3 (29.1, 29.6)	15.1 (15.0, 15.3)
Cumulative incidence	90.7% (90.4%, 90.9%)	34.5% (34.1%, 34.9%)	82.6% (82.3%, 89.3%)	61.4% (61.0%, 61.7%)

The incidence measures were calculated for first-time diagnosis of obesity or type 2 diabetes among at-risk individuals.

Furthermore, our results also suggested that the proportion of individuals engaging in moderate-to-vigorous physical activity and consuming at least five servings of fresh fruit and vegetables was generally low while the proportion of individuals consuming fast-food and drinking sugar-sweetened beverages was generally high within the simulated cohort. There were also some racial differences among these obesity-related health behaviors. Among the non-White subpopulation, there was a lower proportion of individuals who engaged in moderate-to-physical activity, and a higher proportion of individuals who drank more than one sugar-sweetened beverage a day compared to their White counterparts. In contrast, among the White subpopulation, there was a lower proportion of individuals who ate fresh fruit and vegetables and a higher proportion of individuals who ate fast-food more than once per week compared to their non-White counterparts.

This study provided a unique perspective of the development of obesity and type 2 diabetes among individuals who would have been followed from birth into adulthood in Los Angeles. This approach allowed us to simultaneously appreciate the aging effect on and forecast the future burden of obesity and type 2 diabetes within a birth cohort between 2009 and 2074 (i.e., 2009+65), something that has seldom been done in the literature. In addition, our modeling approach provides different and complementary insights on how disease rates will change in the future in a recent birth cohort. Specifically, our discrete-time modeling approach will allow researchers to see how current or future obesity or diabetes burden could reflect the joint and cumulative effects of prior and current environmental and individual exposures at critical life stages. In other words, as individual and environmental risk factors change over time, so will the trends in obesity and diabetes be expected to change.

Importantly, unless done for calibration purposes, one should be cautious when comparing our estimates to past and projected prevalence and incidence of obesity and diabetes. In fact, many trend estimates are based on cross-sectional data which typically reflect a given period effect and averaged across several age-groups and birth cohorts (37, 38). Nevertheless, these past and projected trends remain important for gauging the current and potential future state of obesity and diabetes in Los Angeles and the US. For instance, in 2011, the prevalence of obesity was 22.4% among children and 23.6% among adults (17) and the prevalence of diabetes was 9.9% (36) among adults in Los Angeles County. In the absence of projection studies in Los Angeles County, one can look to regional and national projection data to better appreciate the burden of disease attributable to obesity and type 2 diabetes. In fact, the UCLA Health forecasting tool, a simulation model that simulated individual life course among California's adult population, predicted that the obesity and type 2 diabetes prevalence will reach 30.8 and 9.93% respectively by 2020 in their baseline scenario (39). In addition, other projection studies based on nationally representative data found that the prevalence of impaired glucose tolerance could reach 15% by 2048 (40) and that the prevalence of obesity could reach 51.1% by the year 2030 (41). The latter study also predicted that 80, 90, and 100% of Americans will become obese by the year 2072, 2087, and 2102, respectively and that the non-White subpopulation may reach those levels sooner compared to Whites (41). Interestingly, when using the linear annual rate of increase reported in that study and the prevalence of obesity among adults in Los Angeles in 2011, we estimated that the projected prevalence of obesity in 2074 would be ∼67%. A study of the growth trajectory, which used a simulation model, also found that about 57.3% could become obese by the age of 35 (42). Lastly, the predicted life-time risk of diagnosed diabetes from age 20 was estimated to be about 40% for

men and women in a nationally representative sample (43). All of these projections reflect similar alarming trends as suggested by our model and their insights warrant immediate action to reverse or slow the epidemic in the US and in Los Angeles County in particular.

This study has several limitations. First, the calibration and validation of the ViLA-Obesity model were suboptimal in the absence of a base cohort in Los Angeles that followed individuals from birth to adulthood and studied our exposures and outcomes of interests. Nevertheless, we used age-group-specific means and proportions from publicly available data (i.e., CHIS) representing whenever available the population of Los Angeles County in 2009. This has some limitations since it does not allow one to disentangle the cohort/secular trend effects from the age effects. As such, we have assumed that the cohort/secular trend effect would be smaller relative to that of the age effect since we are simulating each individual as they age over time within the simulated cohort. Our results may reflect at the very least the age effect but could also reflect age and cohort effects. In addition, as cross-sectional data typically include people who are more likely to have chronic conditions such as diabetes, the use of such data for our calibration could result in the overestimation of the measures of occurrence within our simulation. Nevertheless, in the absence of longitudinal data, using age-group specific data in a specific year appears to be a better alternative than using repeated cross-sectional data to calibrate our model since the latter would not allow one to disentangle age and period effects. Second, while we have incorporated relevant obesity-related environmental exposures, we did not account for the possibility of residual social network effect in this iteration of the model. While there have been some suggestions that obesity can spread through social networks (i.e., induction or person-to-person spread) (8), other authors have demonstrated that such effects may be the result of confounding by contextual exposures (e.g., food environment, built-environment) (44). These authors concluded that after properly accounting for environmental exposures, the social network effects in obesity almost vanished (44). This finding, however, did not mean that peer support could not enhance the effectiveness of certain prevention efforts (45). We hope to explore the added insights gained from incorporating social network effects in the next iteration of the model. Third, the ViLA-Obesity model represented a simplified version of the Los Angeles County population in that the simulated cohort was closed (that is agents could not drop out, die, experience a competing risk, beget children, move in and out of the cohort). This will likely result in an overestimation of the incidence and prevalence measures. Future iteration of the model will incorporate competing risk in the data generating process. Fourth, using larger age categorization for calibration could result in suboptimal model calibration. We chose this approach since the regression parameters obtained from internal data analysis and to some extent from the literature was generally obtained for similar larger age categorization (most likely because of sample size consideration). Fifth, it is possible that the inclusion of large number of parameters and predictors in the model could add some additional uncertainty in the estimates produced by the model. We have included information on both individual factors as well as environmental factors because we intended to evaluate the impact of several interventions including single and combined interventions at the individual level and at environmental level at different critical life stages. Nevertheless, although the model has recently been used to evaluate impacts of obesity related-interventions (13), we believe such models should continue to undergo refinement through continuous validation and calibration as data and methods improve and new applications are found. In addition, the model was built to represent a 100th of the actual population of Los Angeles and agents were only allowed to engage in certain behaviors (e.g., smoking, alcohol consumption, and develop type 2 diabetes) after their 18th birthday.

Uses of the ViLA Modeling Suite

The current model will be kept up to date to reflect current trends and changes in trends in individual and environmental factors over time. In addition, we hope to incorporate additional outcomes including but not limited to cardiovascular diseases and cancer. The ViLA-Obesity suite has been used to evaluate single and combined (i.e., joint and cumulative) impact several known and hypothetical interventions that target individual and or environmental factors (13). For instance, the Los Angeles County Department of Public Health (LAC/DPH) in collaboration with the Center for Disease Control and Prevention (CDC) implemented from 2010 to 2012 several interventions to curb the obesity epidemic such as the "Community Putting Prevention to Work (CPPW)" with the RENEW project (Renew Environments for Nutrition, Exercise, and Wellness). The project "sought to implement policy, systems, and environmental changes to improve nutrition, increase physical activity, and reduce obesity, especially in disadvantaged communities" (46). As an initial modeling endeavor, we proposed to evaluate the long-term effects of individual-level dietary interventions (e.g., breastfeeding promotion, and reduction of sugar-sweetened beverages) and environmental physical activity-related interventions (e.g., increasing access to parks and recreations and designing pedestrian-friendly communities) on obesity and diabetes incidence in the ViLA cohort (13). Generally, to evaluate the effectiveness of an intervention, we would contrast the projected incidence and prevalence under say a hypothetical scenario where we would "alter" the exposure status to the desired level (intervention course) to the projected incidence and prevalence under the natural course (no interventions) (13).

CONCLUSION

We developed and validated a virtual cohort representing Los Angeles County wherein we explored the development of obesity and diabetes from birth to adulthood. Our findings suggest that the incidence and prevalence of obesity and type 2 diabetes within the ViLA-Obesity model were generally high and increasing with age during the individual life span. In this virtual Los Angeles, one in three children and adolescents and four in five adults will become obese before age 17 and age 65 respectively and one in two adults will develop

type 2 diabetes before age 65. We also noted the presence of racial disparities in obesity, type 2 diabetes, and obesity-related behaviors. This virtual cohort serves as a platform for conducting *in silico* experiments and testing hypothetical public health interventions to inform evidence-based clinical decision and policymaking. This study illustrates the usefulness of simulations like agent-based models in forecasting the burden of disease within a population over time to support the need for effective interventions.

DATA AVAILABILITY STATEMENT

The relevant data used in this study are included in the article/**Supplementary Material**, further inquiries about the full list of data citations can be directed to the corresponding author/s.

AUTHOR CONTRIBUTIONS

RN participated in the study conception, design, analysis, and wrote the first draft of the article. OA supervised and participated in the study conception, design, analysis, reviewed, and revised the manuscript. All authors provided critical input and insights into the development, writing of the article, and approved the final manuscript as submitted.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpubh.2022.818816/full#supplementary-material

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The Reliability and Validity of Recalled Body Shape and the Responsiveness of Obesity Classification Based on Recalled Body Shape Among the Chinese Rural Population

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Background: The reliability and validity of recalled body shape were unknown in China. This study was conducted to examine the reliability and validity of recalled body shape as well as the responsiveness of obesity classification by recalled body shape among the Chinese rural population.

Methods: A total of 166 people from the Henan rural cohort were enrolled. The Spearman's correlation coefficient (SCC), intraclass correlation coefficient (ICC), and Cronbach's α were calculated to assess the reliability and validity of recalled body shape. Additionally, the receiver operator characteristic curve (ROC) was performed to assess the responsiveness.

Results: The SCC between the twice recalled body shape ranged from 0.383 to 0.578, and the ICC ranged from 0.357 to 0.615. Besides, the Cronbach's α of the recalled body shape questionnaire was 0.845. At the age of 20–70, the SCC between recalled body shape and actual body mass index (BMI) and waist circumference (WC) ranged from 0.563 to 0.699 and 0.409 to 0.661, respectively. Furthermore, above the age of 20, the area under the curve (AUC) of classifying general obesity and abdominal obesity by recalled body shape ranged from 0.833 to 0.960 and 0.686 to 0.870, respectively.

Conclusion: The results indicated that recalled body shape had moderate reliability, validity, and discriminative degree for earlier obesity among the Chinese rural population.

Keywords: reliability, validity, responsiveness, recalled body shape, rural area

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INTRODUCTION

In recent decades, the disease burden has shifted from primarily infectious to non-communicable chronic diseases (NCDs) globally and in China (1, 2). NCDs have a long latency, which means the exposure to etiological factors may have occurred in the distant past before diseases are diagnosed (3, 4). Therefore, the past exposure to risk factors of NCDs and long-term trends of the exposure may be more significant than the current exposure to risk factors of NCDs. For instance, previous studies found that obesity in childhood and adolescence was associated with many NCDs in adulthood (5–8). However, in many epidemiological studies, the participants' recollection may be the only way to acquire the early exposure and was frequently used (9–11).

The validity of recalled weight at an earlier age has been demonstrated in populations with high education levels (12, 13), but it was affected by elapsed time, current body mass index (BMI), weight gain and loss, and weight variability (14). Nevertheless, among the rural population with low education levels and limited resources, recalling weight may not be accurate because they were less likely to measure their weight and pay less attention to their weight. Thus, recalling body shape may be an effective way to obtain information about previous obesity in the rural population.

The pictorial body diagrams were developed first by Stunkard et al. (15), which was validated by Must et al. (16) in Boston. The results indicated that recalled body shape could provide useful information independent of current weight status. Two other studies conducted in America found that young women can accurately recall their body shape at menarche and indicated that recalled body shape may offer advantages in certain situations (17, 18). Although the pictorial body diagrams have been developed for a long time, the reliability, and validity of recalled body shape were still unknown among a Chinese population. Previous studies in west countries found that body shape trajectories were associated with the incidence of depression, hypertension, type 2 diabetes mellitus (T2DM), cardio-metabolic disease, cancer, and mortality (19–24). As far as we know, relevant research has not been reported among a Chinese population. Currently, participants in a Henan rural cohort have provided body shape information recalled for earlier ages. However, the reliability and validity of recalled body shape as an indicator of earlier obesity were still unknown. Thus, the aims of this study were to examine the reliability and validity of recalled body shape as well as the discriminative degree of obesity classification *via* recalled body shape among the Chinese rural population.

MATERIALS AND METHODS

Study Population

The population of this study was selected from the Henan rural cohort, a large population-based prospective cohort study aiming to explore the prevalence and incidence of chronic diseases and their risk factors. In brief, the cohort study recruited 39,259 participants aged from 18 to 79 living in Yuzhou, Suiping, Tongxu, Xinxiang, and Yima counties of Henan province in China *via* multi-stage stratified cluster sampling. From 2015 to 2017, the baseline survey of this cohort has been completed with a response rate of 93.7%. The detailed information of the cohort has been described in a previous publication (25).

The recruitment for the reliability and validity of recalled body shape examined in the current study was conducted from September to November 2020. A total of 166 people were willing to participate in this study, whose previous height, weight, and waist circumference were recorded at local medical facilities. To test the reliability of the recalled body shape, participants took the second recalled body shape questionnaire survey about 4 weeks after completing the first. In the second recalled body shape questionnaire survey, a total of 155 participants were surveyed again with a response rate of 93.37%, while 11 participants lost to follow-up or refused to be investigated. Most specialists believe that the time interval of a repeat survey of 4 weeks was rational, which can avoid the influence of the first survey (26, 27).

The Henan Rural Cohort Study was approved by the Zhengzhou University Life Science Ethics Committee and conducted in accordance with the principles of the Declaration of Helsinki [Code: [2015] MEC (S128)]. Participants were required to provide informed consent, and both the researchers and respondents agreed to use the data for scientific research purposes only.

Data Collection

According to a face-to-face interview, a structured questionnaire was asked by well-trained research staff. We collected participants' demographic characteristics, lifestyle factors and recalled body shapes at different ages. Demographic characteristics included age in years, gender, marital status (married/cohabiting and widowed/separated/divorced/single), education level (elementary school or below, junior high school, and senior high school or above), and average monthly income ($<$500 RMB, 500- RMB, and $\geq$1,000 RMB). Lifestyle factors including smoking and drinking (never, former, and current) were also collected. The definitions of current smoking and drinking can be seen in a previous publication (28).

The pictorial body diagrams were developed first by Stunkard et al. (15), which is shown in **Supplementary Figure 1**. Participants were asked to report which one of the 9 pictorial body diagrams best reflected their body shape at the age of 5, 10, 20, 30, 40, 50, 60, 70, and current. Four weeks after the first recalled body shape survey, the second recalled body shape survey was conducted for the reliability test. The previous height, weight, and waist circumference (WC) of participants were obtained from physical examination data at local medical facilities. The current height and weight of participants were measured twice, and the average readings were computed to analyze. The body mass index (BMI, kg/m^2) was calculated through weight (kg) divided by square of height (m).

Gold Standard Definition of Obesity

At the age of 5, the gold standard of definition of obesity was height-for-weight according to the reference standards for the growth and development of children under 7 years old in China developed in 2009 (29). At the age of 10, the gold standard of definition of general obesity was according to BMI threshold for obesity in children aged 7–18 years established

by the Working Group of Obesity in China (WGOC) in 2004 (30), while abdominal obesity was defined by the WC threshold established by WGOC in 2010 (31). For the age at 20 or above, in accordance with the Chinese standard of BMI and WC (32), BMI $\geq$ 28 kg/m^2 was defined as general obesity, and WC $\geq$ 90 cm for men and WC $\geq$ 80 cm for women were classified as abdominal obesity. In addition, we also performed a sensitivity analysis using the World Health Organization's (WHO) definition of obesity. At the ages of 5 and 10, the gold standard of the definition of obesity is that BMI-for-age is >2 standard deviations above the WHO Growth Reference median (33). For the age of 20 or above, in accordance with the WHO standard of BMI and WC (33, 34), BMI $\geq$ 30 kg/m^2 was defined as general obesity, and WC $\geq$ 102 cm for men and WC $\geq$ 88 cm for women were classified as abdominal obesity.

Statistical Analysis

Statistical descriptions of continuous and categorical variables were presented as mean with standard deviation (SD) and frequency with percentages, respectively. *T*-test was performed to compare differences between different groups for continuous variables, while the Chi-squared test was utilized for categorical variables.

In order to evaluate the consistency between the twice recalled body shape, the scatter plot of first vs. second recalled body shape at different ages was drawn. It was considered as a good consistency that the difference between the twice recalled body shape was no more than 1. To assess the test-retest reliability of recalled body shape, the Spearman's correlation coefficient (SCC), the Pearson correlation coefficient (PCC[a]), and the intraclass correlation coefficient (ICC) between the twice recalled body shape were calculated. Besides, Cronbach's α was calculated to evaluate the internal consistency. The SCC between the first recalled body shape and the actual BMI/WC/weight was calculated to assess the validity of recalled body shape. Considering the current BMI and age influence on recalled body shape, the partial correlation coefficient (PPC[b]) adjusted current BMI and age was also calculated.

Besides, the receiver operator characteristic curve (ROC) was performed to assess the responsiveness of obesity classification based on recalled body shape at different ages and to find the best cutoff value. The gold standard definition of obesity was described above. The sensitivity and specificity were calculated to measure the accuracy of defining obesity *via* recalled body shape, while the area under the curve (AUC) was utilized to assess the discriminative degree of obesity defined by recalled body shape.

The figures were produced using the R language software 4.0.2. Statistical analyses were performed by SPSS 21.0 software package (SPSS Institute, Chicago), and all *P*-values were two-tailed with a statistical significance level of 0.05.

RESULTS

Characteristics of Participants

The characteristics of all 166 participants in this study according to gender are shown in **Table 1**. Compared with women, men were more likely to have higher education levels and lower average monthly income, and be current smokers and drinkers (all $P < 0.05$). There were no significant differences between men and women in terms of age and marital status (all $P > 0.05$). The age distribution of the study participants according to gender is presented in **Supplementary Figure 2**. In total, participants aged from 20 to 86. Among both men and women, most participants aged from 50 to 70. The comparison of the characteristics of participants between the current study and the cohort is presented in **Supplementary Table 1**. Compared with the participants in the cohort, participants in the current study were more likely to be old, men, current smokers, and have a higher level of average monthly income, and were less likely to be current drinkers (all $P < 0.05$). Additionally, there were no significant differences between participants in the current study and the cohort in terms of marital status and education level (all $P > 0.05$).

TABLE 1 | The characteristics of participants in this study.

Characteristics	Men ($n = 89$)	Women ($n = 77$)	*P*
Age (year), (mean and SD)	60.45 (12.41)	56.89 (14.27)	0.087
Marital status *n* (%)			
Married/cohabiting	78 (87.64)	71 (92.21)	0.333
Widowed/separated/divorced	11 (12.36)	6 (7.79)	
Educational level *n* (%)			
Elementary school or below	22 (24.72)	39 (50.65)	0.002
Junior high school	47 (52.81)	30 (38.96)	
Senior high school or above	20 (22.47)	8 (10.39)	
Average monthly income *n* (%)			
<500 RMB	25 (28.09)	10 (12.99)	0.032
500- RMB	19 (21.35)	26 (33.77)	
≥1,000 RMB	45 (50.56)	41 (53.25)	
Smoking status *n* (%)			
Current smoking	53 (59.55)	0 (0.00)	<0.001
Former smoking	12 (13.48)	0 (0.00)	
Never smoking	24 (26.97)	77 (100.00)	
Drinking status *n* (%)			
Current drinking	38 (42.70)	2 (2.60)	<0.001
Former drinking	17 (19.10)	0 (0.00)	
Never drinking	34 (38.20)	75 (97.40)	

SD, standard deviation; RMB, Renminbi.
T-test was performed to compare the differences in continuous variables; Chi-square test was used to compare the differences in the categorical variable.

Reliability of Recalled Body Shape

Figure 1 shows the scatter plot of first vs. second recalled body shape at different ages. The results showed that most participants recalled similar body shape twice, with a difference of less than one body shape. Before the age of 40, most participants selected the small body diagrams, while more people selected the larger body diagrams after 40. The correlation coefficients between the twice administration of recalled body shape are shown in **Table 2**. The mean of SCC was 0.473 between the twice recalled body shape, ranging from 0.383 (age 20) to 0.578 (age 60). After adjusting the current BMI and age, the PCC[b] between the twice recalled body shape ranged from 0.405 (age 20) to

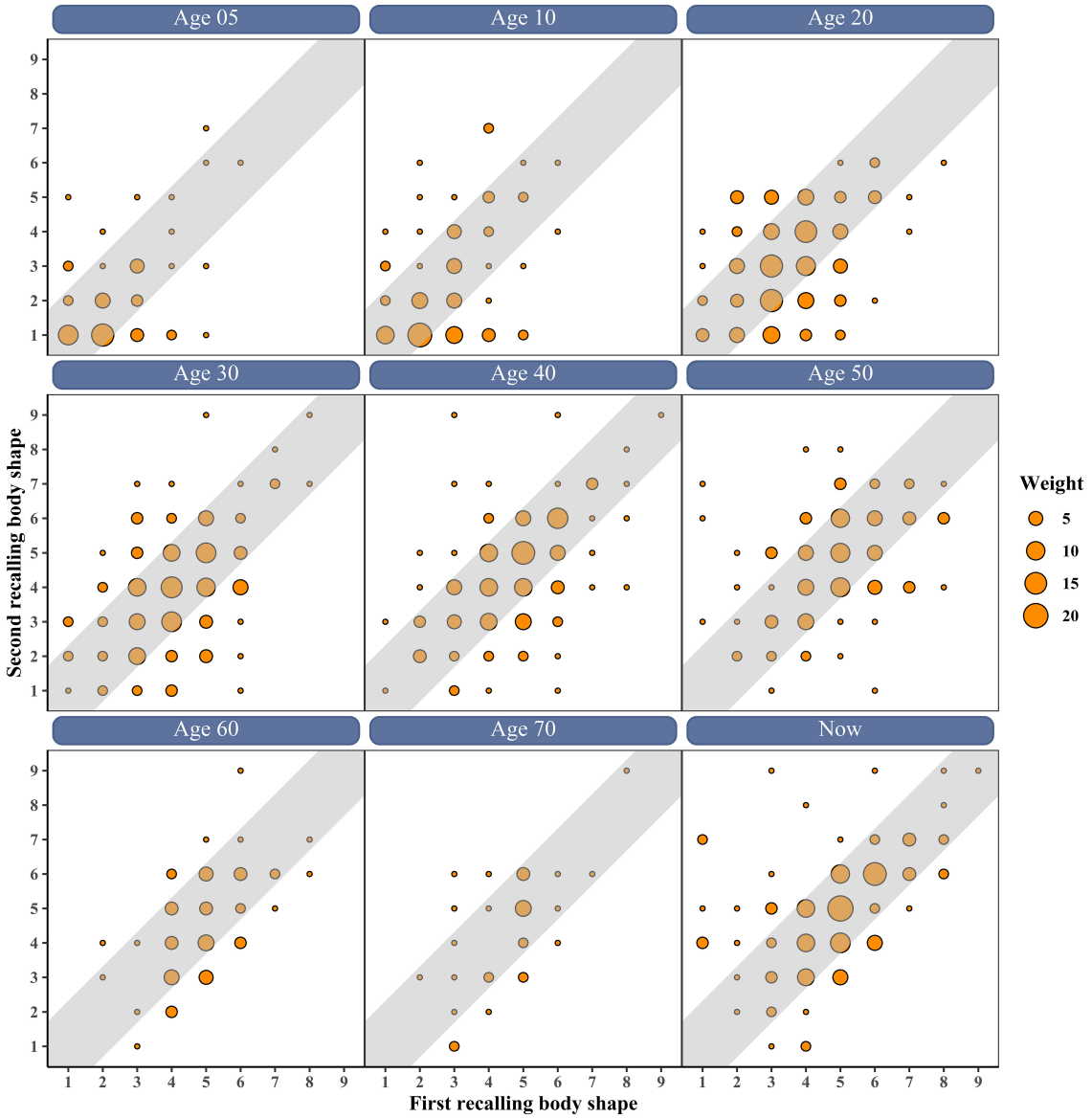

FIGURE 1 | The scatter plot of first vs. second recalled body shape at different ages.

0.522 (age 5) except for age 50 (0.278; all $P < 0.05$). The mean of PCC [a] between the twice recalled body shape was 0.502, ranging from 0.375 (age 50) to 0.640 (age 70). In addition, the mean of ICC between the twice recalled body shape was 0.493, ranging from 0.357 (age 50) to 0.615 (age 70; all $P < 0.05$), Additionally, the Cronbach's α of the recalled body shape questionnaire was 0.845. The correlation coefficients between the twice recalled body shape according to gender are presented in **Supplementary Table 2**. The SCC between the twice recalled body shape ranged from 0.376 (age 5) to 0.668 (age 60) in men and ranged from 0.338 (age 30) to 0.588 (age 70) in women.

Validity of Recalled Body Shape

Table 3 summarizes the correlation coefficients between the first recalled body shape and actual BMI and WC. At the age of 5, the SCC and PCC[b] between recalled body shape and actual weight were 0.271 and 0.310, respectively. At the age of 10, the correlation between recalled body shape and actual BMI was weak but increased after adjusting for current BMI and age. However, there was a non-statistically significant correlation between recalled body shape and actual WC at the age of 5. At the age of 20–70, the SCC between recalled body shape and actual BMI/WC ranged from 0.563 (age 50) to 0.699 (age 40) and 0.409 (age 20) to 0.661 (age 70), respectively (all $P < 0.001$). The SCC between body shape and BMI/WC at current were 0.669 and 0.622, respectively. Adjusting for current BMI and age had little influence on the correlation coefficients at age 20–40, but the correlation coefficients decreased significantly after age 40. The correlation coefficients between the first recalled body shape and BMI/WC according to gender are summarized

in **Supplementary Table 3**. The SCC between the recalled body shape and weight/BMI ranged from 0.242 (age 5) to 0.734 (age 40) in men and ranged from 0.209 (age 10) to 0.850 (age 70) in women. In addition, the SCC between the recalled body shape and WC ranged from 0.300 (age 10) to 0.680 (age 60) in men and ranged from 0.360 (age 10) to 0.765 (age 70) in women.

Responsiveness of Defining Obesity by Recalled Body Shape

Figure 2 presents the receiver operator characteristic curve of determining obesity by recalled body shape at different ages. The responsiveness of defining obesity by recalled body shape was low at the age of 5. In addition, the responsiveness of defining abdominal obesity by recalled body shape was higher than general obesity at the age of 10, while the responsiveness of defining general obesity by recalled body shape was higher than abdominal obesity after the age of 20. **Table 4** shows the best cut-off value to define obesity based on recalled body shape, and the sensitivity and specificity of the definition. After the age of 20, the AUC of defining general obesity by recalled body shape ranged from 0.833 (age 70) to 0.960 (age 20), and the AUC of defining abdominal obesity by recalled body shape ranged from 0.686 (age 20) to 0.870 (age 70; all $P < 0.05$). The results indicated that the responsiveness of defining general and abdominal obesity by recalled body shape was effective after the age of 20. More details can be seen in **Table 4**. The best cut-off value to define obesity based on recalled body shape, and the sensitivity and specificity of the World Health Organization's definition is presented in **Supplementary Table 4**. Compared with the Chinese definition of obesity, the best cut-off values of the WHO standard were generally larger.

TABLE 2 | The correlation coefficients of twice recalled body shape.

Age	N[#]	SCC	PCC[a]	PCC[b]	ICC
5	64	0.412*	0.542**	0.522**	0.533**
10	91	0.424**	0.470**	0.428**	0.450**
20	155	0.383**	0.424**	0.405**	0.424**
30	148	0.428**	0.481**	0.438**	0.474**
40	142	0.524**	0.532**	0.441**	0.529**
50	118	0.414**	0.375**	0.278*	0.375**
60	62	0.578**	0.569**	0.462**	0.554**
70	33	0.541*	0.640**	0.492*	0.615**
Now	148	0.557**	0.487**		0.487**

SCC, Spearmen correlation coefficient; PCC[a], Pearson correlation coefficient; PCC[b], partial correlation coefficient; ICC, intraclass correlation coefficient.
[#]Sample sizes vary due to miss value.
**P < 0.05, **P < 0.001.*

DISCUSSION

The results of this study showed that the recalled body shape questionnaire had good internal consistency indicated by Cronbach's α (0.845) above the conventional threshold of 0.700. Besides, the correlation coefficients between twice-recalled body shape, and between recalled body shape and actual BMI/WC were moderate, indicating that recalled body shape can contribute useful information about earlier obesity. Moreover, the high AUC manifested that the responsiveness of classifying general and abdominal obesity by recalled body shape was effective.

In this study, the consistency between the twice recalled body shape was examined, indicating the consistency was moderate. A moderate correlation between recalled body shape and actual BMI/WC were also found, which was similar to the previous study conducted in Harvard (16). Another study in America found that the correlation coefficient between actual BMI and recalled body shape at the age of menarche was 0.61 (17), similar to the current study. However, a previous study conducted in

TABLE 3 | The correlation coefficients between first recalled body shape and BMI and WC.

Age group	BMI (kg/m^2)/Weight (kg)		WC (cm)		SCC[†]	SCC[rm‡]	PCC[b†]	PCC[brm‡]
	n[#]	mean (SD)	n[#]	mean (SD)				
Age 05[a]	88	22.45 (7.46)			0.271*		0.310*	
Age 10	118	21.51 (5.56)	45	62.04 (7.89)	0.249*	0.140	0.314*	0.293
Age 20	166	21.07 (3.20)	161	76.06 (9.63)	0.648**	0.409**	0.610**	0.434**
Age 30	158	22.59 (2.74)	157	80.18 (10.34)	0.652**	0.497**	0.627**	0.465**
Age 40	148	23.44 (3.00)	147	82.98 (10.97)	0.699**	0.576**	0.567**	0.501**
Age 50	120	23.83 (3.10)	115	84.93 (9.98)	0.563**	0.499**	0.351**	0.337**
Age 60	67	23.65 (3.32)	68	84.79 (12.30)	0.641**	0.639**	0.392*	0.355*
Age 70	36	22.93 (3.28)	36	84.34 (10.80)	0.593**	0.661**	0.176	0.400*
Now	166	23.79 (3.27)	166	76.06 (9.63)	0.669**	0.622**		

BMI, body mass index; WC, waist circumference; SD, standard deviation; SCC, spearmen correlation coefficient; PCC[b], partial correlation coefficient.
[a]At age 05, weight (kg) was used to calculate the correlation coefficient.
[#]Sample sizes vary due to miss value.
[†] Body shape and BMI.
[‡]Body shape and WC.
**P < 0.05, **P < 0.001.*

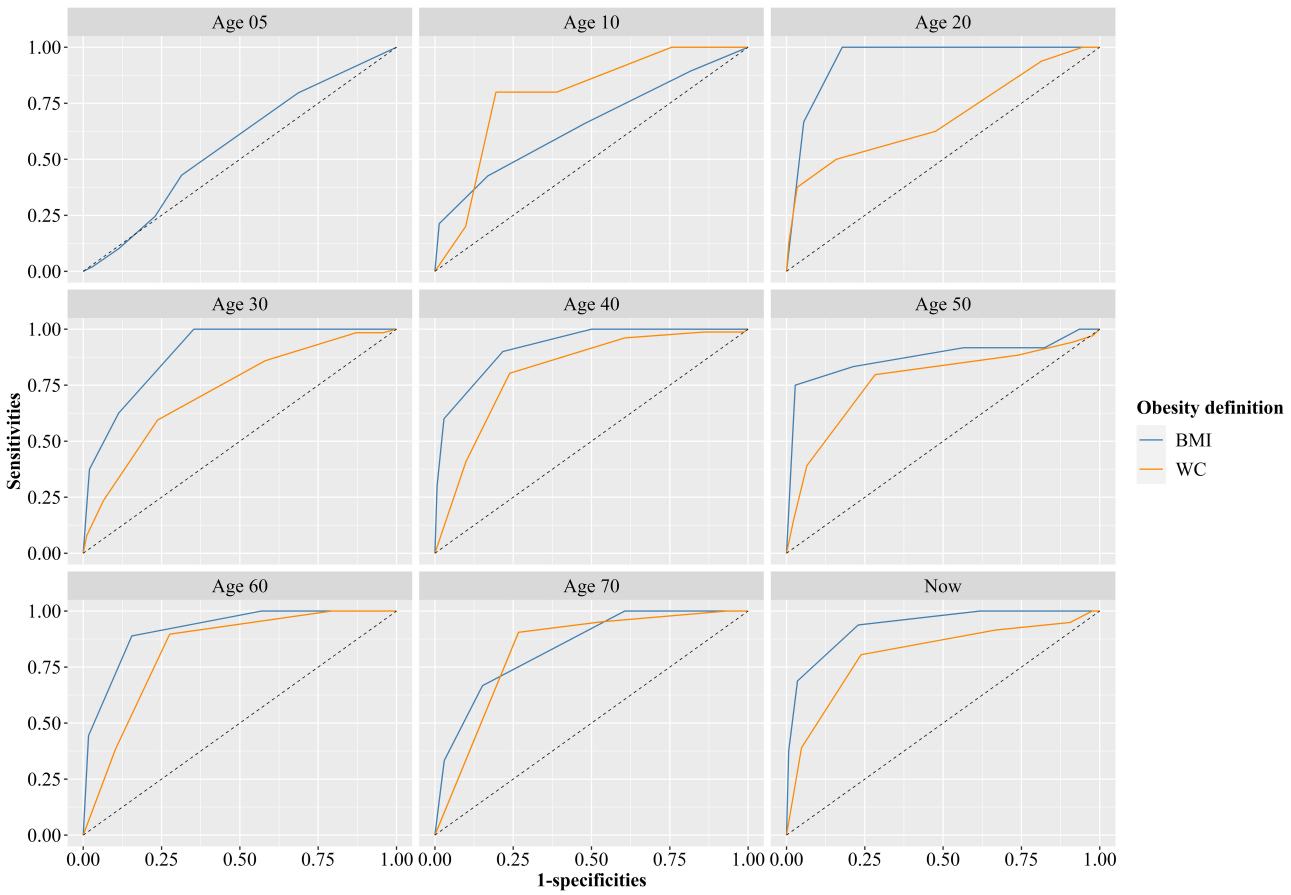

FIGURE 2 | Receiver operator characteristic curve of determining obesity by recall of body shape at different ages (Gold standard definition of obesity at age 5 was weight-for-height based on Chinese standard in 2009, gold standard definition of obesity at age 10 was BMI and WC classification criteria for screening Chinese school-age children developed by the China Working Group on Obesity).

America found that the correlation coefficient between actual BMI and recalled body shape at the age of menarche was 0.77 (18), which was higher than the current study. This may be explained by the age of the participants in this study ranging from 14 to 19.5. The study participants were younger than the participants in the current study and had a short distance from the time point of recall. Additionally, menarche was a particular time, and participants may find it easier to recall the information at that time.

The current study found that the correlation coefficients between recalled body shape and actual BMI/WC/weight were low at the age of 5 and 10, as well as the low AUC of classifying obesity. This may be explained by the time gaps being too long for participants to accurately recall body shape at that time. Another possible reason was that the body images depict adult body shapes, which makes it difficult for participants to recall their childhood body shape based on these images accurately. The current study also found that adjusting for current BMI and age had little effect on the correlation coefficients at the age of 20–40, but the correlation coefficients decreased significantly after the age of 40. The result indicated that the current BMI and age would affect participants' recollections of their body shape in the recent past, but not their recollections of body shape in the distant past, which was consistent with the previous study (16). After the age of 20, the AUC of classifying general obesity ranged from 0.833 to 0.960, and the AUC of defining abdominal obesity ranged from 0.686 to 0.870 (all $P < 0.05$). This result showed that recalled body shape was a good indicator of earlier obesity. Moreover, the current study found that the responsiveness of defining general obesity by recalled body shape was higher than abdominal obesity after the age of 20. This may be due to the images reflecting the whole body so that participants were more accurate in recalling the condition of general obesity.

To the best of our knowledge, this was the first study to examine the reliability and validity of recalled body shape and the responsiveness of obesity classification based on recalled body shape in the Chinese rural population. The results showed that the reliability and validity of recalled body shape were moderate and indicated that recalled body shape could provide useful information about obesity at an earlier age. However, there were also several limitations in this study. Firstly, selection bias may influence the results of this study because reasons for refusing or losing follow-up may be related to the accuracy of recalled body shape. Participants probably refused to be surveyed because they could not accurately recall their previous body shape. Secondly, the previous height, weight, and waist circumference

TABLE 4 | The best cut-off value to define obesity based on recalled body shape, and the sensitivity and specificity of the definition.

	Cutoff value	Sensitivity (%)	Specificity (%)	AUC (95% CI)	*P*
BMI					
Age group					
Age 05[a]	Body shape ≥ 3	42.90	68.60	0.564 (0.437, 0.691)	0.320
Age 10[b]	Body shape ≥ 4	42.55	83.10	0.654 (0.550, 0.758)	0.005
Age 20	Body shape ≥ 5	100.00	82.21	0.960 (0.891, 1.000)	0.006
Age 30	Body shape ≥ 5	100.00	64.67	0.895 (0.811, 0.978)	<0.001
Age 40	Body shape ≥ 6	90.00	78.30	0.921 (0.846, 0.995)	<0.001
Age 50	Body shape ≥ 6	83.33	78.70	0.869 (0.709, 1.000)	<0.001
Age 60	Body shape ≥ 6	88.90	84.50	0.920 (0.833, 1.000)	<0.001
Age 70	Body shape ≥ 6	66.70	84.80	0.833 (0.620, 1.000)	0.003
Now	Body shape ≥ 6	93.80	77.10	0.933 (0.874, 0.992)	<0.001
WC					
Age group					
Age 05[a]					
Age 10[b]	Body shape ≥ 4	80.00	80.00	0.780 (0.586, 0.974)	0.043
Age 20	Body shape ≥ 5	50.00	84.10	0.686 (0.529, 0.844)	0.015
Age 30	Body shape ≥ 5	59.38	76.30	0.725 (0.645, 0.805)	<0.001
Age 40	Body shape ≥ 5	80.30	76.10	0.820 (0.751, 0.889)	<0.001
Age 50	Body shape ≥ 5	79.71	71.70	0.769 (0.681, 0.858)	<0.001
Age 60	Body shape ≥ 5	89.74	72.41	0.835 (0.733, 0.936)	<0.001
Age 70	Body shape ≥ 5	90.48	73.33	0.870 (0.751, 0.989)	<0.001
Now	Body shape ≥ 5	80.50	76.20	0.808 (0.736, 0.881)	<0.001

BMI, body mass index; WC, waist circumference; AUC, area under the curve; CI, confidence interval.

[a]*Gold standard definition of obesity at age 5 was weight-for-height based on Chinese standard in 2009.*

[b]*Gold standard definition of obesity at age 10 was BMI and WC classification criteria for screening Chinese school-age children developed by the China Working Group on Obesity.*

of participants were obtained from physical examination data at local medical facilities, and the actual values of BMI for age 0 and 10 were obtained from relatively young participants, which may lead to bias. Thirdly, the sample size of this study is limited and it is necessary to carry out a study with a larger sample size. Fourthly, the results were based on only one province of China, which might not be a representative sample of the Chinese rural population. However, the rural population of the Henan province accounts for 8.9% of the rural Chinese population, and the results based on this relatively large rural cohort study, to some extent, could represent the Chinese rural population. Moreover, although the correlation coefficients between the twice recalled body shape as well as between recalled body shape and BMI/WC remained significant after adjusting current BMI and age, we did not consider other factors affecting recalled body shape, such as weight gain and loss.

In conclusion, although the validity of recalled weight has been demonstrated in populations with high education levels (12, 14), recalled body shape was an effective way to obtain information about earlier obesity in rural populations with low education levels and limited resources. In the current study, the moderate all over correlation coefficients and high AUC of obesity classification based on recalled body shape suggested that recalled body shape can provide useful information about earlier obesity and have a good discriminative degree for obesity among a Chinese rural population. This evidence may inform life-course epidemiological studies that consider the recalled body shape to indicate earlier obesity.

DATA AVAILABILITY STATEMENT

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

ETHICS STATEMENT

Written informed consent was obtained from the individual(s) for the publication of any potentially identifiable images or data included in this article.

AUTHOR CONTRIBUTIONS

WL: investigation, formal analysis, validation, visualization, writing—original draft, and writing—review and editing. XL: investigation, formal analysis, and writing—review and editing. NK: investigation, validation, visualization, and writing—review and editing. MN: investigation, validation, and writing—review and editing. YS, LW, and DW: investigation and writing—review and editing. PL, JH, and CW: formal analysis and writing—review and editing. CS and ZM: data curation and writing—review and editing. YL: conceptualization, data curation, methodology, and writing—review and editing. All authors critically revised the manuscript and approved the final version for publication.

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Adolescent Obesity Prevention in Saudi Arabia: Co-identifying Actionable Priorities for Interventions

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Background: Childhood obesity is a serious issue in the Kingdom of Saudi Arabia, but there is no known community intervention. The aim of the study was to use a participatory approach to obtain the perspectives of students, school staff and Ministry of Education (MoE) representatives and parents on important and feasible intervention opportunities for school-based obesity prevention for adolescent girls.

Method: The study was conducted in two intermediate schools for girls (13–15 years old) in Jeddah that were purposefully identified with the support of the MoE. Group concept mapping, a mixed method approach, was conducted with 19 adults which included staff from the MoE and schools, school canteen suppliers and mothers. Adults generated statements in response to two prompts (P); P1 *"The factors influencing adolescent obesity in Saudi are..."* and P2 "*The content of school-based programmes should focus on...."* Photovoice-enhanced concept mapping was used with students (*n* = 15 students) to capture adolescent perspectives on what influences their dietary and physical activity habits. Students generated statements' using their own photographs. Stakeholders, both adult and students, sorted the statements into themes and rated each statement for relative importance and feasibility. Multidimensional scaling and hierarchical cluster analyses were used to produce concept maps with the input from students and adults.

Result: Adults generated 35 statements in response to P1 and identified five themes that influenced adolescent obesity including "Home Environment," "Lifestyle," "School Environment," "Community," "Biology." They generated 42 statements in relation to P2 and identified four themes including "Ministry of Education Support," "School Environment," "Public health programmes" and "Wider environmental influences." Students generated 42 statements from 39 pictures. They identified five themes that influenced their dietary and physical activity habits—"Role of Government," "School Environment," "Home Environment," "Retail Environment" and "Cultural Practices." Both groups identified several common important and feasible actions with a strong emphasis on improving the school environment, in particular food provision, with MoE support. Exemplar corresponding statements from adults were "*Offer healthy foods in the canteen," "Remove chocolates*

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and sweets" and *"Educate children about healthy foods"* and from students were "*Offer fruit and vegetables in the canteen," "Remove chocolates from the canteen," "Healthy meals should not expensive."* Lack of correspondence related to students' emphasis on access to both healthy foods and physical activity in schools and the wider environment (e.g. retail environments), while adults emphasized school-based education and food provision. After further consultations, both stakeholder groups agreed on improving access to healthy foods in the canteen.

Conclusions: Students and school and MoE staff jointly agreed that a canteen-based intervention was important and feasible to improve dietary habits and thus help to prevent obesity among adolescent girls. This was the first time a participatory approach was used with students for intervention development in Saudi Arabia. A co-development approach may have value to improve their school food environments.

Keywords: adolescents, obesity, intervention, concept mapping, prevention

INTRODUCTION

Childhood obesity is a major public health concern in the Kingdom of Saudi Arabia. The most recent data available in 2014 showed that ∼1 in 3 boys and 1 in 4 girls aged 12–18 years old were either overweight or obese (1). The Saudi-based literature is scant but high intake of sugar-sweetened beverages, eating away from home, skipping breakfast and low hours of physical activity appear to be key drivers (2). Similar to patterns observed in low- and middle-income countries (3), there have been reports of a positive association between socioeconomic circumstances and overweight and obesity in Saudi (4, 5). In Saudi, all healthcare costs are government funded and recently The Saudi Vision 2030 recognizes the financial burden obesity is placing on government resources. As a result, regulatory interventions are emerging. As part of the 2030 Vision, an excise tax of 50% on carbonated beverages was implemented in 2017 and in 2018 energy information was required on menus in restaurants, including dine-in restaurants and fast-food restaurants (6). There are, however, no known community-level interventions, particularly those targeting young people. School-based interventions have the potential for effective obesity prevention and promotion (7). Most children spend half of their waking hours in school and consume a significant proportion of their daily calories at school.

Rapid economic development in Saudi has been driven by the oil boom of the 1970s (8). Saudi is one of the top twenty economies in the world and the largest in the Arab world and the Middle East (9). Household income increased by 75% between 2004 and 2013 and was largely driven by higher public sector employment and salaries (8). From a nutrition transition perspective (10), Saudi Arabia is considered to be in an advanced stage of transition where non-communicable diseases account for 78% of all deaths (11). Similar to low- and middle-income countries, there has been a shift away from diets composed of whole foods (e.g., pulses and whole grains) and low in refined oils and sugars to an energy-dense and nutrient-poor diet composed of fat and sugar-rich diets, and processed foods (12).

Jeddah, located in the western region of Saudi Arabia, on the coast of the Red sea is the second largest city in the Kingdom, with a population of 4,697,000 people after the capital Riyadh (13), and is an important commercial center. Saudi Arabia is an Islamic state and Jeddah is known as the gateway to the holy cities (Makkah and Medinah). As a result, Jeddah has historically attracted people from different parts of the Islamic world to settle there. Forty percent of the population of Jeddah are not native-born Arabic people, with migrants mainly from Southern Asia, particularly India, Pakistan and Bangladesh. In 2012, the prevalence of obesity in Jeddah was 35% in adults of both sexes, which was higher for Saudi Arabia overall in the 2013 national survey (14). In 2011, the prevalence of overweight and obesity combined among children and adolescents (ages 6–19 years) in Jeddah was 7.1% and 14.4% respectively. As mentioned, Saudi Arabia has made some effort with regards to obesity prevention such as the excise tax on carbonated beverages (15), energy declaration on the menus (6). However, there is a general lack of community health-promoting programmes, and more specifically co-designed programmes.

The value of co-production and participatory approaches is gaining rapid recognition in public health. This involves researchers, practitioners and the public working together from the outset to jointly develop knowledge that is actionable and that can catalyze transformation of systems (16, 17). Norström et al. defined co-production as *"Iterative and collaborative processes involving diverse types of expertise, knowledge and actors to produce context-specific knowledge and pathways towards a sustainable future*" (18). The issue of the participation of young people has also gained much recognition in policy, research, education and community development initiatives, and recently in driving forward the climate change agenda globally (19, 20). Young people can better identify the problem to be tackled because they understand the needs, experiences and capabilities of young people in ways that adults cannot. Integrating the perspectives of students with those responsible for the planning and provision of care, such as policy actors in education, parents and teachers,

is thus key in the planning of school-based intervention programmes (21).

In this study we used concept mapping, which is steeped in theory-driven evaluation and participatory action research and is increasingly being used to identify and implement effective practices in public health (22, 23). It combines a structured qualitative and quantitative approach with stakeholders throughout the research process (24). It can be flexibly adapted to enhance participation of young people and generate a meaningful conceptualization of the issues being investigated (25). This paper reports on the perspectives of students, school staff, staff at the Ministry of Education, and a mother on the factors that influence adolescent obesity and on feasible priorities for the content of a school-based programme.

METHODS

Setting and Sampling

This study was conducted in the city of Jeddah (KSA). Two intermediate schools for girls (13–15 years old) were purposefully identified with the support of the Ministry of Education. Intermediate schools capture Grades 1 (age 13 years) to 3 (age 15 years). In Saudi Arabia, schools are rated based on specific exams called "Qiyas." These exams aim to detect students' potential abilities and academic skills in the fields of language, mathematics, science and creativity. Of the two schools included in the study one school was rated as below average and the other was rated as average/above average in terms of academic performance, based on Qiyas. Twenty-six students were randomly selected from each year of each school (13 from school 1- and 13 from school 2; 4 from Grade 1, 4 from Grade 2 and 5 from Grade 3 of each school) and invited to participate. Fifteen students agreed to participate (7 from school 1 and 8 from school 2); 90% with at least one parent employed, 44% with mothers who had a University degree. Eleven students did not take part and cited preparation for their examinations as the reason for non-participation. The socio-economic backgrounds of those who did not take part did not differ significantly from those who took part.

Twenty-five adults were purposely selected and invited to take part, 19 of whom agreed and included 10 teachers (five home economics and five science teachers), six administrative staff, two canteen staff, one mother of the students at the participating schools, and six Ministry of Education staff who were responsible for nutrition and health in the participating schools. Six participants (three teachers and three administrative staff) did not participate due to teaching commitments. Only one mother was able to join.

Concept Mapping

Concept mapping enables shared understanding and provides "*balance of power*" as the method is predominantly participant-led rather than researcher-driven (26, 27). The method is described in detail elsewhere (24, 28). Concept mapping has six key steps: (1) Preparation, where stakeholders are identified, and the prompts are developed, (2) Generation, where stakeholders brainstorm a set of statements related to the prompt, (3) Structuring, where each participant sorts the statements into clusters based on perceived similarity of the statements, and also where each participant rates each statements for importance and for feasibility of action, (4) Representation, where the data are analyzed using multidimension scaling , (5) Interpretation, where derived maps are discussed with the group and (6) Utilization (not used in current study), where the concept maps can be used to plan interventions.

In the current study the following process was used for concept mapping. First, concept prompts were developed during initial informal consultations with teachers and students. Adults were then presented with these prompts and then generated statements in response to these; Prompt 1 "The factors influencing adolescent obesity in Saudi are..." and Prompt 2 "The content of school-based programmes should focus on...." Photovoice-enhanced concept mapping (29) was used in the student workshops to capture students' perspectives on what influences their dietary and physical activity habits. In brief, ten students were randomly chosen to take pictures using the "lucky dip" method. Folded slips of paper with the word "camera" were placed in a box and students were asked to pick a slip. Students with a "camera" slip were asked to take pictures of anything in their environments, home, school or elsewhere, that they felt influenced their dietary and physical activity habits. The pictures were then used as prompts to generate statements in a group session with all 15 students. Duplicated statements were removed, and some statements were amended to improve clarity on consultation with the students.

Each participant, both adults and children, then sorted the statements into clusters based on perceived conceptual similarity and provided a word/short phrase to describe the cluster. Following the sorting of the statements, each participant was given rating grids that contained all the generated statements. Participants were asked to rate each statement on a 5-point scale for importance and a 5-point scale for feasibility of achieving a positive change. The 5-point rating scales were: 1 = Relatively unimportant, 2 = Somewhat important, 3 = Moderately important, 4 = Very important, 5 = Extremely important, and for feasibility of achieving a positive change: 1 = Not at all feasible, 2 = Somewhat feasible, 3 = Moderately feasible, 4 = Very feasible, 5 = Extremely feasible.

Data analysis used the Group WisdomTM software (Concept Systems, Inc., Ithaca, NY) (30). A similarity matrix was created to identify how often statements were sorted together in the same cluster. Through multidimensional scaling, the similarity matrix was used to generate a two-dimensional "point map" of each statement to visually represent the sorted data, with statements sorted together more often placed closer on the map. A stress value statistic was generated, which indicated how well the 2-dimensional point map represented the sorted data. Hierarchical cluster analysis was then used to aggregate the point coordinates into clusters which contained similar statements. A bridging value was generated for each statement, indicating whether it was sorted with other statements nearby (referred to as anchoring), or sorted with others across a larger area of the map (referred to as bridging). Lower bridging values (range 0–1) indicated how closely individual statements were related and extent of

TABLE 1 | Students' perspectives on factors influencing their dietary habits and physical activity: average bridging values and average ratings for importance and feasibility for each cluster, statements that were rated relatively high for both importance and feasibility (upper right quadrant of the Go-Zone map) and exemplar photographs taken by students to generate statements.

Cluster name	Bridging value	Average importance score*	Average feasibility score*	Example of statements rated as most important and feasible, with exemplar pictures that were taken by students**
Influences on dietary habits				
Role of Government	0.07	4.19	4.17	4-Healthy food is limited in the mall 5-Healthy meal are high 18-Reduce the cost of healthy food 23-More salad in fast-food restaurants 
School Environment	0.38	3.79	3.82	9-Chocolates are available in the canteen 13-The school environment needs to be supportive 20-The school environment influences behaviors 21-Offer fruit and vegetables in the canteen 22-Provide vending machine for fruit and vegetables 
Home Environment	0.53	3.99	4.02	15-The food at home should be healthy 16-Salads are healthy 17-Eat fruit every day 25-Changes in behavior are influenced by family 
Retail Environment	0.66	3.87	2.43	No statement rated as most important and feasible
Influences on physical activity				
Role of Government	0.09	4.07	3.98	1-Gym prices are high 2-Lack of female gyms 7-Unhealthy food is available at gyms 12-Lack of attractive activities in the community 16-Provide gyms and walking areas 20-Provide free indoor gyms 
Cultural practices	0.76	3.62	3.17	No statement rated as most important and feasible
School Environment	0.86	3.57	3.29	11-Lack of attractive activities at school, 15- Physical activity as a part of the school curriculum 

*Score out of 5.

**Derived from the upper right quadrant of the Go-Zone map.

agreement in sorting across participants. The number of clusters were initially chosen by the researchers and iterations were dependent on discussions with students. Four quadrants "Go-Zone" maps were also generated, which provided a visual display of an XY graph and was divided into quadrants above and below the mean ratings for importance and feasibility. The statements located in the upper right of the figure were considered to be rated above average for both importance and feasibility.

Permission and ethical approval were received from the Ministry of Education (MoE) in Jeddah (KSA). The project was also approved by King's College London Ethics Committee (*REC Reference Number 3727*) London, UK.

RESULTS

Perspectives of Students on the Factors That Influence Dietary and Physical Activity Habits

Students used 20 photographs to aid the generation of 42 statements, 25 in relation to dietary factors and 17 in relation to physical activity. **Table 1** shows clusters for dietary habits and physical activity, average bridging values and average ratings for importance and feasibility for each cluster, statements that were rated relatively high for both importance and feasibility (upper right quadrant of the Go-Zone map) and exemplar photographs taken by students to generate statements. **Supplementary Table 1** shows all statements by cluster, along with the bridging values and ratings for each statement.

Five clusters were identified in relation to dietary habits—"Role of Government," "School Environment," "Home Environment," and "Retail of Fast Foods." Average bridging values for clusters were lowest for "Role of Government" (0.07) and highest for "Retail Environment" (0.66). The "Role of Government" had the highest ratings for both importance (4.19) and feasibility of change (4.17) and "Retail of fast foods" had the lowest rating for feasibility (2.43). Overall these results reflected that the role of government was felt to be an important determinant of feasible action across students. The clusters "Home Environment" and "School Environment" had high average ratings for both importance and feasibility. The bridging values, however, were high for specific statements which indicated a lack agreement in clustering of these statements across students. For example, the cluster "School Environment" contained statements with high bridging values such as the influence of friends on eating fast foods (bridging value 0.92), peer pressure to eat breakfast at school (0.64), and vending machines for fruits and vegetables (0.84). **Figure 1** shows the Go-Zone map based on students' ratings for importance and feasibility for change for all statements. Approximately half of the statements were rated above average for both importance and feasibility (upper right quadrant). Four of the statements from the cluster "Role of Government" were included and about half of the statements from the "School Environment" and "Home Environment" were included.

The statements that were rated highest on both importance and feasibility in the cluster "Role of Government" indicated an awareness of issues related to availability (e.g. healthy foods limited in malls, salad in fast food restaurants) and accessibility (e.g. costs) of health foods. "School Environment" issues generally referred to availability of foods in the canteen and the "Home Environment" to the family playing an important role in promoting healthy eating habits. Noteworthy is that the statements from the cluster "Retail Environment" were rated below average for both importance and feasibility (lower left quadrant). These referred to the mall being a gathering place for eating fast food.

Three clusters were identified in relation to physical activity—"Role of Government," "Cultural Practices" and "School Environment." Average bridging values for the clusters were lowest for "Role of Government" (0.10) and highest for "School Environment" (0.86). The "Role of Government" had the highest ratings for both importance (4.07) and feasibility of change (3.98) and "Cultural Practices" had the lowest rating for feasibility (3.17). As with dietary factors, the role of government was perceived to be an important determinant of feasible action. All statements within this cluster had low bridging values which indicated strong correspondence across students in how they clustered the statements. In contrast, the statements in the other two clusters had high bridging values. The majority of the statements that were in the upper right quadrant (**Table 1**; **Supplementary Figure 1**) were from the cluster "Role of Government," and referred to structural issues such as the lack of female only gyms, cost of membership, lack of transport and the need for walking areas. "School Environment" issues that were rated high referred to the need for inclusion of physical activity in the curriculum. A notable feature of the Go-Zone map was that the intersection of the importance and feasibility axes was above ratings of 3 (out of 5) and many of the statements that were not in the go-zone were around the intersection. For example, issues related to transport to the gym, and use of technology, were present in the quadrant for low feasibility, low importance quadrant, whereas these were rated above 3 for both importance and feasibility. Cultural practices were rated lowest for both feasibility and importance and were not part of the Go-Zone.

Perspectives of Adults on the Factors That Influence Adolescent Obesity and on Feasible Priorities for the Content of a School-Based Programme

Adults generated 77 statements, 35 in relation to factors influencing adolescent obesity and 42 in relation to the content of school-based programmes. **Table 2** shows clusters, average bridging values and ratings for importance and feasibility for each cluster, and the statements that were rated high for both importance and feasibility (upper right quadrant of the Go-Zone map). **Supplementary Table 2** shows all statements by cluster, along with the bridging values and ratings for the clusters and statements.

Five clusters were generated in relation to factors influencing adolescent obesity. These were "Home environment," "Lifestyle," "School Environment," "Community" and "Biology" (**Table 2**).

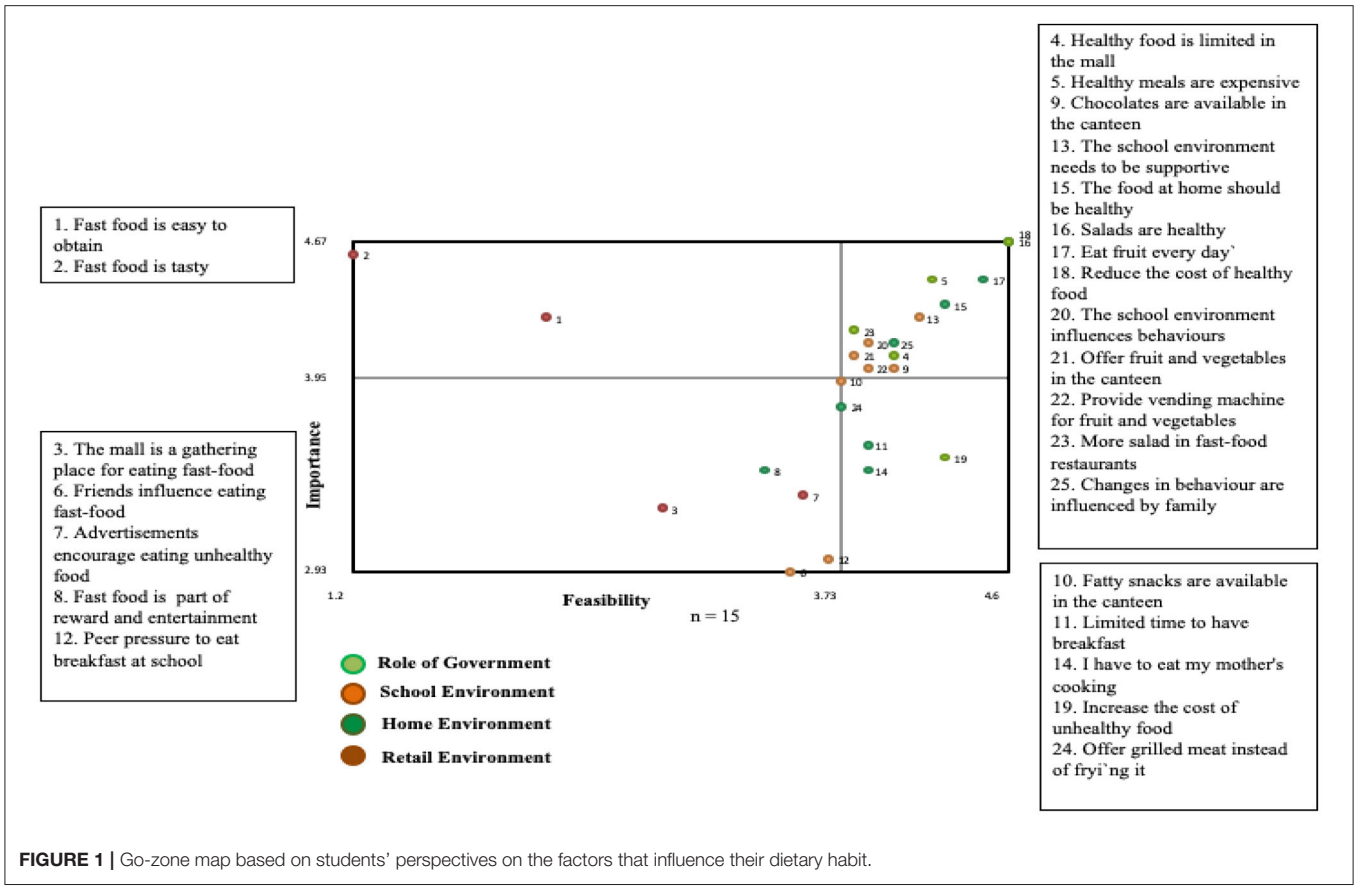

FIGURE 1 | Go-zone map based on students' perspectives on the factors that influence their dietary habit.

There was a high level of agreement across adults regarding how they classified statements in the first three clusters, reflected by the low bridging values. Average cluster ratings ranged from 3.42 to 4.02 for importance and 2.68 to 3.90 for feasibility. "School Environment" had the highest average cluster ratings for importance, and both "School Environment" and "Home Environment" for feasibility. Of the 15 statements in the Go-Zone (**Supplementary Figure 2**), 12 were from the "Home Environment" and "School Environment" clusters that rated high for both importance and feasibility. For "Home Environment," the issues raised related to healthy and regular meals, time spent watching TV and the importance of sleep. For "School Environment," the issues raised referred to insufficient physical activity, importance of drinking water and raising family awareness. Action to reduce high calorie foods and drinks and use of electronic devices were also included in the Go-Zone, captured under the cluster "Lifestyle." "Biology" had the lowest ratings for importance and feasibility. It is also worth mentioning that although issues such as eating fast foods, dining out and advertisements of convenience foods were felt to be highly important, they were rated relatively low for feasibility (upper left quadrant of the Go-Zone map, **Supplementary Figure 2**).

Four clusters were generated in relation to the content of a school programme. These were "Ministry of Education Support," "School Environment," "Public health programmes," and "Wider environmental influences" (**Table 2**). The clusters "Ministry of Education Support" (0.07) and "School Environment" (0.14) had the lowest overall bridging values. The Go-Zone (**Figure 2**) included system related issues raised under the cluster "Ministry of Education Support," such as availability of dietitians, nutritionists, specialist school meal supervisors, and school connections with the health centers. Education activities as well as having students as health guides were raised under "School Environment." In addition, the Go-Zone included issues related to encouraging healthy breakfasts and walking as well as engaging families, which were from the cluster "Wider environmental influences." The intersection of the axes reflected ratings to be relatively lower for importance than for feasibility. Several statements were in the lower left quadrant of the Go-Zone map plot and were rated to be more feasible than important. These included activities such as adapting the school curriculum, and using competitions, workshops and social media to promote healthy eating and physical activity.

DISCUSSION

Using group concept mapping, perspectives from students and those responsible for planning and provision of intermediate school education services provided valuable insights into the factors influencing adolescent obesity and the potential content of a school-based nutrition intervention programme. Students identified several factors at different social-ecological levels,

TABLE 2 | Adults' perspectives on factors that influence adolescent obesity and on feasible priorities for the content of school-based programmes: average bridging values and average ratings for importance and feasibility for each cluster, statements that were rated relatively high for both importance and feasibility (upper right quadrant of the Go-Zone map).

Cluster solution	Bridging value	Average important score*	Average feasibility score*	Statements rated as most important and feasible**
Perspectives of adults on the factors that influence adolescent obesity				
1-Community	0.42	4.02	2.95	No statement rated as most importance and feasible
2-Biology	0.68	3.42	2.68	No statement rated as most importance and feasible
3-Lifestyle	0.13	3.86	3.6	4-High-calorie and high-carbohydrate intake 8-Fizzy drinks and high-calorie energy drinks 15-Sedentary lifestyles associated with electronic devices,
4-School environments	0.22	4.11	3.89	14-Awareness of physical activity,19- Fast-food restaurants 27-Drink water at school 29-Insufficient physical activity 34-Family awareness 35-Check-ups for general health
5-Home environment	0.03	3.94	3.90	20-Eat a healthy diet 24-Eat fruit and vegetables 28-Follow Islamic rules in diet habits 30-Snacks in front of the TV 31-Time spent watching TV 33-Awareness of sleep as a healthy behavior
Perspectives of adults on feasible priorities for the content of a school-based programme				
1-Ministry of Education Support	0.07	4.03	3.98	1-Offer healthy food in the canteen 2-Remove chocolate and sweets 7-Have a dietitian to advice the canteen 8-Establish connection between health center and the canteen 13-Attractive healthy meals in school 29-Nutritionists should be part of the programme 32-Lack of healthy and suitable diets 33-Lack of specialist school meal supervisors
2-Public health programmes	0.46	3.79	3.84	3- Awareness of unhealthy foods such as fast foods
3-Schools Environment	0.14	3.83	3.92	4-Educate children about healthy food 5-Educate children about obesity 6-Offer practice programme 26-Health guides in schools
4-Wider environmental influences	0.7	3.96	3.82	12-Encourage healthy breakfasts 14-Encourage walking 30-Promote family responsibility 38-Lack of family knowledge about obesity

**Score out of 5.*

***Derived from the upper right quadrant of the Go-Zone map. The number preceding the statement corresponds to the number of the statement on the Go-Zone map.*

including the role of government, family life, school and wider environments and traditions that influence their dietary and physical activity behaviors. These factors largely resonated in the perspectives of the school and Ministry of Education staff on factors influencing adolescent obesity. Several focused suggestions were given for a school-based programme by both students and adults, with the support of Government felt to be important and feasible. This study adds to a scant evidence base on the use of participatory approaches with schools in the Gulf region. Both students and adults engaged with enthusiasm to express their perspectives on obesity-related health behaviors based on their different experiences, expertise and perception of needs to address the complex issue of prevention.

There was consistent consensus across students and adults that the support of government was important and feasible for the prevention of obesity. Regulatory interventions are essential to drive sustainable environmental and social changes to reduce obesity (31). The recent initiatives in Saudi relating to carbonated drinks and energy labeling on menus could have created a context of heightened awareness for the need for obesity prevention initiatives (6, 32). But it is also worth considering the changing social and economic landscape of Saudi as it prepares for a future

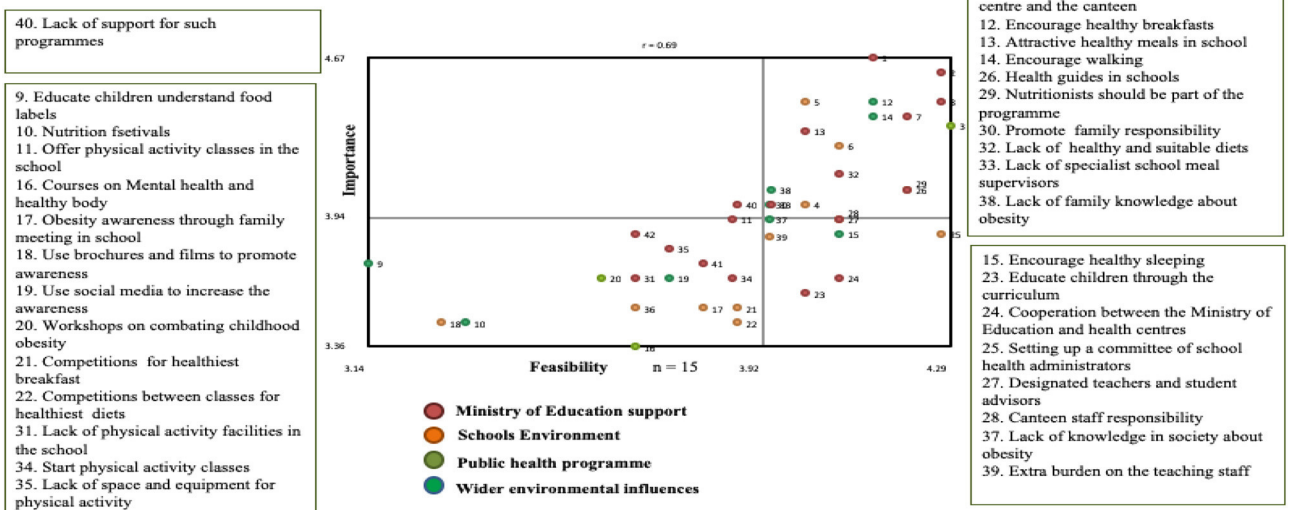

FIGURE 2 | Go-zone map based on adults' perspectives on the content of a school-based programme.

in which oil resources will play a far less significant role in the economy than has historically been the case. Young people are growing up in an interesting transitional context with the potential expansion of entertainment and tourism industries, reforms to the education system as well as increasing use of social media (33). Saudi's Vision 2030 aims to activate the role of youths in society, with Youth Councils being a mechanism for their involvement in decision-making, as well as maintaining loyalty and belonging to the Kingdom (20, 21, 34). The significance of youths in Saudi cannot be underestimated as they comprise 70% of Saudi society. The articulate voices of Saudi adolescents in the current study reflected a unique scenario of adolescents confidently driving their change agenda to protect their health in the context of a societal shift in exposures and belief that government will support their request.

The role of home environments in preventing obesity was also emphasized across students and adults. School and Ministry of Education staff felt that families had a responsibility to limit use of digital devices, time spent watching TV, and consumption of high calorie and sugary foods. A systematic review on the influence of home environment on childhood obesity have shown parenting style and practices (i.e., pressure to eat), knowledge and perceptions about child weight, TV in a child's bedroom, physical activity behavior and shortage of sleep to be associated with child weight status and health behaviors, and that there is a strong interplay between these home environment factors as they reinforce each other (35–37). Involving parents in an obesity prevention programme is therefore essential and was consistently reported by students and adults to be important for establishing healthy lifestyles.

Students and adults identified school environments as targets for feasible interventions. The removal of unhealthy food (high fat and sugary foods in particular) in the school canteen was seen as an important and feasible to change. Provision of healthy food in schools can increase choice and consumption of healthy foods in the school environment (38, 39), and also affect healthy food (fruit and vegetables) purchasing and consumption outside the school environment (40–42). For example, the Child and Adolescent Trial for Cardiovascular Health (CATCH) study showed that modifying food provision in schools and implementing a health curriculum led to a significantly higher decrease in the percentage of energy intake from fat (38.7% to 31.9%, $p =< 0.001$) in the diets of the students in the intervention group compared with those in the control group (43). An intervention that makes a change to the school environment, such as how food is served and presented, might also influence children's behavior by reducing weight gain, facilitating healthy eating choices and creating a supportive school environment. However, without local level implementation support, government school nutrition policies

and school systems are unlikely to yield improvement in the school food environment.

Strengths and Limitations

To our knowledge, this is the first concept mapping study carried out with planners and providers of education services and students in Saudi Arabia to examine adolescent obesity prevention, and which provides significant insights into how students' voices can be integrated into key decision-making dialogues. Strengthened by the use of their own photographs of their environments, the method embedded adolescents in the research from the onset, giving a sense of ownership and contribution. It also drew on the considerations in both individual and group-oriented activities (28). Their experiences and judgments on sorting and ratings of importance and feasibility for change improved the validity of the entire analysis, including the statistical analysis. This mixed approach is a substantially stronger methodological approach than using only a quantitative or qualitative approach for understanding a complex phenomenon, allowing the exploration of multiple themes and their inter-relationships (44). There are, however, several limitations. The study was based on 15 students in two schools and 25 adults, and the findings may not be generalizable. Insufficient number of mothers participated and although there was strong agreement on the feasible actions Go-Zone, a larger and socio-economically diverse sample of parents may have raised different issues (e.g. time restrictions among working mothers to prepare freshly cooked meals, deferring such responsibilities to careers etc.) (45, 46). Concept mapping methodology shares limitations associated with issues around the generalizability of the findings due to non-random sampling, dependence on the capabilities of the participant, and participants not having contributed equally in statements generation sessions. For cultural reasons, fathers were not included in the concept mapping workshops and we were unable to conduct the study with boys as it would have required a male researcher. That was clearly a major gap that should be addressed in future studies.

CONCLUSION

Students and school and MoE staff jointly agreed that a canteen-based intervention was important and feasible to improve dietary habits and thus help to prevent obesity among adolescent girls. This was the first time a participatory approach was with students for intervention development in Saudi Arabia. Students and adults engaged with the entire process with enthusiasm and respect, which signaled that a co-development approach may have value to improve school food environments in Saudi Arabia.

DATA AVAILABILITY STATEMENT

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

ETHICS STATEMENT

Written informed consent was obtained from the individual(s), and minor(s)' legal guardian/next of kin.

AUTHOR CONTRIBUTIONS

MA conceived the idea as part of her doctoral thesis, conducted all workshops, and led the initial draft. SH and MO'K were PhD supervisors of MA. All authors participated in the discussions that led to the design of the study, contributed substantially to the development of the study, made critical revisions to the manuscript, and provided final approval of the version to publish.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpubh.2022.863765/full#supplementary-material

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

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Trends and Disparities in Adult Body Mass Index Across the 47 Prefectures of Japan, 1975–2018: A Bayesian Spatiotemporal Analysis of National Household Surveys

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Background: Among high-income countries, Japan has a low prevalence of obesity, but little is understood about subnational trends and variations in body mass index (BMI), largely owing to the lack of data from representative samples of prefectures. We aimed to examine long-term trends and distributions of adult BMI at the prefecture level in Japan from the late 1970s using a spatiotemporal model.

Methods: We obtained cross-sectional data for 233,988 men and 261,086 women aged 20–79 years from the 44 annual National Health and Nutrition Surveys (NHNS) conducted during 1975–2018. We applied a Bayesian spatiotemporal model to estimate the annual time series of age-standardized and age-specific mean BMI by 20-year age group and sex for each of the 47 prefectures. We assessed socioeconomic inequalities in BMI across prefectures using the concentration index, according to population density.

Results: In men, the age-standardized prefectural mean BMI ranged from 21.7 kg/m^2 (95% credible interval, 21.6–21.9) to 23.1 kg/m^2 (22.9–23.4) in 1975 and from 23.5 kg/m^2 (23.3–23.7) to 24.8 kg/m^2 (24.6–25.1) in 2018. In women, the age-standardized prefectural mean BMI ranged from 22.0 kg/m^2 (21.9–22.2) to 23.4 kg/m^2 (23.2–23.6) in 1975 and from 21.7 kg/m^2 (21.6–22.0) to 23.5 kg/m^2 (23.2–23.8) in 2018. Mean BMI was highest in the southernmost prefecture for most of the study period, followed by northeast prefectures. The increase in mean BMI was largest in southwest prefectures, which caught up with northeast prefectures over time. The concentration index was negative, indicating higher BMI in less-populated prefectures. Absolute values of the concentration index were greater in women than in men and increased over time.

Conclusions: There were variations in adult mean BMI across prefectures, and geographic distributions changed over time. Further national and local efforts are needed

to address the rising trend in mean BMI, particularly among men in rural prefectures, and socioeconomic inequalities among women. Bayesian hierarchical modeling is useful for reconstructing long-term spatiotemporal trends of mean BMI by integrating small-sized survey samples at the prefecture level in the NHNS.

Keywords: body mass index, prefectures, Japan, Bayesian spatiotemporal model, National Health and Nutrition Survey, obesity

INTRODUCTION

The worldwide prevalence of adult overweight and obesity has been rising (1), and high body mass index (BMI) is considered to be one of the leading risk factors in the global burden of noncommunicable disease (2). Japan has some of the lowest mean BMI values among high-income and industrialized countries (1), as well as one of the highest life expectancies at birth in the world (3). In Japan, the mean BMI for men and women in 2016 was 23.7 kg/m^2 and 21.8 kg/m^2, respectively, whereas the respective global values were 24.5 kg/m^2 and 24.8 kg/m^2 (1). Understanding how body weight is controlled in the Japanese population could therefore help global public health professionals in developing effective policies and programs for obesity prevention.

Information on long-term trends and distributions of mean BMI among adults at the subnational level is essential for monitoring the progress of population-wide strategies to prevent obesity. In Japan, the National Health and Nutrition Survey (NHNS) is the main source of data on measured BMI in the adult population from the 1970s. The NHNS has been used to examine national trends in adult weight status (4–9) and the disease burden attributable to risk factors, including high BMI, at the subnational level (i.e., prefecture) in 2015 and 2019 (2, 10). However, it remains unknown how levels and distributions of adult BMI have changed across Japan's 47 prefectures over a long period because the NHNS was designed to be representative at the prefecture level only in 2012 and 2016 (11, 12).

In this study, we aimed to obtain stable estimates of annual mean BMI among adults across the 47 prefectures of Japan from 1975 to 2018. We applied the Bayesian spatiotemporal method to leverage the NHNS data at the prefecture level accumulated over the long term. We examined how spatial distributions of prefectural mean BMI had changed over four decades by sex and age. We also explored long-term trends in socioeconomic inequalities of prefectural mean BMI by sex.

MATERIALS AND METHODS

Data Source and Study Participants

We used individual-level data from the National Nutrition Surveys between 1975 and 2002 and the National Health and Nutrition Surveys between 2003 and 2018 (henceforth both referred to as the NHNS) (13). The NHNS is an ongoing cross-sectional household interview and examination survey conducted annually by the Japanese government. We obtained government approval to use individual-level data according to the Statistics Act (14). No ethical review was required because use of the NHNS is exempt according to the Ethical Guidelines for Medical and Biological Research Involving Human Subjects (15).

Methodological details of survey sampling in the NHNS have been described elsewhere (16, 17). Briefly, the sampling frame was the list of all residential census enumeration areas stratified into 47 prefectures, with each census enumeration area consisting of approximately 50 households. The surveys used a stratified two-stage cluster sample design to obtain a nationally representative sample of the non-institutionalized Japanese population. Census enumeration areas were randomly drawn from each prefecture in the first sampling stage. Selected census enumeration areas were divided into unit blocks such that each block consisted of 20 to 30 households, and unit blocks were randomly sampled from each prefecture in the second stage. All individuals aged $\geq$1 year living in a private household in 300 sampled unit blocks were eligible for the survey. The expanded surveys in 2012 and 2016 used a stratified single-stage cluster sample design to obtain representative samples at the prefecture level. In these surveys, census enumeration areas were randomly drawn from each prefecture, and all residents aged $\geq$1 year in 475 selected census enumeration areas were eligible for the survey (11, 12).

All participants were asked to undergo physical examination. Standing height was measured to the nearest millimeter using a stadiometer and with participants wearing no shoes, and weight was measured to the nearest 0.1 kg with participants wearing light clothing. We calculated BMI as weight in kilograms divided by the square of height in meters.

We limited study participants to individuals aged 20 to 79 years. We obtained a sample of 495,074 survey participants (233,988 men and 261,086 women) from 1975 to 2018, after excluding 3,605 participants who were pregnant. We regarded BMI level $<$10 kg/m^2 as implausible and recoded seven cases as having missing values accordingly. Of 495,074 participants, 110,984 (20.4%) had missing data for BMI. We filled in missing values of BMI and created five imputed datasets for analysis by predictive mean matching with one nearest neighbor for a single continuous variable. We applied this partially parametric method to have imputed BMI values within the range of observed data. We used sex, age in years, and prefecture as predictors in the imputation model and performed separate imputations by survey year. **Supplementary Tables 1**, **2** summarize the sample size and national mean BMI values estimated from multiple imputed datasets in each survey year.

Statistical Analysis

In this analysis, we estimated mean BMI by age group and sex for all 47 prefectures of Japan from 1975 to 2018. We conducted all analyses separately by sex because levels and trends of the national mean BMI differed between men and women. We applied a Bayesian spatiotemporal model to obtain robust

estimates of prefectural mean BMI from a small sample at the prefecture level (18). As data preparation, we used multiple imputed datasets to calculate point estimates and standard errors of the observed mean BMI by 20-year age groups (20–39, 40–59, and 60–79 years), sex, prefecture, and survey year. For the calculation of standard errors, we conducted mixed-effects linear regression of BMI on indicator variables for prefectures, accounting for the multistage survey sampling design that included stratification by prefecture and clustering by census enumeration areas.

We formulated the Bayesian spatiotemporal model to incorporate features of prefectural mean BMI in relation to age, prefecture, and survey year. In the model, we assumed that an observed prefectural mean BMI (Y_{apt}) in age group a (= 1, 2, 3), prefecture p (= 1,...,47), and year t (= 1,...,44) follows a normal distribution,

$$Y_{atp} \sim N(\mu_{atp}, \sigma^2 se^2_{atp}).$$

The parameter μ_{atp} signifies the expected value of prefectural mean BMI and $\sigma^2 se^2_{atp}$ signifies the variance of prediction error weighted by squared standard errors of the observed mean BMI specific to age, year and prefecture, se_{atp}, reflecting the sample size in the survey. We weighted each data point by squared standard errors such that data points with smaller standard errors had a greater influence on the estimated prefectural mean BMI. We specified Y_{atp} as a linear function of time,

$$Y_{atp} = (\alpha_0 + \beta_0 \times t) + (\alpha_{1a} + \beta_{1a} \times t) + (\alpha_{2p} + \beta_{2p} \times t) + (\alpha_{3ap} + \beta_{3ap} \times t) + \gamma_{1at} + \gamma_{2pt}$$

where α_0 and β_0 are the common intercept and trend, respectively, across age groups and prefectures.

The age-specific intercept (α_{1a}) and slope (β_{1a}) quantify the deviation in age group a from α_0 in level and β_0 in trend, respectively. To ensure smoothness over adjacent age groups, we used a first-order random walk prior on α_{1a} and β_{1a}, holding α_{11} and β_{11} for the youngest group to 0. The first-order random walk takes the general form of $\alpha_{1a} \sim N(\alpha_{1a-1}, \sigma^2_{\alpha 1})$.

The prefecture-specific intercept (α_{2p}) and slope (β_{2p}) measure the deviation in prefecture p from α_0 in level and β_0 in trend, respectively. We modeled α_{2p} and β_{2p} using the Besag, York, and Mollié (BYM) model, which allows mean BMI in each prefecture to be estimated using its own data and those of its neighboring prefectures. In the BYM model, information is shared both locally between neighboring prefectures through spatially structured random effects with a conditional autoregressive prior, and globally among all prefectures through spatially unstructured (independent and identically distributed) Gaussian random effects (19). We imposed the spatial structure of the conditional autoregressive prior through the adjacency matrix that specified the geographic proximity among the 47 prefectures. A map of prefectures is provided with information on population density in **Supplementary Figure 1**. We considered a pair of prefectures to be neighbors if they shared a land border or were connected by a bridge or tunnel across the sea. We joined Okinawa, the southernmost prefecture, to the nearest prefecture (Kagoshima) based on ferry connections from island to island. There was no change in boundaries among prefectures during the study period. Maps of the spatially smoothed random effects component of the intercepts and slopes are shown by sex in **Supplementary Figure 2**.

The age-prefecture interaction terms α_{3ap} and β_{3ap} account for age-specific deviations in intercepts and slopes, respectively, in prefecture p from those of other prefectures. The α_{3ap} and β_{3ap} were assumed to be independent and identically distributed Gaussian random effects. The model included first-order random walks over time to allow for nonlinearity from the average linear trend for each age group (γ_{1at}) and each prefecture (γ_{2pt}). We used weakly informative priors such that inference in parameters was driven by data. All standard-deviation parameters had $\sigma \sim U(0,2)$ priors. For the global intercept (α_0) and slope (β_0), we used N(0, 100,000).

We fitted the Bayesian spatiotemporal model with the Markov chain Monte Carlo algorithm in WinBugs 1.4.3 (20). For each analysis by sex, we ran the model with two chains until convergence was reached. We visually monitored convergence of the chains using trace plots. Convergence was reached with 5,000 iterations, and we ran a further 5,000 iterations on each chain to collect 10,000 postburn in samples for inference from the posterior distributions of parameters. We averaged these samples to yield point estimates of prefectural mean BMI and reported 95% credible intervals as the 2.5th and the 97.5th percentiles of the 10,000 samples.

Using estimated prefectural mean BMI, we computed the concentration index to examine socioeconomic inequality in BMI among prefectures. The concentration index is a relative measure of inequality that indicates the extent to which a health indicator is concentrated according to socioeconomic status (21). The concentration index ranges from −1 to 1 and equals zero when there is no inequality. It takes a negative value when a health variable is concentrated at lower socioeconomic levels. As a socioeconomic variable of prefecture, we used population density (total population per square kilometer of total land area) by age group, sex, prefecture, and year. Population density is a stable measure of urbanization of prefectures over the four decades. To generate this variable, we divided the age- and sex-specific total population by total land area in each prefecture and each year obtained from the System of Social and Demographic Statistics (22). As a health variable, we generated the total BMI per square kilometer of total land area calculated as the product of mean BMI and population density. We sorted prefectures in ascending order of population density and calculated cumulative proportions of population density and total BMI in each prefecture. We computed the concentration index as twice the sum of the difference between the cumulative proportions of population density and total BMI across prefectures (21).

We used R version 3.6.0 (www.r-project.org) for data preparation and Stata version 15 (StataCorp LP, College Station, TX, USA) for data preparation and analysis of the concentration index. For age-standardization, we obtained the total population, by 20-year age groups, from the 2010 Population Census of Japan (23).

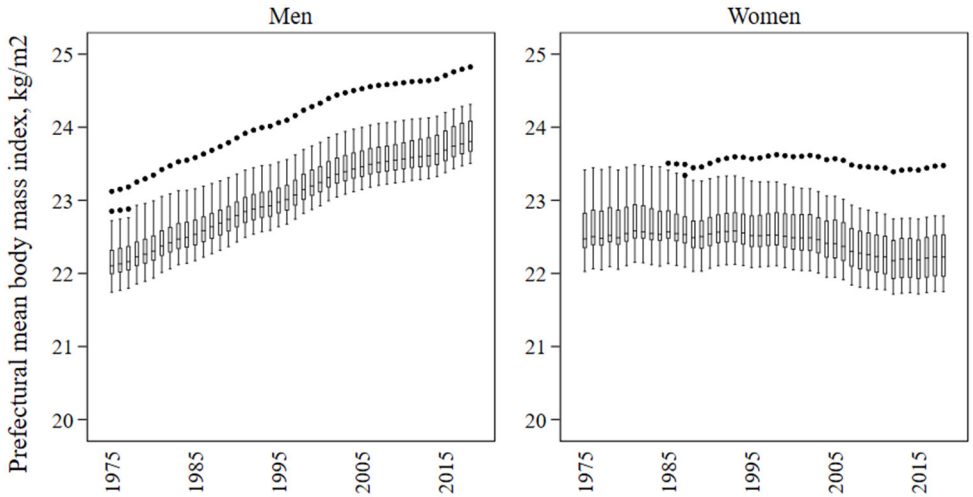

FIGURE 1 | Distribution of the age-standardized mean body mass index (kg/m^2) across the 47 prefectures of Japan in each year from 1975 to 2018. The box shows the 25th, 50th, and 75th percentiles. The lower adjacent line indicates minimum values or values less than the first quartile minus 1.5 times the interquartile range. The upper adjacent line indicates maximum values or values greater than the third quartile plus 1.5 times the interquartile range. Points show values below the lower adjacent value or above the upper adjacent value.

RESULTS

Annual Changes in the Distribution of Prefectural Mean BMI

Figure 1 demonstrates annual changes in the distribution of age-standardized mean BMI values estimated by the Bayesian spatiotemporal model across the 47 prefectures between 1975 and 2018. Among men, the whole distribution of the age-standardized prefectural mean BMI consistently shifted upward during the study period, and similar trends were found for the distributions of prefectural mean BMI by age group (**Supplementary Figure 3**). Among women, the distribution of age-standardized prefectural mean BMI remained almost constant until starting to gradually shift downward in the 2000s (**Figure 1**). Trends varied among age groups in women (**Supplementary Figure 3**). The distribution of the prefectural mean BMI started to shift downward during the 1980s among young and middle-aged women whereas in older women, it continued to move upward until starting to shift downward in the early 2000s. The age-standardized mean BMI was substantially higher in Okinawa than in other prefectures across survey years for men and from the late 1980s for women (**Figure 1**).

Spatiotemporal Changes in Prefectural Mean BMI

Maps in **Figure 2** show changes in spatial distributions of age-standardized prefectural mean BMI. The age-standardized mean BMI in 1975 was higher in Hokkaido, Okinawa, and northeast prefectures than in other prefectures for both sexes. The geographic distribution of the age-standardized prefectural mean BMI had changed by 2018. The age-standardized mean BMI was highest in Okinawa, followed by those in northeast and southwest prefectures for both sexes. The age-standardized mean BMI increased more in southwest prefectures than in other prefectures for both sexes over time. The decrease in age-standardized mean BMI for women was largest in Hokkaido (1.2 kg/m^2 [95% credible interval, 0.8–1.5]).

Similar spatiotemporal trends were found for age-specific prefectural mean BMI values across all sex and age groups (**Supplementary Figures 4**, **5**). The increase in mean BMI between 1975 and 2018 was largest for men aged 60–79 years in southwest prefectures. The decrease in mean BMI was largest for women aged 40–59 years in Hokkaido.

Changes in Socioeconomic Inequality for BMI Across Prefectures

Figure 3 shows trends in the age-standardized concentration index for total BMI according to total population per square kilometer of total land area across prefectures. The concentration index was negative for both sexes and was lower in women than in men throughout the study period. The concentration index in 1975 was −0.02 (95% credible interval, −0.05 to 0.01) for men and −0.13 (−0.17 to −0.09) for women. The concentration index in men gradually decreased over time to −0.06 (−0.09 to −0.03) in 2018. In women, it decreased relatively rapidly to −0.19 (−0.22 to −0.17) in 2004 and thereafter remained stable at −0.18 (−0.22 to −0.14) in 2018.

DISCUSSION

Using NHNS data and the Bayesian spatiotemporal method, we obtained stable annual estimates of mean BMI among adults across the 47 prefectures of Japan over four decades. Our study is novel in that we revealed long-term changes in geographic and socioeconomic variations of prefectural mean BMI. Such

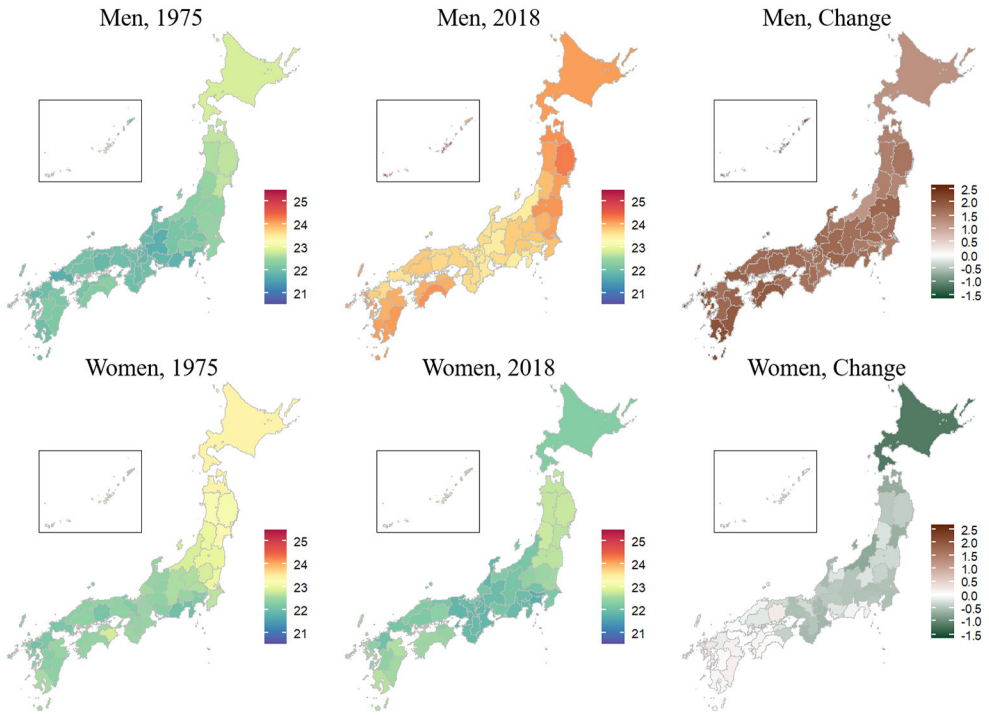

FIGURE 2 | Geography of the age-standardized prefectural mean body mass index (kg/m^2) in 1975 and 2018 and its changes among adults aged 20–79 years in the 47 prefectures of Japan, by sex. The prefectural mean body mass index was estimated using a Bayesian spatiotemporal model. The insets are enlarged views of Okinawa.

information on subnational variations in mean BMI is important for the evaluation of national health promotion strategies, but this has been unclear using NHNS samples directly, which are not representative at the prefecture level. The estimation method is valid (18) and has been used to examine long-term trends and distributions of BMI indicators across countries worldwide (24–26). This method has also been applied to improve district-level population health estimates from national surveys in various countries, such as the under-five mortality in Ghana (27), child nutrition in South Africa (28), and life expectancy in the United Kingdom (29, 30).

Our results confirmed that long-term trends in prefectural mean BMI values were different between men and women. Prefectural mean BMI in men increased steadily across all age groups throughout the study period. Prefectural mean BMI in young and middle-aged women decreased during the 1980s; in older women, these values increased until starting to decrease in the early 2000s. These overall trends of prefectural mean BMI were consistent with previous findings on national trends estimated using the NHNS for individuals aged 20 years and over between 1976 and 1995 (5), women aged 15–29 years between 1976 and 2000 (6), and individuals aged 65 years and over between 1973 and 2016 (8). Thus, our model was able to reflect national trends in the estimation of prefectural mean BMI.

Our results suggest that mean BMI has been relatively high in northeast prefectures and Okinawa throughout the study period, which might be attributable to lifestyles developed under

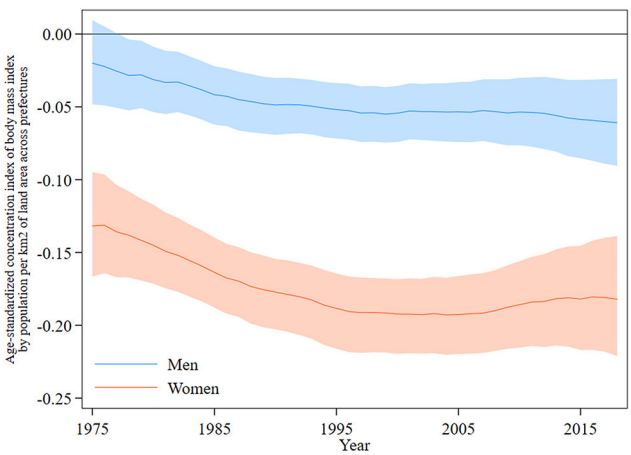

FIGURE 3 | Concentration index for the total body mass index across the 47 prefectures of Japan in each year from 1975 to 2018, by sex. The height of the shaded area shows the 95% credible interval.

climatic and historical environments. Around the late 1970s, a relatively high mean BMI was mainly observed in northeast prefectures. This result might partly reflect prolonged exposure to unfavorable lifestyles in a cold climate, such as physical inactivity and a diet high in salt. Historically, dietary salt intake has been high in northeast regions to maintain body temperature

and preserve food for storage (31–33). A positive association of dietary salt intake with BMI was found in a multi-country study (34). Moreover, the trends in overweight and obesity were already obvious among men living in Okinawa during the late 1970s. One explanation for the distinctly high mean BMI in Okinawa at that time might be lifestyles under American occupation between 1945 and 1972. In fact, animal fat intake from imported meat products increased rapidly in Okinawa during the 1960s, as compared with Western countries (35). Our finding of high mean BMI in Okinawa agrees with that of a previous longitudinal analysis based on self-reported height and weight in the 1990s and early 2000s (36). Okinawa was once ranked first in longevity but has shown relatively poor performance in recent years, which may be partly attributable to the distinctive trends in adult BMI.

We found that the geographic distribution of prefectural mean BMI changed over time, mainly because southwest prefectures caught up with northeast prefectures. In recent years, prefectural mean BMI has been relatively high toward the northeast and southwest rural regions of Japan. One explanation for this geographic change in mean BMI might be a decrease in dietary salt intake across the country over time (37). The suppressing effect of reduced dietary salt consumption on the rise in mean BMI might be relatively large in northeast prefectures. Another possible explanation might be decreased physical activity, particularly in less-populated prefectures, within increased motorization and use of privately owned cars rather than public transport. Previous studies in Japan show a positive association between the size of a municipality and number of walking steps per day (38) and an inverse association between walkability of a residential neighborhood and BMI (39, 40).

Another key finding of this study was that socioeconomic inequalities in overweight and obesity have increased over time in Japan. The concentration index of BMI was negative, as expected, reflecting an inverse relationship between mean BMI and population density across prefectures. Widening socioeconomic inequalities might be partly attributable to the relatively rapid increase in mean BMI in less-populated southwest prefectures. Moreover, socioeconomic inequalities were markedly larger in women than in men. This difference between men and women might partly reflect the increased concentration of adult women who are employed in the Tokyo metropolitan area (41), where mean BMI is rather low for women. A previous study in Japan reported that young adult women living in metropolitan areas are more likely to want to be thin than those living in towns (42).

From a public health perspective, a series of national health promotion campaigns have been implemented since the late 1970s to improve lifestyles in the Japanese population (43). Health Japan 21 (the second term), underway during fiscal years 2013 to 2023, is a campaign that has set numerous targets that include reducing health inequalities and increasing the proportion of people who can maintain a healthy weight (44). To achieve these targets, local governments, such as prefectures and municipalities, have developed their own basic plans under the Health Promotion Act (45). The NHNS in 2012 and 2016 were conducted using expanded samples to obtain prefecture-level estimates for subnational evaluation of Health Japan 21 (the second term) (11, 12). Despite these efforts, mean BMI in some prefectures was still inconsistent between the two surveys. For example, mean BMI among middle-aged women in Kyoto was the seventh highest in 2012, at 23.2 kg/m^2; it was the second lowest in 2016, at 22.0 kg/m^2. The lack of consistency and comparability in estimates might be partly owing to methodological issues such as survey sampling and implementation in each prefecture and each year. The ranking of prefectural mean BMI reported in the NHNS would therefore be somewhat misleading for the assessment of local public health promotion programs. The Bayesian spatiotemporal method applied in this study would compensate for such shortcomings by integrating small-sized survey samples to reconstruct long-term trends of prefecture-level mean BMI.

Our findings and implications are relevant to global public health policies for the prevention of obesity. The prevalence of overweight and obesity among OECD countries in 2019 was lowest at 27% in Japan, followed by 34% in South Korea, while it exceeded 70% in Chile, Mexico, and the United States (46). The prevalence of overweight and obesity has been rising in all OECD countries, especially it has increased by 15% or more between 2009 and 2019 in Chile, Mexico, and Turkey. Even in Japan, a high-income country with a low obesity prevalence, there are subnational variations in BMI and geographic distributions and socioeconomic inequalities have changed over time. Mean BMI has been steadily increasing across prefectures particularly for men, and the increase was larger in less-populated prefectures toward the northeast and southwest rural regions of the country. These results partly support a previous finding of a persistently higher BMI in rural areas in high-income and industrialized countries (25).

Our study has several methodological limitations that should be addressed in future research. First, we did not examine the prevalence of underweight, overweight, and obesity with a different probability distribution from that of mean BMI. Long-term trends of the prevalence of these BMI categories at the prefecture level should be assessed as a next step in spatiotemporal analyses based on the NHNS. Second, it would be challenging to obtain prefecture-level estimates on other important cardiometabolic risk factors such as blood pressure, blood glucose, and serum cholesterol because samples of these items are even smaller than those of body height and weight in the NHNS (33). A possible solution for this challenge might be modification of the model by adding hierarchical structures of prefectures. Finally, the Bayesian spatiotemporal method is still too difficult to be used in regular monitoring of prefecture-level BMI in the NHNS. The development of simplified models is necessary to introduce the estimation method in routine survey practice.

In conclusion, there were variations in adult mean BMI across prefectures, and geographic distributions changed over time. Further national and local efforts are needed to address the rising trend in mean BMI, particularly among men in less-populated prefectures in the northeast and southwest rural regions, and socioeconomic inequalities among women. Understanding body weight status at the subnational level is essential to formulate effective national and local strategies for ensuring health and well-being in countries worldwide that are aiming for sustainable development. Global efforts should be continued to strengthen coherent actions across sectors in establishing food systems that

deliver a balanced and healthy diet at an affordable price for all individuals, as well as residential environments that promote daily walking and physical activity. Bayesian spatiotemporal modeling is a promising approach for using existing national surveys in the assessment of health system performance to control obesity at the subnational level.

DATA AVAILABILITY STATEMENT

The data analyzed in this study is subject to the following licenses/restrictions: Statistics Act. Requests to access these datasets should be directed to NI, ikedan@nibiohn.go.jp.

ETHICS STATEMENT

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. Written informed consent for participation was not required for this study in accordance with the national legislation and the institutional requirements.

AUTHOR CONTRIBUTIONS

NI designed the study, created data applications for the government, conducted statistical analyses, and drafted the article. TN developed the adjacent matrix and provided input on spatial analyses in Japan. JB helped draft the statistical codes and provided input on the Bayesian spatiotemporal model. ME provided guidance for spatiotemporal analyses at the subnational level from the perspective of global health. NN supervised the study. TN, JB, ME, and NN interpreted the results and critically revised the article for important intellectual content. All authors contributed to the article and approved the submitted version.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpubh.2022.830578/full#supplementary-material

Supplementary Figure 1 | Map of the 47 prefectures of Japan, colored by total population per square kilometer of total land area in 2010 from the system of social and demographic statistics.

Supplementary Figure 2 | Maps of the spatially smoothed random effects component of the intercepts and slopes by sex. The variance of these spatially structured components accounted for between 51% and 99% of the variance of intercepts and slopes for both men and women.

Supplementary Figure 3 | Distribution of the age-specific mean body mass index (kg/m^2) across the 47 prefectures of Japan in each year from 1975 to 2018. The box shows the 25th, 50th, and 75th percentiles. The lower adjacent line indicates minimum values or values less than the first quartile minus 1.5 times the interquartile range. The upper adjacent line indicates maximum values or values greater than the third quartile plus 1.5 times the interquartile range. Points show values below the lower adjacent value or above the upper adjacent value.

Supplementary Figure 4 | Geography of the age-specific prefectural mean body mass index (kg/m^2) in 1975 and 2018 and its changes among men aged 20–79 years in the 47 prefectures of Japan. The prefectural mean body mass index was estimated using a Bayesian spatiotemporal model. The insets are enlarged views of Okinawa.

Supplementary Figure 5 | Geography of the age-specific prefectural mean body mass index (kg/m^2) in 1975 and 2018 and its changes among women aged 20–79 years in the 47 prefectures of Japan. The prefectural mean body mass index was estimated using a Bayesian spatiotemporal model. The insets are enlarged views of Okinawa.

Supplementary Table 1 | Sample size and mean body mass index estimated from multiple imputed datasets by age group and survey year in male participants aged 20–79 years.

Supplementary Table 2 | Sample size and mean body mass index estimated from multiple imputed datasets by age group and survey year in female participants aged 20–79 years.

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Australian State and Territory Eclectic Approaches to Obesity Prevention in the Early Years: Policy Mapping and Perspectives of Senior Health Officials

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Background: The international increase in the prevalence of childhood obesity has hastened in recent decades. This rise has coincided with the emergence of comorbidities in childhood—such as type II diabetes, non-alcoholic fatty liver disease, metabolic syndrome, sleep apnoea and hypertension—formerly only described in adulthood. This phenomenon suggests global social and economic trends are impacting on health supportive environments. Obesity prevention is complex and necessitates both long-term and systems approaches. Such an approach considers the determinants of health and how they interrelate to one another. Investment in the early years (from conception to about 5 years of age) is a key life stage to prevent obesity and establish lifelong healthy habits relating to nutrition, physical activity, sedentary behavior and sleep. In Australia, obesity prevention efforts are spread across national and state/territory health departments. It is not known from the literature how, with limited national oversight, state and territory health departments approach obesity prevention in the early years.

Methods: We conducted a qualitative study including policy mapping and interviews with senior officials from each Australian state/territory health department. A series of questions were developed from the literature to guide the policy mapping, drawing on the *World Health Organisation Ending Childhood Obesity Report*, and adapted to the state/territory context. The policy mapping was iterative. Prior to the interviews initial policy mapping was undertaken. During the interviews, these policies were discussed, and participants were asked to supply any additional policies of relevance to obesity prevention. The semi-structured interviews explored the approaches to obesity prevention taken in each jurisdiction and the barriers and enablers faced for policy implementation. Thematic analysis was used to analyse the data, using NVivo software.

Results: State and territory approaches to obesity prevention are eclectic and while there are numerous similarities between jurisdictions, no two states are the

same. The diversity of approaches between jurisdictions is influenced by the policy culture and unique social, geographic, and funding contexts in each jurisdiction. No Australian state/territory had policies against all the guiding questions. However, there are opportunities for sharing and collaborating within and between Australian jurisdictions to establish what works, where, and for whom, across Australia's complex policy landscape.

Conclusions: Even within a single country, obesity prevention policy needs to be adaptable to local contexts. Opportunities for jurisdictions within and between countries to share, learn, and adapt their experiences should be supported and sustained funding provided.

Keywords: early childhood, policy, obesity prevention, systems-thinking, qualitative, eclecticism

INTRODUCTION

The international increase in the prevalence of childhood obesity has coincided with the emergence of comorbidities formerly only described in adulthood—such as type II diabetes, fatty liver disease, metabolic syndrome, sleep apnoea and hypertension (1, 2). The first 2,000 days (from conception to about 5 years of age) is a key life stage to establish lifelong behaviors for health and to prevent obesity (3, 4).

In Australia, the issue of childhood obesity emerged as a distinct policy agenda in the early 2000s. Over the last two decades obesity has risen and fallen from national and subnational political agendas. Federalism shapes the ability to take policy initiatives. The six states (New South Wales (NSW), Victoria, Queensland, South Australia (SA), Western Australia (WA) and Tasmania) and two territories [Australian Capital Territory (ACT) and Northern Territory (NT)] are constrained by "vertical fiscal inequality"—the disproportion between Commonwealth dominance of tax revenues and the high spending responsibilities of the states. The Commonwealth uses its fiscal dominance to set conditions on expenditure in national funding agreements, e.g., the National Housing and Homelessness Agreement. State and territory governments have limited resources to fill funding gaps. Commonwealth fiscal decisions can greatly influence the social determinants of health, including the social safety net (e.g., welfare payments and conditions), housing policy and funding, out of pocket costs for primary health care, and industrial relations policy such as workforce casualisation and minimum wage (5). In 2008, the National Partnership Agreement on Preventive Health (NPAPH) was Australia's largest national investment in prevention and included a national Healthy Children's Initiative which focused on childhood obesity. Since that national funding was cut prematurely in 2014, subnational governments have independently pursued childhood obesity prevention initiatives.

The Early Prevention of Obesity in Childhood (EPOCH) Collaboration sought to answer if interventions in early life could prevent obesity across a range of modalities in real world intervention settings (6). The cohort included more than 2,300 first-time mothers in Australia and New Zealand. These interventions commenced in pregnancy or by 6 months of age and all ended by 2 years of age. They focused on knowledge, skills and self-efficacy for parents (usually mothers, although not exclusively) in relation to breastfeeding, transition to solids, the importance of "tummy time," avoidance of screen time, and sleep (6). The EPOCH trials resulted in improved behaviors and small but significant improvements in child body mass index compared to controls at 18–24 months follow-up (6). Internationally, there is a paucity of programs to support parents in the latter half of the first 2,000 days (2–5 years) (7).

As some form of childcare is attended by approximately two thirds of children aged 1–4 years in Australia (8), early childhood education and care (ECEC) services are considered a key community setting for health promotion interventions for obesity prevention and establishing healthy lifestyle behaviors in the early years. A recent study among mothers of young children in NSW identified strong support for these interventions in ECEC settings (9). State and territory education departments (and the communities department in WA) have tasked Authorised Officers to enter and assess ECEC services against regulatory obligations and standards set by the national authority for the ECEC sector, the Australian Children's Education & Care Authority (ACECQA). State authorities and their Authorised Officers are given little guidance on how to support services to maximize the health and well-being for children attending care (10, 11). Nor has there been extensive engagement with the sector to identify how (or if) health promotion could be part of their core business.

Despite the positive intervention effects found in the EPOCH trials, difference between intervention and control groups had disappeared at follow-up at 3.5 and 5 years of age (12). This suggests that families need ongoing intervention to overcome the obesogenic environments in which they live. Families exist within societies and provide their children with opportunities for healthy nutrition and being active based on the environments in which they live and the resources available to them. Spheres of influence include the child and their family and their community

Abbreviations: ACT, Australian Capital Territory; NSW, New South Wales; NT, Northern Territory; SA, South Australia; WA, Western Australia; ACECQA, Australian Children's Education & Care Quality Authority; ECEC, Early childhood education and care; GQ, Guiding question; HPM, Health Promotion Model; LG, Local government; LHN, Local Hospital Network; NPAPH, National Partnership Agreement on Preventive Health; WHO, World Health Organisation.

(including ECEC settings, public spaces and infrastructure, public transport), and societal and political influences (industry, agriculture, media, transport and planning, healthcare, and social norms) (13). To prevent "fade-out effects" such as seen in the EPOCH trials it is prudent to align early childhood obesity prevention interventions with broad environmental actions to prevent obesity (14). That is, to consider broad social/whole of population strategies along with specific interventions for families during the first 2,000 days. However, a recent study found that policies for this life stage tend to focus on support programs for parents (usually mothers) and more recently the ECEC sector (7).

Where we live matters. A 2017 Australian health analysis found people in the lowest two quintiles by socioeconomic status have significantly increased risk of poor health outcomes (15). The proportion of the population in the two lowest socioeconomic status quintiles differ across jurisdictions—while 4.2% of the population in the ACT are in the lowest two quintiles, for Tasmania it is 63.3% (16). There are key contextual differences between Australian jurisdictions, including population size and density, budgets, and degree of rurality. Australia's urban populations (just over 70%) experience determinants of health very differently to the almost 30% of the population in non-metropolitan areas (including rural, regional and remote) (17). See **Supplementary File 1.1** for a summary of key demographic differences between the jurisdictions.

Given the complexity of childhood obesity prevention, it is important to examine "where we are" and "why we are." Frameworks for obesity prevention consider these spheres of influence noted above and identify points where governments can influence and possibly prevent it. Systems approaches and sense-making frameworks (18, 19) seek to identify key areas where public policy can influence both lifestyle behaviors and the wider determinants of health. Systems thinking places a "high value on understanding context and looking for connections between the parts, actors and processes of the system" (20) and aligns strongly with ecological models which consider the social determinants of health (21). A recent study of 18 Australian policy-makers found a trend toward the uptake of systems thinking in developing "new prevention narratives," although a minority were unclear of its utility and methods (21), suggesting emerging opportunities for collaborative partnerships.

We have previously undertaken a comparison of national policies for the early prevention of obesity in childhood for Australia compared to five similar countries (7). The present study had two aims. The first aim was to provide a snapshot of policies for the early prevention of obesity in childhood, across the public health spectrum, at the state and territory level in Australia. The second aim of this study was to explore the perspectives of senior state and territory health department officials about their experiences and the local context of developing and implementing policy options for childhood obesity prevention. To our knowledge, this is the first publication of cross-sectoral policy mapping for obesity prevention in the early years among Australia's jurisdictions.

METHODS

Study Design

We conducted a qualitative study of early childhood obesity prevention policy (including prevention programs and initiatives) among Australian states and territories using (1) policy mapping and (2) semi-structured interviews with senior health officials who have responsibility for obesity policy. The purpose of the policy mapping was to provide context and evidence of government policy in addition to the subjective responses of the participant interviews.

Policy Mapping and Analysis

Tool Development

A policy mapping tool was adapted to the Australian state and territory context from the *WHO Ending Childhood Obesity Report* with additional supportive literature (**Supplementary File 1.2**), to develop guiding questions to prompt policy searches. This report provides an action plan to "translate evidence into practice" emphasizing the importance of regulation (22). This adaption included public health approaches to obesity across the social model of health (23) and built upon an earlier Australian policy mapping analysis (7) that identified state and territory governments) policy responsibilities. The broad policy areas were governance, health supportive environments, ECEC settings, and health services aimed at the first 2,000 days. The policy mapping provided a snapshot of key policy examples for early childhood obesity prevention across Australian jurisdictions.

Mapping

We identified relevant government agencies in each state and territory, developed a search strategy, and extracted data. The policy search was an iterative process undertaken by EE commencing 1 October 2018 (prior to interviews in late 2018) with follow-up after interviews prior to mapping being finalized on 30 June 2019. The online search used key words, from the guiding questions of the policy mapping tool, in embedded search engines in identified agency websites. These searches were augmented by the advanced search tool function in the Google search engine [described in a previous study (7)]. To minimize bias the incognito function was used, the researcher browser history, cache, and cookies were cleared, and regional settings were used to localize results to Australia.

Analysis

Data were extracted by EE (and reviewed by CR) using a policy content analysis approach (24) and included policy name and a description of how policies were being used to achieve the elements of the guiding principles, or ways that they could potentially be leveraged to do so, and an overall rating was given. The ratings are described in **Table 1**.

Interviews With Senior Health Officials

A semi-structured interview tool was developed based on systems approaches to obesity prevention and adapted to each jurisdiction (see **Supplementary File 1.3**). Ethics approval for

TABLE 1 | Ratings and descriptions for the policy mapping analysis.

Result		Description*
	Policy (or initiative) in place	There is a policy or initiative in place that aligns to the guiding question. This does not mean the policy has been implemented or evaluated for effectiveness.
	Policy Infrastructure	Moderate alignment to existing policies or frameworks. There are many elements in place but to extend or develop a policy in this space requires input from key stakeholders to develop or adapt to local context.
	Policy Scaffolding	Low alignment to existing policies or frameworks, however, there is some potential (in a single or multiple policy settings) for development of a policy or program in this area.
	Policy Void	No policies were found at the time of mapping, or an absence of alignment. In some instances, policies were not contextually relevant or possible for that jurisdiction (in which case it is noted in **Supplementary File 2**).

**Mapped policies were publicly available online. It is likely that some policies are in existence but were not found in the desktop review nor provided by jurisdictional informants at the time of interview.*

this project was granted by the University of Sydney Human Research Ethics Committee (Project 2017/507).

Purposive snowball sampling was used to identify potential informants through the professional networks of the authors and their colleagues. Senior officials with current active responsibility for obesity prevention in each jurisdiction's health department—a handful in each jurisdiction—were eligible for participation (inclusion/exclusion criteria). Prospective participants were invited to participate via email. Three attempts were made to reach identified informants before attempts were made to contact another informant. In three instances, the person invited referred our invitation to a colleague within the same branch, who then accepted. In total, nine informants were recruited (of 12 invited) from Australian state and territory health departments, one from each jurisdiction except the Northern Territory, which had two informants. All participants contributed to the development and/or implementation of obesity prevention policy and programs. Interviews with state and territory informants were conducted between November and December 2018. First order coding after each interview was performed to ensure saturation point had been achieved while ensuring one interview per jurisdiction as a minimum for equal representation. Interviews averaged 63 min (range: 42–95 min).

All interviews were conducted via telephone, recorded and transcribed verbatim. Interviews were coded using thematic analysis in NVivo 10 software. All data coding and extraction were undertaken by EE. CR and LMW cross-referenced a sample of interviews to ensure a consistent coding frame. Thematic analysis (25, 26) is a tool or a method to identify, analyse, and interpret meaning—"themes"—from qualitative data. The themes provided structure to report on research findings separate to or with the use of theoretical frameworks.

RESULTS

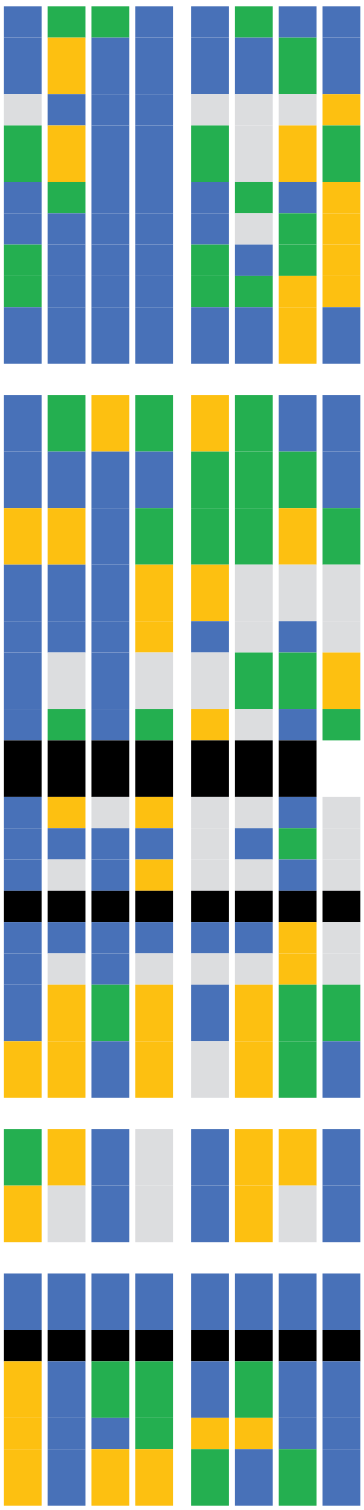
The results of this study are presented in four sections. The first section summarized the policy mapping and describes a key finding of the policy mapping and interviews with senior health officials—that Australia has two distinct local health promotion models. The second and third sections describe the approaches taken to collaborate across government agencies and health supportive environments. The final section identifies key political drivers and policy levers for obesity prevention.

Policy Mapping and Local Health Promotion Models

References to policy mapping are indicated by their Guiding Question (GQ) area or specific identifier, e.g., (GQ area A) or (GQ A.1.1) throughout the results. The policy mapping found that childhood obesity was identified as a problem in most jurisdictions (GQ A.1.1). The key life stages of pregnancy and/or early childhood (or as the first 2,000 days) were less well-defined in key strategic documents (GQ A.1.2). Having an overarching policy framework or strategy to address obesity/childhood obesity (GQ A.3) did not guarantee action or implementation plans in the areas of health supportive environments, ECEC settings, or health settings. Instead, the language used to describe the causes of obesity and to identify policy action areas were a better indication of policy infrastructure available across these areas. For the most part the initiatives that flowed out from the key strategic frameworks in Areas B–D were focused on increasing skills and knowledge at the family level, whereas the language to describe the structural causes of obesity in the context of policy options was vague, e.g., "partnerships to improve environments." Where clear language was used to identify specific areas (e.g., food advertising) as contributing to obesity in key policy documents, specific policies to address the social determinants of health and health supportive environments were more likely. Less than half of jurisdictions had statewide funded programs to support food and physical activity environments and curriculum in ECEC services (GQ area C.1). While antenatal care and child health services/universal checks were present in all jurisdictions (GQs D.1.1, D.2.1), sub-elements within these areas were less prevalent. Additionally, programs aimed at obesity prevention across the first 2,000 days were limited (GQ D2.2.2). The limitations of these areas followed workforce capacity considerations such as training and resources (GQ area D.3). Policy mapping results were tabulated and ranked, as shown in **Table 2**. A one page summary and the full policy mapping

TABLE 2 | Policy mapping tabulated results, by Health Promotion Model type.

Area	Guiding questions	Local Government				Local health network			
		ACT	SA	Vic	WA	NSW	NT	Qld	Tas
A. Governance and leadership									
A.1 Leadership	A.1.1 Has childhood obesity prevention been identified as a priority by leadership?								
	A.1.2 Is there an overarching policy framework, or a series of key policies or action plans to guide initiatives for the early prevention of obesity in childhood?								
	A.1.3 Does public health legislation include prevention/health and wellbeing?								
	A.1.4 Are their statutory grant-giving bodies with a remit to fund prevention-related community projects?								
A.2 Partnerships	A.2.1 Are partnerships across government noted in "key policy" identified above?								
	A.2.2 Are there formal mechanisms for collaborative exchange across sectors?								
A.3 Equity	A.3.1 Do the key policies identified outline the structural causes of obesity?								
	A.3.1a Do recommendations for action address these structural causes?								
	A.3.2 Are target populations, with higher risk of developing obesity, identified for additional support?								
B. Environments in which we live									
B.1 Health supportive environments	B.1.1 Do planning policies orientate built environments toward principles of active living?								
	B.1.2 Are there investments for public infrastructure (e.g., footpaths or bikeways) to encourage being active?								
	B.1.3 Are there food/nutrition policies aimed at ensuring a nutritious, affordable, accessible food system?								
	B.1.4 Are there programs to support vendors to improve food offerings in food outlets (restaurants, cafes, take-away, vending machines)?								
	B.1.5 Is nutrition information at food outlets (menu board labeling) required by legislation?								
	B.1.6 Is there engagement with food retail (supermarkets, grocers, corner stores, etc.) to reduce the availability and promotion of discretionary choices in-store?								
	B.1.7 Are local governments empowered to encourage health-supportive environments?								
	B.1.8 Are there any initiatives to reduce exposure to the marketing/promotion of discretionary choices in:								
	B.1.8a out-of-home advertising within government control?								
	B.1.8b healthcare settings?								
	B.1.8c other government-controlled buildings/parks?								
	B.1.9 Are there policies limiting the availability/provision of discretionary choices in:								
	B.1.9a healthcare settings (for visitors and staff)?								
	B.1.9b buildings, community centers, and parks under government control?								
B.2 Health promotion campaigns	B.2.1 Are there health promotion campaigns aimed at encouraging healthy lifestyle behaviors?								
	B.2.2 Are there health promotion campaigns aimed at developing/supporting healthy food systems and built environments (incl. community-capacity building)?								
C. ECEC settings									
C.1 ECEC settings	C.1.1 Are there support programs for center-based care settings to encourage healthy food provision?								
	C.1.2 Are there programs to support provision of food and physical activity experiences as part of the curriculum?								
D. Health									
D.1 Antenatal and birth services	D.1.1 Does antenatal care screen and manage hypertension, hyperglycemia, appropriate gestational weight gain?								
	D.1.2 Antenatal care within public health services:								
	D.1.2a Do they include nutrition counseling for healthy pregnancy or are there other healthy lifestyle support programs available during pregnancy?								
	D.1.2b Is breastfeeding education free (standalone or embedded into services)?								
	D.1.3 Do maternity facilities fully adhere to the Baby Friendly Health Initiative (based on 10 *Steps to Successful Breastfeeding*)?								



(Continued)

TABLE 2 | Continued

Area	Guiding questions	Local Government				Local health network			
		ACT	SA	Vic	WA	NSW	NT	Qld	Tas
D.2 Early childhood health services	D.2.1 Are there free health/parenting services to support early childhood growth/nutrition (e.g., breastfeeding, complementary feeding, transition to family foods)?								
	D.2.1a Is information to support parents readily available (e.g., phonelines, websites)?								
	D.2.1b Do these include breastfeeding support?								
	D.2.2 Are there healthy lifestyle (education) programs to support families during early childhood?								
	D.2.2a Are target populations identified and actively recruited for programs?								
	D.2.3 Are Supported Playgroups offered for families that need additional support and do they include healthy lifestyle skills?								
D.3 Workforce	D.3.1 Are there training and resources available for health care professionals to support families?								
	D.3.1a Is preconception advice for nutrition and being active provided to prospective parents?								
	D.3.2 Is there a state/territory health promotion…								
	D.3.2a …agency (independent or adjunct to health department)?								
	D.3.2b …workforce (to implement initiatives locally)?								

ACT, Australian Capital Territory; SA, South Australia; Vic, Victoria; WA, Western Australia; NSW, New South Wales; NT, Northern Territory; Qld, Queensland; Tas, Tasmania.

Legend *Policy in place* *Policy infrastructure* *Policy scaffolding* *Policy void.*

results, augmented with quotes from participants, can be found in **Supplementary File 2**.

Policy mapping indicated that no two jurisdictions were the same in their approach to obesity prevention. Policies were eclectic and sporadic, rather than coordinated or long-term. These heterogenous results emerged out of the different health promotion contexts which have developed across Australia. We found that Australian state and territory governments have developed unique authorizing environments for obesity prevention. Across Australia's six states and two territories there were broadly two local Health Promotion Model (HPM) types. These HPMs relate to the eclectic practices of local program delivery, the presence and structure of Local Hospital Networks (LHN) (see **Supplementary File 1.1**), and the extent of involvement from Local Governments (LG).

In the first local HPM, obesity prevention activity is primarily delivered through local hospital or health networks, which link hospitals and population health services across a geographic area (LHN HPM). In the second, health promotion activity is primarily driven through local government (LG HPM). **Table 2** is organized by these two HPM types.

The LHN HPM was typified by NSW and included the NT, Queensland, and Tasmania. In NSW the authorizing environment sat under the Premier's Priority to reduce childhood obesity by 5%. The health department developed a statewide prevention strategy (*Healthy Eating and Active Living*), and the Office of Preventive Health delivered the *Healthy Children Initiative* with settings-based approach (**Supplementary File 2.2**). *Munch & Move* is a program to improve ECEC settings delivered by a dedicated health promotion workforce embedded in health promotion units of the 15 Local Health Districts in NSW. It is the main state-wide early years initiative in NSW. Another program funded by the Office of Preventive Health is the *Get Healthy in Pregnancy* program (a coaching services delivered via telephone and managed by a third-party provider). Under this model, the Office of Preventive Health provides centralized support and strategic direction to Local Health Districts for specific settings and does not offer centralized support for healthy food and built environments.

In 2013 Queensland lost its dedicated health promotion workforce embedded in its Hospital and Health Services (see **Supplementary File 2.4**, GQ D.3.2). It does have Children's Health Queensland, a state-wide Hospital and Health Service aimed at health service delivery for children. However, at the time of mapping and interviews Children's Health Queensland lacked state-wide early childhood programs for obesity prevention. Recent election commitments were made to rebuild the health promotion capacity and a new authorizing environment for prevention was established, including the *Health and Wellbeing Strategic Framework* (27), and Health & Wellbeing Queensland as an independent health promotion agency. Queensland led intergovernmental work for childhood obesity prevention and the development of the national obesity strategy.

The *Healthy Tasmania Five Year Strategic Plan* (28) is guided by the Premier's Health and Wellbeing Council and identifies the early years as a key life stage for health (**Supplementary File 2.6**). Tasmanian approaches to preventive health implementation drew from previous experiences of success at a community level. The Tasmanian participant noted that several initiatives/programs have been running for more than 10 years, including *Neighborhood Houses*, *Eat Well Tasmania*, and *Family Food Patch*.

While historically child health has been more focused on remote communities in the NT, there has been a shift toward whole-of-NT child health services which includes emerging attention toward obesity prevention (**Supplementary File 2.3**). This is supported by the 10 year *Starting Early for a Better Future* (29) strategy. The *NT Nutrition and Physical Activity Strategy* (30) has five objectives including remote food security, healthy gestational weight and an early years focus. NT has the highest proportion of people living in remote areas, as well as the highest proportion of First Nations people. NT Health is working with the Aboriginal Health Forum to develop standardized reporting against national BMI key performance indicators across NT. The Northern Territory and Tasmania have very small local governments, with very limited capacity in some instances to participate in health promotion activity:

> *"There is huge disparity between those local government councils that have got big capacity, versus those that have got little capacity… we've got 29 local government councils for half a million people" (Tasmania)*

The second type, LG HPM, was typified by Victoria, but also included SA, WA, and the ACT. Victoria, SA, and WA have pivoted toward LG responsibility for health promotion, each updating their Public Health Acts, while the ACT acts as both territory and LG. A state public health plan is the primary central mechanism for health promotion work, and LGs are required to develop local plans in response.

Victoria has had a more fragmented public health administrative structure, historically, local government has played a much greater role than in other states (**Supplementary File 2.7**). In addition to the health promotion goals of the *Victorian Public Health and Wellbeing Plan* (31), Victoria's *Early Years Compact* (32) is an agreement between health, education, and LGs to ensure continuity of services across the early years. Local councils are also supported through nine Regional Assemblies by regional arms of state departments. VicHealth is a statutory health promotion foundation that provides structural support to LGs and community health promotion projects. As VicHealth is independent it has the autonomy to be able to take a longer-term view to health promotion, advocate for broad public health actions at the state and territory level, and challenge industries that are harmful to health. VicHealth also runs health promotion campaigns (GQ B.2) aimed not only at personal/family behaviors, but also aimed at changing cultural norms.

Western Australia's *Sustainable Health Review* (33) has underpinned a significant amount of recent and ongoing health system change. The WA *Public Health Act 2016* (34) requires a state-wide State Public Health Plan (Chief Health Officer) and Local Public Health plans (from each local district). The first objective of the *State Public Health Plan* (35) is to enable healthy living (including healthy eating, being active, reducing sedentary time) and is supported by the *WA Health Promotion Strategic Framework* (36). At the time of mapping, LGs were not yet required to develop their local public health plans, although some had already commenced these activities (see **Supplementary File 2.8**, GQ A.1.3). The *Western Australian Health Promotion Foundation Act 2016* (37) merged two grant-giving bodies, Healthway (∼$20 million spend) and Lotterywest (∼$260 million community grant spend):

> *"The two organizations merging together provided some efficiency in terms of a shared corporate governance system, but also had potential to expand the reach and influence of Healthway and its messages" (Western Australia).*

The *SA Public Health Act 2011* (38) established the new health promotion model in SA, requiring LGs to respond to state public health plans. The Act enables partnerships at the local level to connect LG and Public Health Partner Authorities with state entities, e.g., in planning, transport, and environment. Although SA has established strong cross-government mechanisms, the SA participant noted that the most recent state health plan could have gone further to promote a whole of government approach to prevention:

> *"It missed the mark to address the whole government agenda, it's a bit of a gap at the moment" (South Australia)*

SA also recently updated their planning laws, which centralized authority on local planning decisions to state authority. At the time of mapping, there appeared to be little additional structural support for LGs. Like Queensland, SA lost their health promotion workforce in 2013 under a review of health system services (**Supplementary File 2.5**, GQ area D.3). *Wellbeing SA* was being established at the time of mapping, designated to be a health promotion agency within the health department, although without the independence or funding capacity of other similar organizations (e.g., VicHealth, Lotterywest, Health & Wellbeing Queensland).

For both SA and WA their LHNs provide additional health promotion support to LGs. Like Victoria, the ACT has no LHNs (**Supplementary File 1.1**). While the ACT Public Health Act does not specify principles of prevention and well-being, a core role of the Chief Health Officer is prevention:

> *"The Public Health Act tends to be… a bit old school public health… There is still a focus though on protecting and promoting the health of the population as a key role and a statutory function of the Chief Health Officer" (Australian Capital Territory)*

The uniqueness of the ACT as both territory and LG and the absence of LHNs, aligns the ACT more with the LG HPM (**Supplementary File 2.1**). Its *Healthy Weight Initiative* leveraged this capacity to deliver on projects that normally require at least two levels of government (more on this in the next section).

While jurisdictions were similar in the leadership areas under both models (GQ A.1), the LG HPM jurisdictions have more policies in all areas, most notably in the health supportive environments areas (see **Table 2**). Policies and policy infrastructure were more likely under the LG HPM for health promotion workforce (GQ area D.3), universal child health checks and parent support lines/online information (GQ D.2.1),

health supportive environments (GQ B.1), and a stronger emphasis on equity and partnerships (GQ areas A.2–A.3). Policies and policy infrastructure were more likely under the LHN HPM for statewide universal healthy lifestyle programs and targeted programs for families needing additional support (GQs D.2.2–D.2.3), antenatal care (GQ area D.1), and slightly more likely for health promotion campaigns (GQ area B.2). However, these associations are not necessarily causally related.

Health departments in most jurisdictions engage with the strong community not-for-profit sector who have positive community standing to deliver programs or fill service gaps. For example, Nutrition Australia is a not-for-profit health promotion organization with branches in most jurisdictions. In their ACT and Queensland branches, they offer pay-for-service programs into the ECEC sector where neither funding nor health promotion capacity is forthcoming from government. In contrast, the Victorian branch of Nutrition Australia is funded directly by the health department to deliver the *Healthy Eating Advisory Service* (alongside the Cancer Council who deliver the *Achievement Program*) into ECEC settings (**Supplementary File 2.7**, GQ C.1). In Victoria's service model delivery, the health department does not deliver services but funds a mixture of government and non-government agencies to provide services. These "frontline" organizations provide feedback on community needs and contribute to the evidence base used to develop policy in Victoria. Health departments use a range of different ways to report on the progress of policy implementation, presenting an opportunity to contribute to building evidence and justify ongoing investment into initiatives, e.g., Public Health Information Management System in NSW (**Supplementary File 2.1**, area D.3).

Participants noted the use of a range of structural elements to keep health promotion and prevention on the agenda. These included updated public health (Victoria, SA, WA) and planning acts (Queensland, Tasmania, SA) and legislation to include/consider the prevention side of public health and well-being, and the establishment of statutory agencies (Victoria, NSW, Queensland) with a health promotion and prevention remit. Several jurisdictions noted the waxing and waning of mandates to progress prevention policy is influenced by political ideology.

Partnerships that developed through these HPMs were at the local health network or council level and may include local implementation arms of state/territory departments such as transport or planning. This is different to the centralized health promotion work managed by health departments in conjunction with other state/territory government agencies in a more top-down approach. That work tends to focus on strategic partnerships and initiatives at the state/territory or regional level, which is the context for the next sections.

Approaches to Collaboration Across Government Agencies

This study identified many themes and subthemes from the interviews and policy mapping. **Table 3** provides a summary of these themes sorted into enablers and barriers to policy development and implementation. References to the appropriate policy mapping area are indicated throughout the text.

This section explores approaches to collaboration across government agencies, commencing with two brief case studies (ACT, SA) before exploring broader experiences across all states and territories. Consistent enablers were ongoing support from leadership, clearly defined scope, flexibility, shared outcomes and successes, and incremental change. Barriers to collaboration across sectors were perceptions of health "imperialism," limits on leadership, departmental restructuring, and funding or workforce capacity.

The ACT has a well-developed approach to cross-government prevention (39). From 2011 the health department had a mandate from their Chief Minister, who was also the Minister for Health, to undertake several years of collaborative work across sectors, including commissioning research and partnering with academics and non-government health promotion organizations to provide an evidence base for population approaches to obesity prevention. In developing their *Healthy Weight Action Plan* (40) the ACT had multiple discussions across government and invited experts:

> *"…into the room with us. And we talked through [the evidence and]…what people have suggested in terms of their contributions from a Directorate [government agency] perspective and what was achievable and what wasn't" (Australian Capital Territory)*

The key factors identified as helping in this policy development were a clearly defined scope, inviting perspectives from all relevant agencies about what might be feasible or not, and having agencies take ownership of specific policy areas. At the core of implementation was a clear mechanism for collaborative work across agencies, that brought:

> *"…the whole of government together and having really good mechanisms of working across government to achieve big policy outcomes" (Australian Capital Territory)*

Similarly, Health in All Policies (HiAP) in SA adopted a broader whole-of-government approach (41–44). This benefited from significant support from state leadership over an extended period. Starting in 2007, with an opportunity to experiment with policy innovation, was followed by an ongoing mandate to build on their community of practice for over 12 years. The *SA Public Health Act 2011* established partnerships across government (vertical and horizontal) and principles such as the equity principle required by the Act, which also enables the *State Public Health Plan*, create a long-term enabling environment beyond single policy cycles (**Supplementary File 2.5**, area A). This in turn supported developing relationships in an ongoing manner, reflecting:

> *"…an evolutionary change in the South Australian public sector policy group where we've all been learning from each other and incrementally, hopefully, getting better at doing it" (South Australia)*

TABLE 3 | Summary of themes—barriers and enablers.

Enablers	Barriers
Leadership enablers • Provide mandate • Facilitate structural support incl. legislation, strategic oversight, funding • Proactive investment • Ministerial support beyond health	Limitations of leadership • Perception of health "imperialism" • Perception that health is already well-funded • Funding and workforce capacity • No enduring structural support for prevention • Personal beliefs of ministers • Preference for immediacy, visibility
Governance • Flexibility in policy design • Flexible funding considerations • Clearly defined scope • Multi-strategy approaches • Long-term strategies and investment • Creative approaches to policy e.g., use of legal infrastructure (not regulatory)	Governance • Focus on health services/family-directed • Departmental restructuring, workforce implications • Nature of short policy cycles, conflict with long term investment for prevention • Limitations on policy experimentation
Collaboration enablers • Partnership approach, minimize competition • Policy co-production • Commitment to participate (by all parties) and maintaining relationships • Supporting submissions/business cases • Ongoing mechanisms for collaboration to build off existing successes • National funding supports longer-term investment, policy experimentation and sharing	Barriers to Collaboration • *Ad hoc* partnerships • No or limited understanding of other agencies priorities
Discourse • Physical activity initiatives have more positive narratives, e.g., social connectivity, seen as giving people more	Discourse • Nutrition initiatives have negative narratives, e.g., "nanny state" or taking something away from people • Economic rationalism • "Personal responsibility" • Resistance to regulatory pathways
Evidence • Evidence of policy efficacy and impacts across sectors • Policy experimentation • Re-framing narrative to "evidence-informed" rather than "evidenced-based"	Evidence • Attribution tricky • Trend toward single initiatives focus on the individual/families
Economic • A place for well-being • Liveability, population growth • Food tourism	Economic • Industry influence
Other • Public acceptability	Other • Poor communication with the public • Hyper-focus on obesity narrative

This authorizing environment, over time, changed public sector culture toward collaboration. If the policy workforce tends to stay in the public sector, even as they move across agencies, it enriches these networks over time—although this may be more possible in SA with a smaller bureaucracy (like the ACT) than other jurisdictions:

> *"Most policy people… they might move around [the public sector] …but they don't leave it" (South Australia)*

With a mandate, SA were able to develop their own HiAP methods appropriate to an Australian context over time, such as Health Lens Analysis and 90-day Projects (**Supplementary File 2.5**, area A). They took the view that starting with a determinants approach opened up the dialogue with other government departments by making opportunities for alignment more explicit and:

> *"… working with them in ways that respects their understanding and their ways of knowing and their evidence approaches… The co-design methodology, the shared agenda, the shared responsibility, the finding of common solutions acceptable to all, is the cornerstone of our approach" (South Australia)*

While many jurisdictions supported the principles of HiAP several noted barriers to using the approach, such as its time-consuming methods. They also noted the language appears to preference health which may put-off other agencies they are trying to engage, two jurisdictions referring to their own processes of collaboration as HiAP "by stealth" (WA,

ACT). SA recognized that HiAP has a different meaning in other jurisdictions:

> *"…for South Australia people know what that means in the policy world. So the understanding of what it is and how we work precedes the name" (South Australia)*

Elements identified for successful engagement across government include having a mandate from leadership and the provision of concurrent structural opportunities to undertake the work. These include long-term strategic policies (Queensland, WA, ACT), Public Health Acts which ensure the long-term maintenance of a health and well-being mandate (Victoria, SA, WA), and a dedicated health promotion workforce (NSW). No jurisdiction had all of these elements at the time of mapping.

Participants noted barriers to engagement with other sectors included the perception that health already has a lot of funding to deliver on their core business and health's "imperialist" reputation (based on historical context). These barriers can be overcome by taking steps to understand the priorities of those agencies:

> *"we take that whole government lens, without being health imperialistic… actually asking people, 'What do you guys do?' And then assessing where there are elements of co-production that they may not have been aware of…" (Australian Capital Territory)*

Informants from all jurisdictions felt that it was the role of health departments to make connections with external partners to prevent obesity. However, as their capacity to do so can be limited the default becomes *ad hoc* relationships or negotiating to the point where strategies are developed but initiatives not implemented (and an expectation that other agencies will take the lead). Participants noted that health departments were clear on the actions needed, and which departments were responsible, but have neither the authority nor the capacity to lead other agencies. When health departments do have capacity to seek policy alignment with other sectors, participants noted elements that supported success. These included minimizing competition between agencies and taking pro-active investment for capacity building. Partnerships developed out from offering support, identifying common ground, working on small projects, developing good will, maintaining relationships, and co-defining problems and solutions. This process of alignment supported the sustainability of cross-government relationships by finding solutions that both appease "the hierarchy" and focused on shared outcomes:

> *"So that means that the agencies that we partner with have to be prepared to put people around the table in a consistent way and we have to listen to them… it doesn't mean there's not tension, but it's generally characterized with positive outcomes" (South Australia)*

It also means being creative in filling some of the capacity gaps in other sectors, for example funding positions in other agencies to ensure a health lens is included in policy formation and implementation. Study participants highlighted some examples such as Victoria funding health promotion positions in LGs during the *Healthy Together Victoria* initiative. The ACT funds an official in education to act as a health-education nexus, and Tasmania has a HiAP-trained health official seconded to contribute to liveability projects with the Department of Premier and Cabinet. Other examples were given of health providing capacity support for funding:

> *"You need to apply quite a lot of ingenuity to get things done… We will sometimes partner or provide letters of support, to other agencies (government, NGOs, research groups), when it comes to funding submissions…" (Western Australia)*

> *"So how can we support each other even in business cases and submissions to government and things like that, to do things with mutual benefits" (Australian Capital Territory)*

Some participants also talked about utilizing different parts of the health department to engage in different activities in order to maintain relationships, by:

> *"…seeking mutual gains – the 'carrot' approach… [however], where a mutual gain outcome is not possible… [it] is not our role [to push for an outcome] as this work would compromise our positive relationship. So, we need other players in the health department to play the 'stick' role" (South Australia)*

Some jurisdictions (ACT, SA, WA) noted other sectors initiating engagement with health when reviewing or updating their own high level policy frameworks in recent years (GQ A.2.2). This indicates that cross-government work is being considered and there is a growing willingness to harmonize strategies. Examples include harmonizing active travel policies with emissions reduction targets for climate change (ACT) and reducing traffic congestion (ACT, NSW, WA, Victoria), and planning legislation updates (Queensland, SA, ACT) were developed in partnership with health. While collaboration on prevention is desirable it is not core business for most agencies so when funding contracts, whole of government work is unlikely to continue in the absence of structural support such as the methodologies undertaken in SA and ACT (GQs A.1.2, A.2.2), or public health acts that embody partnership principles (SA, Victoria—**Supplementary Files 2.5, 2.7**, GQ A.1.3).

Childhood obesity is widely recognized as a public health problem, requiring collaboration across sectors to implement "multiple strategic approaches" (Tasmania). However, the specific mix of interventions and investments needed to address it are not yet known:

> *"Determining the dose, scale, volume and mix of a variety of types of interventions… remains a challenge" (Tasmania)*

While the role of environments in obesity prevention are becoming more accepted, where and how to act is less well-understood. Participants noted the challenges in pursuing environment policy where the evidence was less clear about how to translate or scale up in different jurisdictional contexts or making the business case for economic investment:

"It's also quite difficult to make some of the economic arguments around it because attribution is so challenging" (Australian Capital Territory)

"There might be some windows coming up soon, but we probably need a little bit more evidence from where other places have tried to do this sort of work" (Tasmania)

The next section explores the key components of health supportive environments through the lenses of physical activity and food/nutrition.

Health Supportive Environments

The themes that emerged about policy development and implementation for health supportive environments were the importance of leadership beyond health, the interplay of positive and negative discourses about physical activity and nutrition, and the influence of industry. Successful strategies took a long-term multi-strategy approach, building upon successive policies and looked beyond single strategies aimed solely at parents.

By promoting the mental health benefits and social and community connectedness, and its impacts on learning, rather than a focus on an energy balance or physical fitness alone, physical activity policies have gained more traction with departments beyond health, notably education, planning and transport (active living/transport features in most jurisdictions).

The promotion of the social benefits of an active population and environmental considerations (such as creating and protecting green space), influenced Queensland, Tasmania, ACT, SA, and WA to add broader principles of health and well-being and "liveability" to their planning laws. For planning:

"…terms like liveability and wellbeing are big important issues there. People would rarely think about obesity though, outside of Health" (Queensland)

"In the Act… developers, for example, have to address the active living principles in their application… So yeah, walkability and liveability are key considerations" (Australian Capital Territory)

In SA, the impact of recent changes to the Planning Act on health will depend on new compliance rules under development at the time of this study. SA health and environment departments were partnering to support the planning department in developing compliance rules to support healthy built environments, in turn supported by Cabinet. However, this process came with resistance from other players in the built environment:

"Well, industry is lobbying, of course, the government. The Department of Planning is drafting the guidelines, so we are consulting with them. We're trying to help shape and inform the way they do it, but they've got lots of needs to balance… And we're working really hard (and to some small success) to increase the focus on 'healthy liveable neighborhoods'… The work we do with the Environment Department is… really about increasing the community's re-connection with nature and open green space… So there's tension and that tension is being played out here, but the Environment Department and the Health Department are working together to present a united voice to the Planning Department" (South Australia)

A study was undertaken in the ACT that demonstrated the connection between physical activity and academic outcomes in school (GQ B.1.1). This supported engagement with education about physical activity and alignment with the national curriculum. However, this alignment has not driven similar approaches to ECEC settings (GQ area C.1). The ACT also commissioned research to look at both physical activity and food environments, they:

"…saw some evidence of effects, particularly in the physical activity space, but in terms of nutrition and… the food environment, there was really nothing, the best we can hope for there was sort of 'promising' things as evaluated by them" (Australian Capital Territory)

The physical activity evidence was another lever that made engaging with other agencies more straightforward. The limitations of evidence for food environments were an extension of the limitations in government monitoring of food environments. The issues raised with the availability and use of evidence was a recurring theme, explored further in the next section.

Some study participants noted that it was politically easier to promote physical activity because of positive messaging attributes—being active "gives" you more—whereas a lot of the messaging about nutrition comes across as restricting people. The high attribution to personal responsibility and a concurrent concern about being perceived as infringing on personal choice (i.e., "nanny-state" approaches) can result in policy choices regressing toward personal/family skills and knowledge unless efforts are made to gain public interest:

"A lot of those things by default can come back to people, knowledge and skills" (Queensland)

At the same time, advocates for the food and advertising industries can influence politicians across multiple sectors, and interrupt efforts to act in the food environment, especially when less "scientific" evidence is available. Food manufacturing and the head offices for food retail are limited to two or three jurisdictions, influencing how policy makers act:

"I think for the NT because we're a small jurisdiction and we don't have big manufacturers, we're not bombarded as much, as such. So we don't have that pressure they have in other jurisdictions" (Northern Territory 2)

"We probably don't have the same issues that Victoria and New South Wales have, in that we haven't got a big commercial manufacturing sector, that's constantly lobbying our government" (Tasmania)

Despite these barriers, there are examples of leadership in food environment policy. The ACT and Victoria have policies to remove all promotion of discretionary foods and drinks from

government-controlled settings (GQs B.1.8b-c, B.1.9). The ACT has enacted policy that prohibits discretionary foods and drinks from their out-of-home advertising assets on their bus network, and at the time of mapping Queensland had announced a policy to prohibit discretionary foods and drinks from all government-owned assets (GQ B.1.8a). For the ACT, the transport minister announced the decision to remove discretionary foods and beverages food from public buses, a policy which was supported by Health to implement. It was:

> "*…relatively out of the blue … And obviously we've had good outcomes in that people [department revenue or advertising companies] haven't lost money so the world didn't explode because we don't advertise [fast food]… And I think we should look to extend it, frankly, to other modes of travel" (Australian Capital Territory)*

Key to the policy success (and permanence), was monitoring the potential fiscal outcomes and generating evidence that the policy did not cause a net loss to the transport department. Other jurisdictions note hesitancy and taking a slow approach in the out-of-home advertising policy space. Participants in different jurisdictions noted that barriers to this policy lever include the perception that a non-health agency may lose revenue from advertising on their assets (usually transport), seemingly unaware of the evidence available from the ACT, and hesitancy to implement a policy that might have negative public blow back:

> *"[The concern is] … the transport department may temporarily lose funds if they do a lot of advertising of unhealthy food and drink on public transport vehicles and bus stops… I think it's early days in this space" (South Australia)*

> *"…the government probably wants to see how [the introduction of a ban of alcohol advertising on public transport infrastructure] plays out before it looks to expanding that to junk food for instance" (Western Australia)*

In the ACT, it was the cross-government mechanisms and supportive policy environment that allowed the expansion of healthy food availability and promotion policies from health and school settings to all government buildings and assets across the ACT (GQs B.1.8–B.1.9). By starting with health and education sectors, using consistent criteria, and offering support through the ACT Nutrition Support Service (developed and delivered by Nutrition Australia ACT, a not-for-profit), it gave suppliers and vendors an opportunity to grow to meet a new food supply demand, and then expand into other government settings. It also provided opportunities for businesses to expand their offerings more widely in the community, and for health to establish partnerships with business representatives and to co-create evidence of economic viability. At the same time the partnership with Nutrition Australia ACT established an ongoing workforce who specialize in partnering with businesses to improve their food offerings, which carried over to the *Healthier Choices Canberra* (GQs B.1.4, B.1.6) program:

> *"[It] has unbelievably popular with businesses… We have relationships with the Canberra Business Chamber through the… program and that has been amazingly useful and beneficial in terms of being able to bring businesses along and really getting them to see themselves as a partner in establishing that there is in fact a market" (Australian Capital Territory)*

Some programs exist to support better stocking practices and promotion signaling in local food retail (NT, ACT), or to support the sport and recreation sector to establish appropriate sponsorship (i.e., not from fast food) while maintaining their capacity to attract funding (ACT). Support for local stocking practices in food retail can be very different for urban vs. remote communities. While in the ACT this included using information tags on products to promote comparable healthier options in-store, in remote NT communities it can be around the cost of healthy food and making sure appropriate infant foods are available at all (**Supplementary Files 2.1, 2.3**, GQ B.1.6).

Support for foodservice outlets (GQ B.1.4) included engaging with training institutes to build capacity among the hospitality workforce (ACT, Tas) and engaging with businesses to develop healthy food options on menus (ACT) or children's menus (SA). Take away food outlets in remote areas have been flagged as a potential element to increasing rates of obesity and chronic disease in some remote communities in the NT:

> "*Take-away stores are becoming more prevalent and affecting the local food environments. With longer opening hours than remote stores, some concerns have been raised about the potential link between increasing obesity and chronic disease in remote areas with increased take-away options" (Northern Territory 2)*

Underlying the development and implementation of prevention policy were some key political drivers and levers, explored in the next section.

Key Political Drivers and Levers

The key political drivers identified by study participants included funding, a deregulation agenda, economic growth, and positive perceptions of the government by the public. Levers included creative policy experimentation, positive framing, and community engagement. Some participants noted while external funding from the Commonwealth can enable major investment into obesity prevention initiatives, its withdrawal can damage structural support especially in jurisdictions with less resources.

Key economic drivers, such as funding changes within health departments, influence the approaches taken to achieve long-term outcomes. While having supportive departmental leadership is essential, changes to funding can incapacitate the workforce to deliver policy outcomes, e.g., defunding the health promotion workforces in SA and Queensland (**Supplementary Files 2.4, 2.5**, GQ D.3.2). Health departments undergo restructuring often which has implications in terms of loss of corporate knowledge and relationships within and beyond the health department. It takes time to build up a community of practice for preventive health work and requires an authorizing environment. While the prevention of obesity was noted as a priority in all jurisdictions health departments,

participants described that the level of funding attributed to prevention (compared to "frontline" services) and workforce capacity (e.g., due to restructuring) reflected that it was less urgent than other priorities.

Participants noted the barriers to taking a legislative approach under a broader deregulation agenda:

> *"...the whole regulatory impact statement work, is to distill things [each single initiative] down to, 'Well, what is the evidence that this will make a difference?'" (Tasmania) [original emphasis]*

When faced with resistance to regulatory approaches to prevention, departments can be creative in circumnavigating the regulatory framework ideology to normalize health-supportive environments. These include using procurement policies to meet food standards in government-controlled settings and contracts with companies who sell advertising space on public assets to remove discretionary choices advertising—both using legal infrastructure to modify food environments.

In response to this—and their own unique circumstances—Australian states and territories take quite eclectic and occasionally experimental approaches to obesity prevention. Many note that what is missing is providing adequate funding to learn from natural experiments to find "what works" in different contexts:

> *"…doing 'safe-to-fail' experiments… you throw a lot of small amounts of money out to see what comes up from the grass roots and where the strengths are. Then, you can start to play to community strengths… [It's] a more creative approach to [explore] what the mix of interventions that we need might be" (Tasmania)*

There are a lot of different types of evidence used in policy (45), and its use in obesity prevention is complicated. While scientific evidence is valued by policy elites, it is not the only factor taken into consideration and there are evidence gaps about what works best especially for physical activity and food environments. Most health officials are acculturated to think in terms of "evidence-based practice," which is appropriate for clinical and acute health care needs. However, this study found many participants were changing evidence narratives, referring to "evidence-informed" prevention policy making. This was found to be a more inclusive in considering a broader policy context:

> *"…there's a lot of different ways that we describe evidence" (Victoria)*

This approach includes peer-reviewed literature but also respects different forms of evidence, including: community voices, personal and practitioner experiences, informal process evaluation to demonstrate impact of programs, using case studies to develop workforce capacity, international consensus (e.g., the *WHO Ending Childhood Obesity Report*), policy benchmarking (e.g., www.informas.org), and commissioned research/scoping reviews which identify "promising" interventions to make the case for policies aimed at built and food environments. It can also include the experiences of other departments and leveraging off routinely collected data to develop policy and monitoring systems for policy experimentation.

Participants discussed leveraging economic growth aims for health and well-being aims. For example, the concept of "liveability" is emerging as important in the planning sector. It presents an opportunity for a determinants approach to be taken to influence policy decisions about social and affordable housing, public transport and services accessibility. Liveability intersects with smaller jurisdictions seeking to increase their populations (to encourage economic growth) by promoting liveable neighborhoods (**Supplementary Files 2.5, 2.6**). Food tourism is another area which can be leveraged to progress healthy environments, especially in SA and Tasmania. For example, in Tasmania there is political appetite for supporting tourism, because of its positive impact on the economy. The *Eat Well Tasmania* campaign has leveraged off this appetite to engage with primary producers and retailers to develop Tasmania's local food culture (**Supplementary File 2.6**). Additionally, they have worked with training institutes to build the capacity of the food service work force, impacting on the local economy, and making healthy affordable food available locally:

> *"There is quite an interest that is evolving with the food culture thing, at a whole government level. … because tourism is a major economic driver, but if you make it available for tourists, you're also going make it available for the local community. We're trying to intersect with the tourism sector… [and] the primary producers" (Tasmania)*

An identified barrier to successfully make the case for investments for long-term population level interventions, is the political driver to demonstrate policy success within short political/election cycles. While some jurisdictions identified policymakers are beginning to see the political value of investing in long-term strategies, that prevention is a "marathon not a sprint" (ACT), there are many barriers to securing ongoing support and keeping prevention on the agenda:

> *"I think some politicians recognize there may be votes in being committed to longer term agendas" (Tasmania)*

Participants noted a political preference toward immediacy (being able to show what actions are being taken now), over longer-term actions such as legislative changes. This preference for something visible and fast can override the value of evidence:

> *"The experience of just making something happen fast and for it to be visible, can preference what is evidenced-based practice" (Queensland)*

This preference for visibility reflects a culture where policies and programs aimed directly at families as recipients are perceived by policy makers as having a higher value than policies aimed at addressing determinants of health and the food and physical activity environments. This culture is influenced by political leanings:

"A political environment can influence how much is focused on individual responsibility, versus more community collaborative collective impact." (Tasmania)

Decision makers are influenced by a range of factors relating to personal and political party ideology, and perceptions of public value. Senior officials respond to their ministers' needs which are influenced by industry, stakeholder, and community group representatives who speak to the interests and portfolios of politicians. Having a strong mandate (e.g., NSW Premier's Priority) represents an opportunity to influence ministers across multiple sectors, however, it is limited by the ideological constraints of "personal responsibility," a deregulation agenda, and economic growth. The presence of economic rationalism is strong on both sides of politics, and presenting a business case for prevention across a system is trickier than tapping into lesser interests of ministers:

"…politicians of the day have particular issues that they are specifically interested in, perhaps because stakeholder groups have come in and spoken about it, or they've heard it through their interactions with the Victorian community" (Victoria)

The potential influence policy makers may lay in approaches to engagement with the public. Study participants had divergent views about the way obesity prevention is/should be portrayed to the public. Some cited concerns over the consequences of stigma relating to public health messages, relying too heavily on telling people *what* to do (rather than *how* to), or the use of non-health settings (such as schools) to monitor childhood obesity prevalence:

"Obviously, we need to be able to track trends in obesity over time… tick yes, that needs to happen. Is it about weighing every child in school? I'm not sure. Then, how do you manage that feedback to the parents… in a way that's sensitive and appropriate?" (Tasmania)

"I think it's far more about having something that people can understand and engage with. When you start talking about physical activity or sedentary behavior or the nutrition environment, [people] will immediately switch off and think that it's like the nanny state" (Australian Capital Territory)

Some jurisdictions identified problems with historical approaches taken by their own departments, such as an overt focus on obesity, rather than its causes. Those participants willing to learn from past misjudgements emphasized the need for public engagement to focus on environmental causes and desired outcomes, such as well-being or social connectedness, to overcome the potential stigmatizing impacts of obesity policy:

"We used the word obesity and that was wrong… I think labeling is really important and not creating a stigma around that. Because we know in South Australia that people in our poorest communities are... you know, over 40% of the population of poor suburbs are big compared to 20% in our wealthiest suburbs. So 'being obese' is normalized in that community… And they're not necessarily in control of that" (South Australia)

DISCUSSION

This study provided a snapshot of obesity prevention policies which impact on the first 2,000 days across Australian jurisdictions. It found that no Australian state or territory had policies in place against all the guiding questions, derived from international consensus on actions for the prevention of obesity in childhood. It also found eclectic policy practices between the jurisdictions, influenced by the unique local contexts in each jurisdiction.

Support Services, Early Childhood Settings and Environments

Health Services/Settings

Standalone obesity prevention programs for pre-conception, during pregnancy, or supporting parents of young children were limited across Australian jurisdictions. The only two guiding questions where all jurisdictions had policies in place—antenatal care and universal child health checks—were also two areas with clear national guidelines (46, 47), suggesting the utility of national policy frameworks.

There are opportunities to extend the support offered in community health settings or telephone-based services to include health promotion messages aimed at obesity prevention. However, the contextual option for such programs is likely to sit with upskilling an existing workforce such as those within universal well child programs and child and family services. Within that option, the maldistribution of the health workforce between urban and rural settings—and its association with poorer health outcomes—needs to be addressed to ensure equity (48). Studies have shown workforce interest in obesity prevention (49), including rural communities (50), but health promotion workforce investment needs to be sustained alongside strong policy infrastructure such as that for the *Key Ages & Stages* program in Victoria. Alternatively, states/territories can tap into existing third party provided telephone-based programs (such as the *Get Healthy* suite of programs). Proportionate or progressive universalism applied to healthcare services is likely to benefit those experiencing deprivation the most (51).

Early Childhood Education and Care Settings

Three jurisdictions had programs to improve the food and physical activity environments and curriculum in ECEC settings. An umbrella review (52) on the characteristics of successful ECEC interventions for nutrition found that ECEC staff need external support to achieve and maintain healthy eating initiatives. Successful interventions were multi-component (i.e., nutrition, physical activity, child development, etc.), multi-strategy (e.g., educator training to increase skills and knowledge, educator feeding styles, menu planning, positive feeding environments, policy support, etc.) and included parents (52).

While ECEC settings are a key setting for child development and equitable health outcomes (53), educators face high burn out due to workload and limited remuneration (54). Those seeking to promote health within ECEC settings should understand the

different roles of those within the sector (e.g., center directors, educators, cooks, etc.). Furthermore, national or statewide policies that seek healthy food provision in ECEC settings must also be supported by policy infrastructure for equitable food access, especially in regional and remote communities. There may be some economies of scale gained from the national harmonization of health promotion policies to support the sector, such as harmonizing state/territory nutrition guidelines which are currently not aligned across Australia (10).

Studies in Australia (55) and the UK (51, 56) confirm interventions in ECEC settings are effective in preventing obesity in the early years especially when partnered with broader community capacity building focused on children in socially deprived areas. However, as with prevention programs aimed at families (14), these too have "fade out" effects in later childhood (51).

Environments

The ACT and Victoria had the highest coverage of policy infrastructure for health supportive environments. Australian overweight and obesity data from the 2017–18 Census reflects that Victoria has the lowest prevalence of childhood obesity in Australia, this had decreased since the previous Census (2014–15) (57). Research data from a Victorian community obesity prevention program, *Romp and Chomp*, showed the effectiveness of community-wide interventions in preventing obesity in the early years (55). Data from the same Census shows that ACT residents (adults) are healthier than other Australians (58). However, it must be noted that the ACT population is generally more advantaged, the jurisdiction is geographically small with a budget less constrained by the disadvantages of population dispersal than other jurisdictions, and the ACT government is enabled to undertake both territory and LG functions. Those features make the ACT public sector quite agile compared to the other states and territory.

Environments are physical sites where systems of power (racism, sexism, capitalism and inequality) are exchanged from society to the individual/families (53, 59). Environmental policies improve the social/individual interface to compensate for inequality, they can exhibit significant cost savings in the mid-to-long term (13), and they can eventually change the norm (60). Such interventions are likely to impact on the wider determinants of obesity across the life cycle and would support any intervention aimed at the family or ECEC settings level.

Two interrelated neoliberal political drivers impacted on the likelihood of policies trying to change food or physical activity environments. Policies perceived to impact on personal freedom, e.g., the removal of sugary drinks from government settings, are bound up within public sector reform to reduce the impact of regulation—the "deregulation agenda" (61). Often referred to as "nanny state" in media discourse (62), implementing regulatory measures require the development of a business case assessed through the national Best Practice Regulation framework. The driver to avoid appearing to be a "nanny state" acts as an ongoing constraint in this policy space and has been noted in other studies (63, 64). This study found several examples of jurisdictions using legal frameworks (procurement policies and contractual agreements), but not regulation, to improve health supportive environments—thus circumventing the deregulation agenda. For those processes to succeed, ministerial support (including beyond health) was required.

A focus on growing the economy was the second political driver. While this driver can act as a constraint in this policy space, i.e., it is difficult to progress policies which can be argued as posing a risk to the economy or jobs, it also represents an opportunity. The increased attention to policies which impact on "liveability" and "wellbeing" are linked to efforts to make an area seem desirable to live and encourage population growth. Many jurisdictions are leveraging these terms (rather than "health" or "obesity") to partner with multiple agencies across government (e.g., planning, communities, environment, transport, and economic development) in addition to LGs and the private sector to progress healthy environments. The co-benefits for liveability with public health, social inclusion, environmental sustainability and the economy "are now well recognized by urban policymakers internationally" (p.1) (65). Currently, although many planning policies aspire toward "liveability" the reality is they are not being implemented. A recent study found that despite the "policy rhetoric championing urban liveability" (p.11) (65) no capital city in Australia performed well on the domains underlying healthy, liveable neighborhoods**.** As such environments continue to be a space requiring more leadership in Australia.

Local Health Promotion Models

The findings of this study show that both LG and LHN HPMs can enable programs and initiatives for the early prevention of obesity in childhood. For example, NSW and Victoria—LHN and LG HPM, respectively—are very similar in their settings-based approaches. They both had ECEC programs and both states had invested in large trials for obesity prevention programs in the early years with additional national research funding support. At the time of writing, both states were working on strategies to scale-up these interventions into existing services state-wide.

Additionally, this study found that jurisdictions with the LG HPM were more likely to have policies for health supportive environments. In Australia, LGs have been identified as a key target for action as "they manage many settings where children congregate" (p.356) (66) as well as local planning considerations for health, e.g., enabling employment opportunities, food access and walkability. The findings of this study suggest the LG HPM may have more capacity to engage with environments at the local level than seen in the LHN HPM. As their primary purpose is to deliver health services, LHNs may have trouble divorcing from a (service delivery or) hospital-centric point of view.

Given the division on power between federal, state and LGs in Australia there are constraints on local governance powers, which sit within their state/territory legislative framework—they are "creatures of the states" with no constitutional autonomy (65). The main independent source of revenue for LGs are property/business owner rates, user charges, and fines (67). A study found these constraints heavily

impeded NSW LGs ability to implement international recommendations for nutrition interventions at the local level (67). Investment by some jurisdictions in systems approaches at the local level in Australia (68) are subject to the overarching strategies of the state government of the day. There may be multiple political cycles where statewide prevention strategies "miss the mark" to enable systems approaches at the local level.

The *Public Health Act 2016 (WA)* is contributing to LGs higher involvement in obesity prevention activities, although there is evidence that LGs have been participating in such activities for over a decade in WA (66), and many Sydney LGs (in NSW) also participate in health promotion policies with no overarching central government structural framework (67), indicating that LGs are interested in health promotion activities. A study investigating Victorian LGs experiences with health promotion found they held a stronger affinity with addressing the social determinants of health (enabled in the Victorian public health Act) than with aligning to the state priorities within the *Victorian Public Health and Wellbeing Plan* (69). This indicates legislative elements of public health or planning Acts may galvanize LGs in the prevention space more so than statewide strategic policies.

We can look to other countries to learn lessons for LG involvement in prevention initiatives. In 2013 the UK transferred the responsibility for public health from the National Health Service to local authorities (local government), taking a clinical mindset with it (70). This included mandatory and non-mandatory services such as obesity prevention. Since the adoption of austerity measures from 2010, local authorities have faced significant funding cuts, forcing the prioritization of statutory functions and trade-offs between non-statutory services (56). A recent natural policy experiment found that these funding cuts were incrementally correlated to increases in obesity among children at school entry, where the *Sure Start* program (community based early years health service with additional supportive links to childcare and employment/income for parents) had been defunded as a result of these austerity measures (56).

This suggests that policy should shift toward the constraints on LGs as there may be validity in decentralization. However, there is a risk that requiring LGs to participate in health promotion, including strategies aimed at improving determinants, could "bring with it a cost-shifting, or even legitimization of state or national governments' divestment of some of their responsibility for public health" (p.86) (69). Instead, Australia needs long-term commitment to prevention and investment for the wider determinants of health at all levels of government.

Systems Approaches

Whole of government approaches represent an opportunity to overcome the siloed nature of government agencies. Leadership is required to declare priorities, establish cross-government meetings, and provide the imprimatur to continue. Study participants felt these structures are important, but also sought organizational commitment through maintaining the presence of the same people over time to develop cohesive relationships. The ACT and SA experiences were the accumulation of a range of supportive structural factors that embedded cooperation across sectors and into a range of public sector workforce practices. The success of working across government was tied to (horizontal) collaborative approaches and shaking off "health imperialist" approaches of the past. Policy harmonization can reduce the barriers to collaboration with other sectors by providing top-down (vertical) signaling from leadership as well as structural support.

Although language around partnerships and equity featured in most jurisdictions' key preventive health documents, when it came to specific initiatives to address these areas there was limited policy infrastructure or policy scaffolding to build upon. Three interrelated concepts may help to explain these findings, "short-termism" (70), "lifestyle drift" (59, 70), and "implementation deficit" (71). Policymakers face many competing interests, and the temptation to follow the path of least resistance (22), coupled with the desirability of showing actions and outcomes in the short term are strong incentives for policymakers to focus on lifestyle factors (70).

However, this only explains some of the gap between identified causes of obesity and the implementation of actions. Implementation deficit is the phenomenon whereby the intent of a government is expressed in their policies, however actions to that end are not carried out (71). Lifestyle drift is a phenomenon whereby there is a shifting from interventions aimed at determinants onto individual/family behavior using language such as "empowerment" and "choice" (59). Neoliberal modes of governance inherently reconfigure the responsibility for health and well-being at the feet of the individual (59), which extends to parents in the case of young children. This is not to dismiss the utility of interventions aimed at individual/family lifestyle behaviors (6, 72, 73) or in ECEC settings (52), rather it is to highlight the need to also address wider determinants concurrently (13, 70, 74). Mixed in with lifestyle drift is another phenomenon known as "policy invisibility" (75). As policies move away from families or key settings toward determinants, they lose their visibility. However, they can be made apparent through resource allocation, identifying material impact, and acceptability (public reaction) (75). Interventions are urgently needed from all levels of government and across the public health spectrum (23) between the family, the environments in which they live, and the broader social (76) and commercial (63) determinants of health. Achieving this requires government commitment including the design of governance for implementation by agencies fit for purpose. Partnering with specialized non-government organizations can be beneficial, such as having a specialized workforce, established community relationships, and the ability to be more flexible and meet local community needs. However, these organizations rely heavily on government funding so their workforce is susceptible to the same economic shocks as health departments. Outsourcing what is essentially a government service (i.e., delivering community programs and policies) slowly erodes the responsibility and accountability of government, key features of neoliberalism and short-termism.

Eclecticism and Collaboration to Find the Way Forward

Multiple jurisdictions referred to their processes as "HiAP by stealth" reflecting a key element of eclecticism across Australian jurisdictions—the way a solution or process is represented in one jurisdiction is often not organisationally compatible in another. While the same or similar concepts can (and have) been taken up across jurisdictions, they first need to be re-packaged to fit into ministerial priorities and use language and jargon that makes sense in the local context. Eclecticism in health care can be associated with negative outcomes (77), but it is not inherently responsible for policy gaps. A systems approach to address obesity will never have a "one size fits all" solution and eclectic practices across jurisdictions help to resist oversimplifying the complexity of the ongoing nature of obesity prevention. An opportunity exists to position systems thinking at the forefront of obesity prevention, without rejecting everything that has come before it (21).

In the UK, guidance for LGs notes that they "should not feel constrained to implement only interventions with evidence of effectiveness. The evidence base to tackle this serious issue will only improve if areas try new interventions and then evaluate them" (p.63) (78). The utility of natural experiments has been identified in the literature as an emerging area to generate evidence for population health interventions aimed at health-supportive environments (79). HiAP was a policy experiment, and it took leadership to permit a shift in the ways sectors collaborated for preventive health in SA.

Taking an eclectic approach allows for innovation within and between states but what is needed are better ways for jurisdictions to learn from each other, to share, adapt, and scale up initiatives so they are contextually relevant but still have some consistency across jurisdictions. To achieve this requires a mechanism to facilitate sharing, learning, and adaptation to context. Previous examples of such mechanisms could be found in the NPAPH and Australian National Prevention Health Agency for intergovernmental exchange, and the ACT *Healthy Weight Action Plan* developed good mechanisms for working across government.

The lack of national funding widens disparity between jurisdictions as only those jurisdictions with enough internal funding can continue to provide health promotion interventions if national funding is revoked. Calls for a renewed national prevention agency and reinvestment in health promotion are not new (7, 80). However, this study identified some key elements that such an agency could provide. An agency that facilitates the sharing of ideas and practice-based knowledge across all levels of government, including LGs (67). It could provide a mechanism for policy makers and practitioners to link up with the right part(s) of agencies within and beyond health who share contextually similar circumstances (e.g., rural vs. urban or LG vs. LHN HPMs). It could shoulder the administrative burden that acts as a barrier to collaboration for public servants between jurisdictions, and it could fund "safe-to-fail" natural experiments and use easy and cost-effective measurements to ascertain the elements of efficacy that are context specific and how they can be adapted across multiple Australian contexts. Creating such a learning policy environment allows for the curiosity and experimentation needed to answer "what works" and "for who" with obesity prevention (81).

Strengths and Limitations

To our knowledge, this is the first study to compare policies for the early prevention of obesity across Australian states and territories. The guiding questions used in the policy mapping tool can monitor progress in policy development over time. It must be restated that the tool did not quantify the effectiveness of found policies, a limitation that extends to this study generally. This study sought to capture some of the complexity of obesity prevention policy between Australian state and territory governments, from the perspectives of senior health officials, and it contributes to the limited empirical evidence of "lifestyle drift" [see also (70)]. This study did not seek out the perspectives from senior officials in other relevant departments, as the primary aim was to consider the complexity of obesity policy between jurisdictions, not within a single jurisdiction. However, future research should consider exploring the complexity of obesity prevention policy within a single jurisdiction across more sectors with policy responsibility (or opportunity to implement policies) for obesity prevention.

CONCLUSIONS

The first 2,000 days is a critical period in which to intervene for establishing lifelong habits. However, without concurrent intervention in environments and the wider determinants of health, the positive effects of interventions in family and ECEC settings are likely to "fade out" and therefore not maximize their potential impact across the life cycle. Even within a single country, obesity prevention policy needs to be adaptable to local contexts. The eclecticism undertaken by Australian states and territories provides opportunities to share, learn, and adapt their experiences within and between jurisdictions (at all levels of government) but need funding and structural support to do so.

This study found that senior health officials worked within a neoliberal paradigm. This often resulted in an implementation deficit between the identified causes of obesity in overarching strategic frameworks and the interventions/programs that flow from them. The global disruption of COVID-19 presents an "important window of opportunity to collectively change the system such that communities are able to live with good health, dignity and in an environmentally sustainable way" (53). Eclectic governance structures enable diverse policy responses in Australia. While eclecticism captures this diversity, a national prevention agency has the potential to create a decentralized, innovative, and experimental learning policy environment to enable learning within and between jurisdictions.

DATA AVAILABILITY STATEMENT

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

ETHICS STATEMENT

This study was approved by the University of Sydney Human Research Ethics Committee (2017/507). The participants provided written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

EE developed the study design, undertook policy mapping and analysis (cross-referenced by LW and CR), conducted the interviews with senior health officials and undertook the analysis (reviewed by LW and CR), and wrote the manuscript. All authors contributed to the final manuscript.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpubh.2022.781801/full#supplementary-material

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