Health & Place 91 (2025) 103410

Contents lists available at ScienceDirect

Health and Place

journal homepage: www.elsevier.com/locate/healthplace

A systematic review of measurement tools and senior engagement in urban nature: Health benefits and behavioral patterns analysis

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ARTICLE INFO

Keywords:
Human-nature interaction
Aging
Detection methods
Physical and mental health
Activities

ABSTRACT

The engagement of senior citizens with urban nature has been shown to provide multiple health benefits and mitigate health issues associated with demographic aging. This review utilized the PRISMA methodology to systematically analyze the relationship between monitoring tools, seniors' behaviors in urban nature, and influencing factors. The main findings are as follows: (1) 4 main types, including self-reports, on-site observations, sensors, and third-party data, and 24 sub-types of measurement tools: ranging from questionnaires to crowdsourced imagery services. Self-reports capture participants' awareness of behaviors, on-site observations record various types of behaviors, sensors collect indicators to detect the body's direct responses, and third-party data provide representative behavior data from large samples. (2) 4 categories and 45 types of behaviors: physical and sports behaviors, leisure and recreational behaviors, relaxation, and passive behaviors, social and care behaviors, based on their characteristics and purposes. Physical and sports behaviors are the most common types for the elderly in urban nature, with walking being the most frequently measured behavior. (3) 36 influencing factors: ranging from diabetes risk to balanced meal habits, classified into 4 categories from physical and vitality health to social and lifestyle health. Physical and vitality health are the most affected category, receiving more academic attention. Gardening is identified as having the most health benefits. This review provides a classification of tools and behaviors, and a detailed discussion of future trends in the field. It provides actionable insights for researchers, urban designers, city managers, and policymakers to select the appropriate measurement tool from 24 sub-tools to better understand behaviors of elderly people in urban nature. It can also help them select the right type of behavior from 45 sub-behaviors to investigate in line with their research goals to improve seniors' health and well-being.

1. Introduction

Urbanization and aging are occurring and growing at an unprecedented rate. By 2050, one-fifth of the world's population is expected to be over 60 years old (WHO, 2022) and about 68% of the world's population will live in urban areas (UN, 2018). In this paper, we define seniors as people aged 60 and older. Urban nature, including public parks, street trees, community greenery, and private gardens, is a crucial part of the urban environment, meeting human needs and providing health benefits (Hung and Chang, 2022; Shanahan et al., 2015). It has various positive effects that greatly enhance well-being (Lau et al., 2021) such as life satisfaction (J. W. Zhang et al., 2014), high self-esteem (Pretty et al., 2007), autonomy (Lawton et al., 2017), attentional capacity (Berman et al., 2008) and cognitive capacity (Berman et al., 2012). Urban expansion has led to significant encroachment and destruction of urban nature, and marketization and privatization have intensified the unequal distribution of urban natural resources (H. Kim et al., 2022). Seniors (over 60 years old) are more affected by environmental changes than younger people (18–59 years old) (Cheng et al., 2019; D. Kim and Jin, 2018). Given the increasing number of seniors in urban (Aguome et al., 2024) and the fact that there are fewer urban nature (H. Kim et al., 2022), urban-dwelling seniors are more vulnerable to these impacts. with significant declines in health and quality of life (Dye, 2008; He et al., 2020a). Lack of physical exercise among seniors in urban with higher population density can also lead to social isolation, depression, cognitive impairment, and other health problems (Petersen

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https://doi.org/10.1016/j.healthplace.2024.103410
Received 11 October 2024; Received in revised form 8 December 2024; Accepted 29 December 2024
Available online 5 January 2025

et al., 2015).

Chronic and aging-related diseases are straining healthcare resources in many countries (Tedesco et al., 2017). Insufficient physical activity increases the risk of cancer, heart disease, stroke, high blood pressure, and diabetes by 20%–30% and shortens lifespan by 3–5 years (Hegde and Solomon, 2015a; Nelson et al., 2007; Penedo and Dahn, 2005). The quality of urban nature encourages physical activities (James et al., 2015; Root et al., 2017; Tabatabaie et al., 2019), like walking (Evenson et al., 2013), singing (Cai et al., 2023; Shakespeare and Whieldon, 2018), and square dancing (Zeng and He, 2023), especially in high-density and aging cities. These activities improve physical health (Markevych et al., 2014; Van Puyvelde et al., 2023), like preventing or reducing the risk of cardiopathy (Kardan et al., 2015), respiratory diseases (Alcock et al., 2017), diabetes (Astell-Burt et al., 2014), high blood pressure (Hegde and Solomon, 2015b), and some types of cancers (Demoury et al., 2017), increasing muscle strength, aerobic capacity, balance, and bone mineral density (DiPietro, 2001). Additionally, they can enhance seniors' psychological health and well-being (Lau et al., 2021; Orsega-Smith et al., 2004; Tabrizi et al., 2023; Zeng and He, 2023), such as improving cognitive ability (Y. Liu et al., 2019; Wells, 2000), relieving stress (Hazer et al., 2018), restoring concentration (R. Wang et al., 2020), regulating negative emotions like anger, anxiety and depression (Helbich et al., 2019; Witham et al., 2014), as well as reducing mental disorders (D. Li et al., 2019; Markevych et al., 2014). In addition to their own benefits, some behaviors, such as child care, can enhance family cohesion (Sadruddin et al., 2019).

Currently, many studies utilize various tools to monitor the behaviors of senior citizens in urban nature (Sun et al., 2020a; W. Wang et al., 2023; Zhai et al., 2021). These studies are complex due to diverse objectives, sample sizes, influencing factors, and research contents, creating a need for an objective and accurate assessment of measuring tools. Additionally, most reviews of monitoring tools encompass all age groups (Frost and Murtagh, 2023; Storgaard et al., 2013), whereas seniors differ significantly in the type and intensity of activities compared to younger adults and children (Sallis, 2000). While some papers focus on specific physical activities like walking, sitting, or running (Harris et al., 2013; Zhai et al., 2023), other behaviors are less studied, resulting in an incomplete understanding. In the field of urban nature, there has been no comprehensive evaluation of the pros and cons of different methods, nor has there been an identification of which behaviors are best monitored by which tools or a detailed account of the benefits each behavior brings to seniors. This lack of systematic and comprehensive attention to all types of tools and behaviors underscores the need for a reference standard to choose appropriate measurement tools and behavior types based on specific research objectives.

To address this gap, this paper aims to comprehensively review the relationship between monitoring tools, seniors' behaviors, and influencing factors. The research questions include: (1) What tools can detect seniors' behaviors in urban nature? (2) What are the advantages, limitations, and considerations of these monitoring tools? (3) What behaviors can be detected? (4) How do these behaviors impact seniors' health and well-being? The remainder of this paper is organized as follows: In Section 1, we introduce the background and importance of the research topic. In Section 2, we explain the research methodology and data analysis framework. In Section 3, we present a statistical analysis of existing studies and categorize measuring tools, seniors' behaviors, and influences. In Section 4, we discuss the relationships among these three factors, the advantages and disadvantages of monitoring tools, and the challenges that need attention.

2. Methods

2.1. Search strategy

This systematic review and meta-analysis were conducted following the PRISMA guidelines (Liberati et al., 2009) and we refer to the checklist and flowchart. We performed a comprehensive literature search using Web of Science and Scopus, both of which maintain high quality control standards.

Two researchers independently proposed similar terms according to the three categories of activity, senior and nature. Then, pre-tests were conducted respectively, and terms related to the three categories were collected from the articles. Then, we conducted pairwise combinations and found that the selected articles were broad and did not meet the research objectives. We combine the words in the three categories, and record and replace the words if any words are added and cannot be filtered into the article. Words that affect the selection results are deleted, such as human-nature, and the final search terms are obtained. Our search terms were divided into three categories: (1) seniors-related terms: "seniors," "elderly," "old people," "older adult," or "older people", (2) activity-related terms: "activity," "walking," "gardening," or "behavior", (3) nature-related terms: "urban," "nature," "green space," "garden," "landscape," "greenery," or "park". Variations in British and American English, as well as singular and plural forms, had negligible effects on search results. We focused our search on titles, abstracts, and keywords of journal articles to ensure relevance, without restricting the time period due to our focus on diverse monitoring methods. As our research focus is to explore the behavior patterns of the elderly in the nature of the city, and the impact of behavior on their health, we didn't include some predominantly medical search terms like MeSH.

We conducted a pilot search on December 1, 2023, after which we assessed the scope and quality of the literature and finalized the review protocol. We then summarized the article information exported from the database with excel tables, including title, abstract, keywords, language, etc. The two researchers individually screened the initial 500 papers according to the criteria. According to the comparison of the screening results of two people, the screening criteria are modified to reduce the screening differences. The two researchers went on to perform the following thousand screenings, and by comparing the results, the screening criteria were further refined. Subsequently, according to the perfect screening criteria, the two researchers screened all the articles by themselves, respectively screening the title, abstract and full text as three check links, if there is any objection to the article will be included in the next screening link, in order to reduce errors.

2.2. Selection criteria, screening, and extraction of information

We have developed the following criteria: (1) the paper is in English, (2) the study occurs in an urban natural context, (3) seniors are the primary subjects, and (4) behaviors are monitored in real natural settings.

As shown in Fig. 1, the Boolean search produced 27,018 articles—5342 from Web of Science and 21,676 from Scopus. We were left with 10,750 articles after removing duplicates, 8787 after reviewing types. Two authors independently examined 8787 titles. If the titles are clearly contrary to the screening criteria, they are removed, and if they cannot be determined, they are selected for the next step. 976 after reviewing the titles. More than half of the papers were mainly medical articles focusing on the physical health of seniors, mainly on the influence of microorganisms on physical conditions of seniors, such as metalloproteinase (S.-J. Kim et al., 2009), D-28k-Immunoreactive Neurons (Choi et al., 2009). And the effects of conditions on the behavior of seniors, such as cancer (Suh et al., 2014), Parkinson's Disease (Song et al., 2022), Rheumatoid Arthritis (Yun et al., 2012). Based on the search terms, it is also possible to search for these articles on seniors' neural elements related to physical function, but not relevant to the subject city nature and seniors' behaviors, so they are excluded. We excluded 638 articles based on abstract review, leaving 338. Full-text reviews focused on methodologies and results led to the exclusion of studies lacking relevant methods for monitoring senior activities or the benefits of human-nature interaction. Our final literature pool consisted of 86 papers, from which detailed information was extracted.

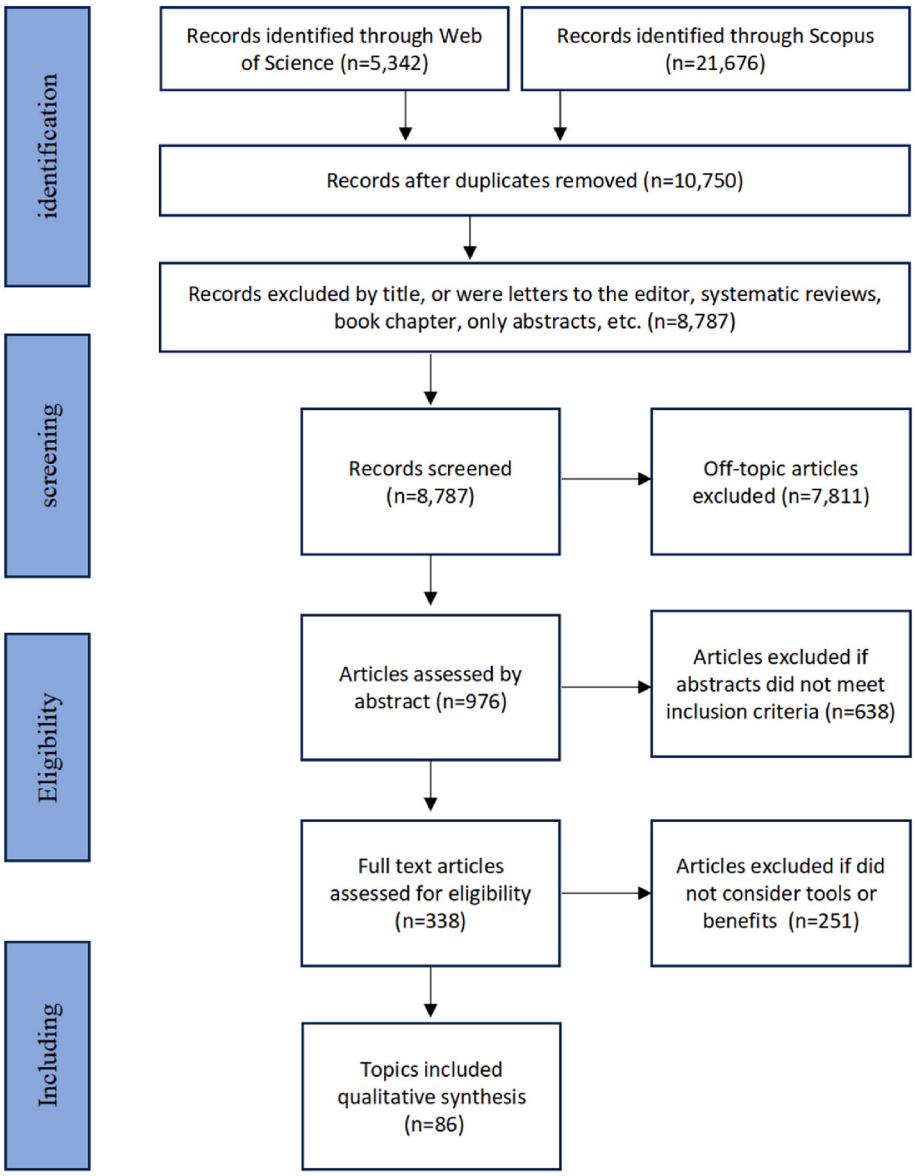
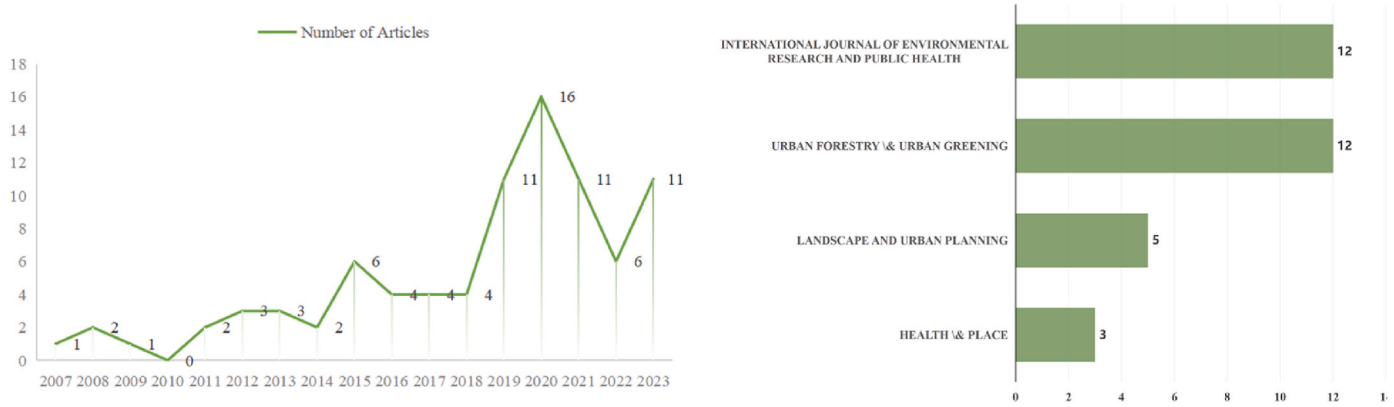


Fig. 1. Flowchart of article selection.



(a) The number of publications per year. (b) Journals that publish articles on related topics.

Fig. 2. The journal publication tendency.

2.3. Bibliography statistics and visualization

Biblioshiny, a module of R Studio software (version 4.3.3), was used for data visualization (Qin et al., 2022). The data, initially in CSV format, was imported into R for analysis. Bibliometric analysis enables comprehensive descriptive insights by examining elements such as authorship, geographic origins, keyword co-occurrence, clustering, and thematic maps. Biblioshiny streamlines the analysis of scientific metrics and delivers visual outputs via its web interface (Yao et al., 2024). The alluvial diagram, created using Rawgraph, an online visualization tool, enhanced the clarity of data flow.

3. Results

3.1. Overview

The 86 papers selected from the 27,018 papers were published between 2007 and 2023. As shown in Fig. 2a, the number of publications has shown an upward trend, with figures in the past 5 years being much higher than earlier years. This suggests a sustained and expanding interest in seniors' behaviors and urban nature.

Fig. 2b shows the journals that published articles on seniors' behaviors in urban nature and the number of articles published on this topic. The most frequently published journals are the International Journal of Environmental Research and Public Health (14%, n = 12) and Urban Forestry & Urban Greening (14%, n = 12), followed by Landscape and Urban Planning (6%, n = 5). These journals reflect a strong interdisciplinary interest in exploring the benefits of urban nature for human well-being. In addition to the 4 journals shown in Fig. 2b.11 other journals published 2 papers each, namely Cities, Frontiers In Public Health, Geriatrics & Gerontology International, Hortscience, Horttechnology, International Journal Of behavioral Nutrition And Physical Activity, Journal Of Transport Geography, Medicine And Science In Sports And Exercise, Plos One, Scientific Reports, Sustainable Cities And Society. Of the 86 papers, Appendix B describes the 25 most global cited articles, including Total Citations, Total Citations Per Year, and Normalized Total Citations.

Fig. 3 classifies themes into four categories based on centrality and density: (1) Motor Themes, which are well-developed and crucial structural themes in research areas; (2) Niche Themes, which are highly developed yet isolated; (3) Emerging or Declining Themes, indicating themes on the verge of disappearance; and (4) Basic Themes, which are general and transversal (Aria et al., 2020; Cobo et al., 2015; Hirsch, 2005; Mühl and de Oliveira, 2022). Studies have linked keywords such as therapy, urban green space, and active aging with horticulture and nature, forming primary clustering themes. This indicates significant attention to the relationship between urban greening, seniors' behavior, and physical health. Emerging or Declining Themes suggest a current research focus on the benefits of large-scale urban greenery over smaller projects like community gardens. Fig. 4 contrasts the chronological order and trend of topics from 2009 to 2023. Since 2015, mental health has become a major focus for scholars, expected to persist. Recently, tools measuring the time seniors spend in urban nature have garnered interest. The inclusion of Hong Kong and South Korea in these studies indicates these regions are frequently used to address aging issues. Appendix C depicts the frequency of terms in abstracts of 86 articles.

3.2. The tools detecting the behaviors of the seniors in the urban nature

Based on the 86 papers, tools were classified into 4 types and 24 subtypes: self-report, on-site observation, sensors, and third-party data (Table 1).

Self-report tools refer to methods where investigators ask seniors to report all forms of behaviors, selecting target seniors in advance. These tools capture participants' awareness of their behaviors (Cai et al., 2023) and their usage patterns of urban nature, including behavior frequency (He et al., 2020b), duration (Witham et al., 2014), forms, and intensity (Storgaard et al., 2013; W. Zhang et al., 2022). Questionnaires, used in 21 papers, represent the largest proportion among all methods, indicating a scholarly focus on detailed evidence to improve age-friendly spaces.

On-site observation is conducted by trained raters using standardized auditing instruments to collect data on participants' behaviors. Tools like The System for Observing Play and Recreation in Communities (SOPARC) and camera gather behavior data across different age groups more quickly than manual counting. However, analyzing and

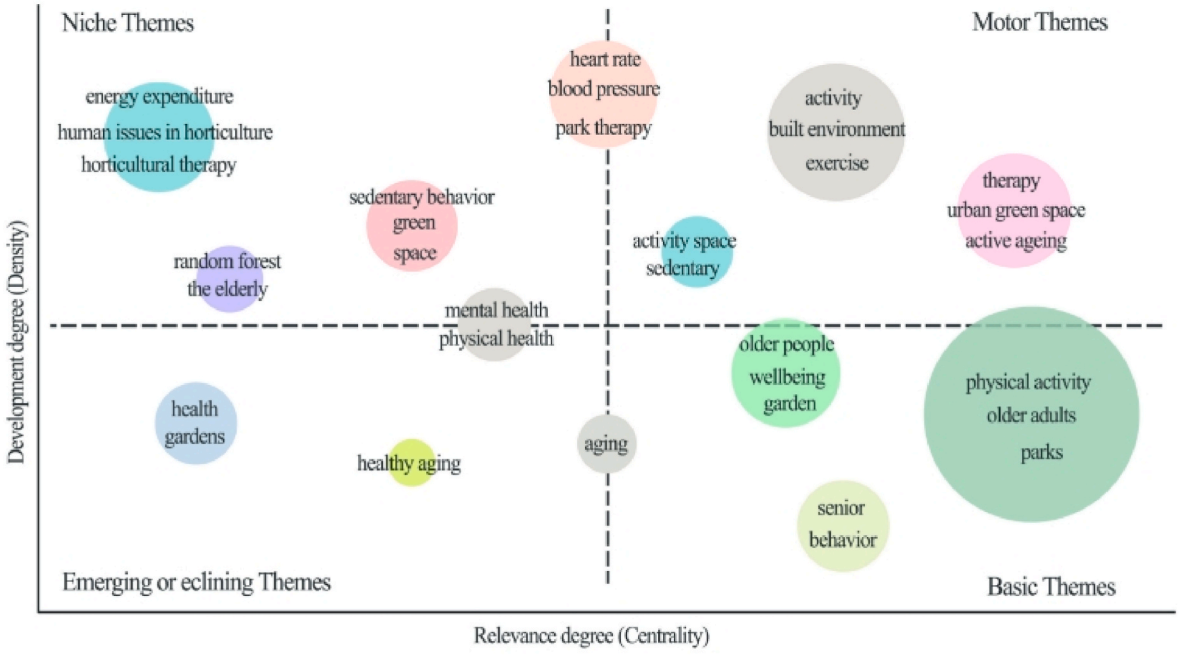


Fig. 3. Thematic map and topic clustering.

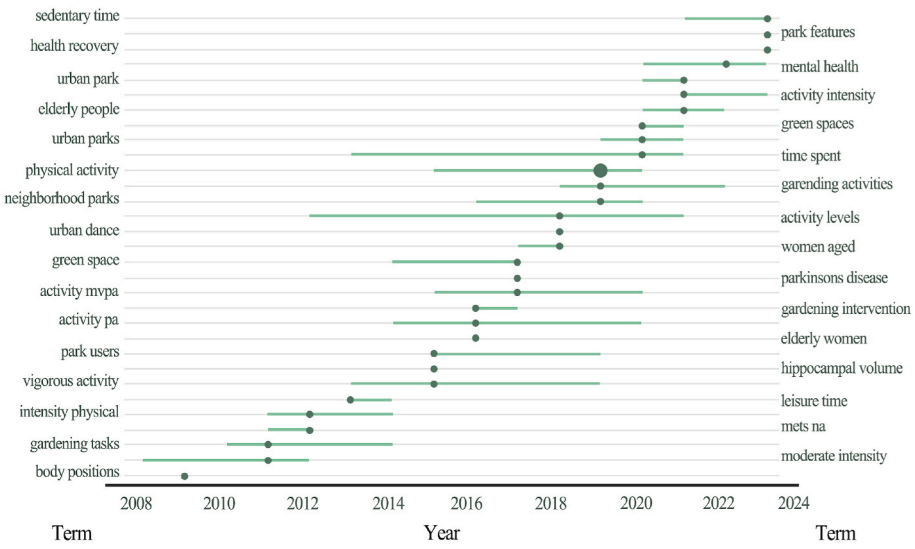


Fig. 4. Trend of topics.

quantifying results demands substantial resources, including detailed data on seniors, while manual counting can initially measure targeted age levels.

Sensors provide high-efficiency, real-time data collection, allowing objective measurement of behavioral influences. These devices measure physical indicators (e.g., moving trajectories, step counts) using GPS monitors, pedometers, shoe-type data loggers, and radar, as well as psychological indicators (e.g., activity intensity, oxygen consumption, blood pressure) using accelerometers, telemetric calorimeters, and digital blood pressure monitors. Accelerometers, used in 21 papers, match the usage rate of questionnaires, highlighting growing interest in immediate physical responses to behaviors.

Third-party data offers extensive information on urban nature visits over time and space, with advantages in geographical coverage, time-effectiveness (Kang et al., 2020), and cost-effectiveness (L. Yang et al., 2021). Seniors' behavior data from government censuses (Hooper et al., 2020; Zeng and He, 2023) and seniors' movement trajectories from communication operators (Evenson et al., 2013) are directly obtained and previously classified by age. However, seniors' behavior images from crowdsourced imagery services require further selection by observers. The use of third-party data is low, with only 5 papers employing this method.

3.3. The different types of behaviors are measured by tools

The classification of behaviors into four categories is based on their primary characteristics and purposes: Physical and sports behaviors aim to improve physical fitness, strength, and endurance. These encompass activities involving physical movement and sports engagement, such as walking (Tabatabaie et al., 2019; W. Zhang et al., 2022), and swimming (Hooper et al., 2020; Tabatabaie et al., 2019). Leisure and recreational behaviors are geared towards amusement, happiness and entertainment, like dancing (J. Liu et al., 2021; Sun et al., 2020b), and music behviors (singing, playing musical instruments, listening opera) (Cai et al., 2023; Mu et al., 2021). Relaxation and passive behaviors focus on helping individuals unwind and recuperate, such as stretching (Duan et al., 2018; M. Liu et al., 2023), and lying down (Evenson et al., 2019, p. 20; K. Park et al., 2020). Social and care behaviors aim to foster social connections and providing care and support to others, for instance, chatting (Lau et al., 2021; Z. Liu et al., 2021), and playing board games (cards, chess, mahjong) (Mu et al., 2021; Yan et al., 2023).

As shown in Fig. 5, the literature primarily focused on Physical and Sports behaviors (56%, n = 48) and Leisure and Recreational behaviors (34%, n = 29). Self-report methods, being traditional and typical, have the highest utilization rate, particularly for Leisure and Recreational behaviors at 59%. On-site observation is also commonly used, playing a significant role in Social and Care behaviors. In contrast, third-party data is the least frequently used tool. Sensors are used only for Physical and Sports behaviors and Relaxation and Passive behaviors, with proportions of 21% and 33%, respectively.

As shown in Fig. 6 and Appendix A, Physical and Sports behaviors encompass the largest variety among the four categories, with 20 sub-behaviors. Walking is the most common activity for seniors, referenced in nearly 40 articles. It is also measured by the widest range of tools, with 16 different methods, including questionnaires (Chang, 2020; Zhou et al., 2020), manual counts (Leng et al., 2020; Zhai and Baran, 2017), interviews (Fontán-Vela et al., 2021; Yan et al., 2023), carried cameras (Sun et al., 2020b), SOPARC (Chow et al., 2016; Duan et al., 2018), and third-party data (Hooper et al., 2020; Vilhelmson and Thulin, 2022). The following behaviors are playing racket games (tennis, table tennis, badminton) (Duan et al., 2018; Tabatabaie et al., 2019), jogging and running (Duan et al., 2018; He et al., 2020b), dancing (Y. Li et al., 2022; Mu et al., 2021), sitting to rest(Lau et al., 2021; Van Puyvelde et al., 2023), and chatting (Chang, 2020; Y. Li et al., 2022), all measured by 7 tools. Besides these, some behaviors in urban nature attract seniors but have received less attention from scholars, such as hiking (Vilhelmson and Thulin, 2022), boxing (Mu et al., 2021), playing frisbee (Pleson et al., 2014), shuttlecock kicking (Mu et al., 2021), praying (Sun et al., 2020b), and painting (Van Puyvelde et al., 2023).

3.4. The seniors' health and well-being affected by behaviors

Influence factors from behaviors can be divided into 4 groups: Physical and vitality health, Functional and sensory health, Psychological and emotional health, Social and lifestyle health, as shown in Table 2.

Physical and vitality health includes factors affecting directly physical health and fitness, such as the risk of diseases, physical strength, endurance, flexibility, bone health, and overall bodily functions, like risk of diabetes (S.-A. Park et al., 2016; Storgaard et al., 2013) and lung capacity (Cai et al., 2023). Functional and sensory health involves aspects impacting the body's functional capabilities and sensory perception, like visual ability (Frost and Murtagh, 2023) and brainwave activity (Hassan et al., 2018). Psychological and emotional health focuses on mental and emotional well-being, including factors like stress (Čukić et al., 2019; Hassan et al., 2018) and sense of purpose (Leaver and

Table 1
The type of tools monitoring seniors' behaviors.

Tools	Sub-tools	Measuring characteristics	References
Self-report	Questionnaire	More personal information, common, recalling bias, low representative	(W. Zhang et al., 2022; Storgaard et al., 2013; Müller-Riemenschneider et al., 2020; Cerin et al., 2023; Koohsari et al., 2020; S.-A. Park et al., 2016; Machida, 2019; S.-A. Park et al., 2008; Scott et al., 2020; J. Guo et al., 2022; S.-A. Park and Shoemaker, 2009; Scott et al., 2015; Lau et al., 2021; Tabatabaie et al., 2019; Duan et al., 2018; Lee et al., 2018; J. Liu et al., 2021; Chang, 2020; Leng et al., 2020; Zhou et al., 2020; Sia et al., 2020)
	Interview	Low burden for seniors, more detail information, time consuming	(Cai et al., 2023; Chen, 2018; Fontán-Vela et al., 2021; Frost and Murtagh, 2023; Harris et al., 2015; He et al., 2020b; Leaver and Wiseman, 2016; Leng et al., 2020; J. Liu et al., 2021; Mu et al., 2021; Sheng, 2022; Tsai et al., 2020; Van Puyvelde et al., 2023; Yan et al., 2023; Y. Yang et al., 2019)
On-site observation	SOPARC	General behaviors, lacking detailed information	(Chow et al., 2016; Cohen et al., 2016; Duan et al., 2018; Evenson et al., 2019; Fontán-Vela et al., 2021; Kaczynski et al., 2011; King et al., 2015; M. Liu et al., 2023; Pleson et al., 2014; Schmidt et al., 2019; H. Tu et al., 2015)
	Manual count	Accurate, time consuming	(Leng et al., 2020; Zhai and Baran, 2017)
	Phone camera	Convenient, saving cost, small range	(J. Liu et al., 2021; Mu et al., 2021)
	Fixed video recording camera	Saving time and effort fixed place behaviors	(Y. Li et al., 2022)
	Carried camera	behaviors closing to daily life, measuring discreetly	Sun et al. (2020b)
	Unmanned aerial vehicle	General behaviors, large range, lacking undertree behaviors	(K. Park et al., 2020)
Sensor	Accelerometer	Sedentary, light, moderate, vigorous activity (activity Intensity)	(Akinci et al., 2022; Amagasa et al., 2019; Cerin et al., 2023; Čukić et al., 2019; Evenson et al., 2013; Harris et al., 2013, 2015; Kerr et al., 2012; Koohsari et al., 2020; Lee et al., 2018; Makizako et al., 2015; Miralles-Guasch et al., 2019; Müller-Riemenschneider et al., 2020; Perchoux et al., 2023; Strath et al., 2012; Teixeira et al., 2023; Togo et al., 2008; Vich et al., 2021; Witham et al., 2014; Zhai et al., 2021, 2023)
	GPS	Movement(trajectory)	(Akinci et al., 2022; Evenson et al., 2013; Kerr et al., 2012; Vich et al., 2021; Yan et al., 2023; Zhai et al., 2021, 2023)
	Digital blood pressure monitor	Blood pressure	(Hassan et al., 2018; Kabisch et al., 2021; S.-A. Park et al., 2017; Pratiwi et al., 2019, 2020; P.-C. Tu et al., 2020)
		Pulse rate	(P.-C. Tu et al., 2020)
	Heart rate sensor	Heart rate	(Kabisch et al., 2021; S.-A. Park et al., 2008, 2017; Pratiwi et al., 2019, 2020; P.-C. Tu et al., 2020)
	shoe-type data logger	Walking gait parameter (speed, stride length, time, gait velocity, cadence, swing phase)	(Aznar-Gimeno et al., 2021; Noh et al., 2020; Schlachetzki et al., 2017)
	Pedometer	Walking step counts	(Harris et al., 2015; Togo et al., 2008; Zhai et al., 2020, 2020, 2020)
	Telemetric calorimeter	Metabolic equivalents (oxygen consumption)	(S.-A. Park et al., 2011, 2012)
	Electroencephalograph headset	Electrical brainwave activity	(Hassan et al., 2018; Neale et al., 2017)
	Radar	Walking speed	Alshamaa et al. (2021)
	Oximeter	Heart rate (oxygen saturation)	Su et al. (2023)
	Wireless temperature data recorders	Skin temperature	Su et al. (2023)
	Salivary amylase monitor	Stress (salivary amylase activity)	(P.-C. Tu et al., 2020)
	Microplate reader	Brain nerve growth factor (Blood sample)	(S.-A. Park et al., 2019)
Third-party data	Government	Representative and general, large samples	(Hooper et al., 2020; Vilhelmson and Thulin, 2022; Zeng and He, 2023)
	Communication operator	Movement (trajectory), high geographical coverage, poor signal, smartphone ownership	(S. Guo et al., 2019)
	Crowdsourced imageries service	Lage samples, cost-effectiveness, fixed place behaviors	(L. Yang et al., 2021)

Wiseman, 2016; S.-A. Park et al., 2012). Social and lifestyle health addresses the impact of social interactions and lifestyle choices on health, such as social connections (Frost and Murtagh, 2023) and adaptation to social change (Chen, 2018; Zeng and He, 2023).

Research supports the association of health-related outcomes with different behaviors (Cai et al., 2023; Chen, 2018; Evenson et al., 2013; Pratiwi et al., 2019). Physical and vitality health is most affected by seniors' behavior and receives more academic attention, encompassing 15 categories, such as the risk of diabetes, cardiovascular diseases, and muscle and joints strain. This is followed by psychological and emotional health, which includes 11 categories like self-esteem, anxiety, and feeling aesthetic pleasure. Among all categories, studies on the influence of cardiovascular disease risk and stress on seniors' behavior are the most numerous, with seven papers.

According to the 86 papers reviewed, most behaviors in urban nature are beneficial for seniors, such as walking (Brawley, 2007; Harris et al., 2015), dancing (Chen, 2018; Sheng, 2022), and singing (Cai et al., 2023), particularly at the psychological level (e.g., happiness, safety, self-esteem). Conversely, sedentariness increases the risk of diabetes and cardiovascular diseases (Storgaard et al., 2013). Some behaviors can have both beneficial and harmful effects; for example, gardening can lower blood pressure (S.-A. Park et al., 2017) and enhance brainwave activity (Hassan et al., 2018), but it can also burden the body or cause injury, increasing the risk of muscle and joint strain (S.-A. Park and Shoemaker, 2009).

As shown in Fig. 7, based on 86 papers, seven behaviors (gardening, sedentariness, viewing landscape, dancing, biking, walking, singing) have definite influences on seniors' four types of health. Gardening affects the most influence types, with a total of 30, including 21 positive effects and 9 negative effects. Singing and biking have the least

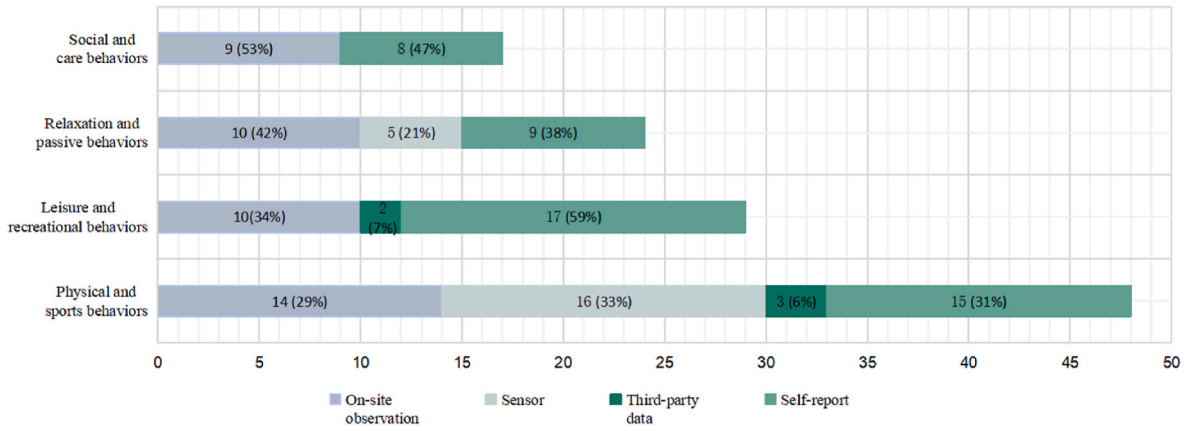


Fig. 5. The number of articles using different tools in four behavior types.

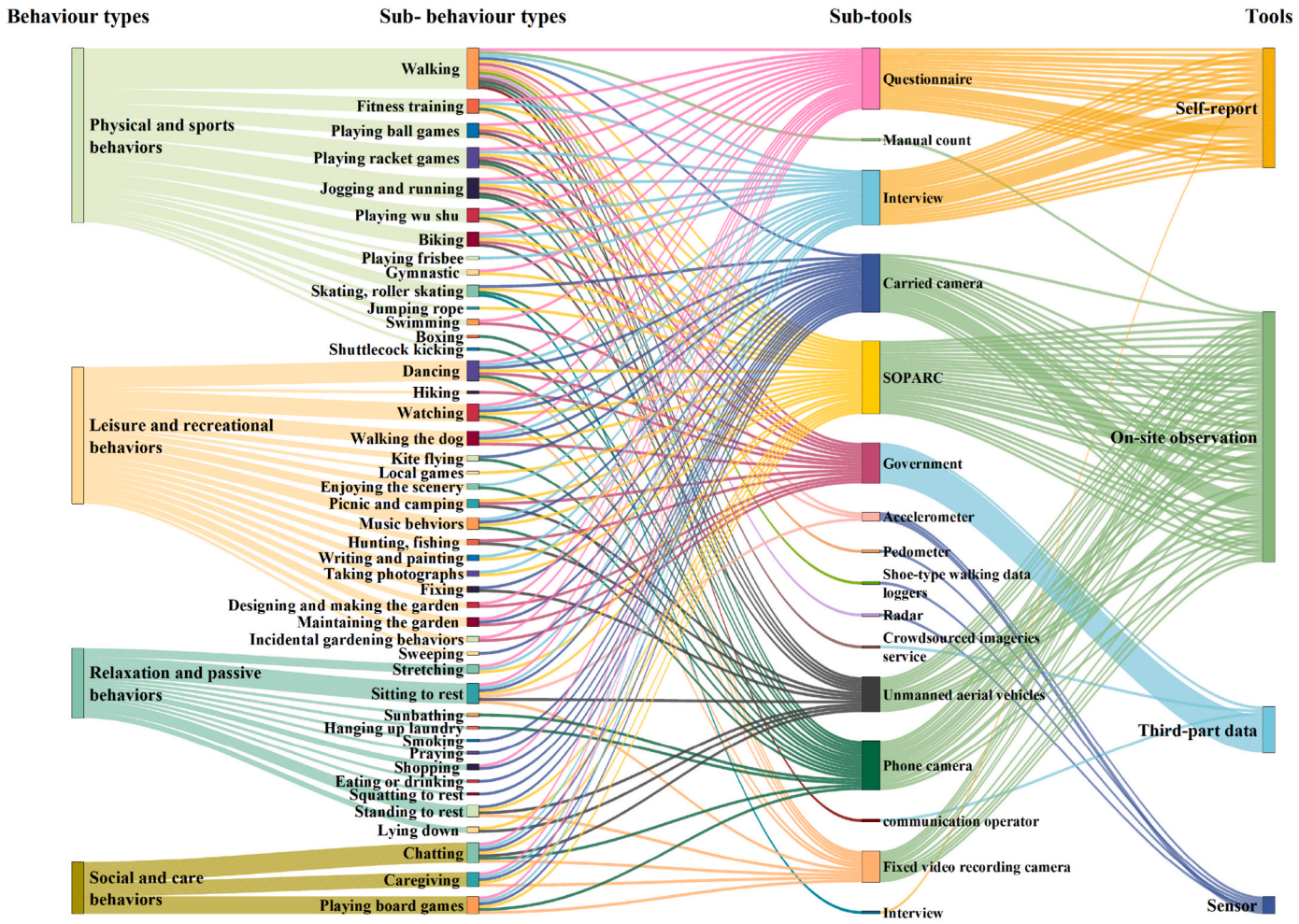


Fig. 6. The relationship between behaviors and tools.

influence, with only one type each.

4. Discussion

4.1. The relationship of tools, behaviors, and influences

Self-report and on-site observation have higher utilization rates for measuring all types of behaviors, as they are traditional and typical methods that are easily employed (Y. Yang et al., 2019). Self-report and sensor methods preselect target seniors, while on-site observation selects data post-measurement. Some third-party data sources contain seniors' information, like communication operator data (S. Guo et al., 2019), while others do not, like crowdsourced imagery services (L. Yang et al., 2021). Self-report methods capture participants' behavioral awareness and local usa ge patterns, emphasizing subjective attributes like age, gender, and health status. In contrast, third-party data focuses on objective regional characteristics, such as greenery, accessibility, and area size. On-site observation assesses the relationship between

Table 2
The type of influence factors from behaviors.

Influences	Sub-influences	behavior types	References
Physical and vitality health	Risk of cardiovascular diseases	Sedentariness (increase)	Storgaard et al. (2013)
		Biking (decrease)	Evenson et al. (2013)
		Dancing (decrease)	Chen (2018)
		Gardening (decrease)	(S.-A. Park et al., 2016, 2017)
		Viewing landscape (decrease)	Kabisch et al. (2021)
		Walking (decrease)	Harris et al. (2015)
	Risk of diabetes	Sedentariness (increase)	Storgaard et al. (2013)
		Gardening (decrease)	(S.-A. Park et al., 2016, 2017)
		Walking (decrease)	Harris et al. (2015)
	Blood pressure	Gardening (decrease)	(Hassan et al., 2018; S.-A. Park et al., 2017)
		Viewing landscape (decrease)	(Kabisch et al., 2021; Pratiwi et al., 2019)
		Walking (decrease)	Pratiwi et al. (2020)
	Activity vigorous	Viewing landscape (decrease)	Pratiwi et al. (2019)
		Dancing (increase)	Chen (2018)
		Gardening (increase)	Scott et al. (2020)
	Muscle and joints strain	Gardening (increase)	(S.-A. Park and Shoemaker, 2009)
		Walking (decrease)	Brawley (2007)
	Obesity	Dancing (decrease)	(Chen, 2018; Sheng, 2022)
		Gardening (decrease)	(S.-A. Park et al., 2016)
	Appetite	Walking (decrease)	Brawley (2007)
	Inflammatory diseases	Gardening (decrease)	(S.-A. Park et al., 2017)
	Risk of vitamin D deficiency	Gardening (decrease)	Frost and Murtagh (2023)
	Lung capacity	Singing (increase)	Cai et al. (2023)
	Muscle strength	Gardening (increase)	(S.-A. Park et al., 2011, 2016)
	Cardiopulmonary endurance	Gardening (increase)	(S.-A. Park et al., 2016)
	Flexibility and body balance	Gardening (increase)	(S.-A. Park et al., 2011, 2016)
	Bone mineral density	Gardening (increase)	(S.-A. Park et al., 2011)
	Immune system	Dancing (increase)	Chen (2018)
Functional and sensory health	Cognitive function	Walking (increase)	Noh et al. (2020)
		Gardening (increase)	(S.-A. Park et al., 2016; Sia et al., 2020)
	Visual ability	Gardening (increase)	Frost and Murtagh (2023)
	Sleep quality	Gardening (increase)	Sia et al. (2020)
	Brainwave activity	Gardening (increase)	Hassan et al. (2018)
	Memory ability	Gardening (increase)	(S.-A. Park et al., 2019)
Psychological and emotional health	Stress	Gardening (decrease)	(Frost and Murtagh, 2023; Hassan et al., 2018; S.-A. Park et al., 2016; Scott et al., 2015, 2020; P.-C. Tu et al., 2020)
		Walking (decrease)	Pratiwi et al. (2020)
	Anxiety	Gardening (decrease)	(Pratiwi et al., 2019; Sia et al., 2020; P.-C. Tu et al., 2020)
		Viewing landscape (decrease)	Pratiwi et al. (2019)
	Feeling aesthetic pleasure	Walking (increase)	Evenson et al. (2013)
		Gardening (increase)	(J. Guo et al., 2022; S.-A. Park et al., 2012; Scott et al., 2015)
	Feeling proud	Dancing (increase)	Chen (2018)
		Gardening (increase)	(J. Guo et al., 2022; Scott et al., 2020)
	Sense of depression	Gardening (decrease)	(S.-A. Park et al., 2016)
	Self-esteem	Gardening (increase)	(Brawley, 2007; Scott et al., 2015)
	Sense of purpose	Gardening (increase)	(Leaver and Wiseman, 2016; Machida, 2019; S.-A. Park et al., 2012; Scott et al., 2015)
	Sense of happiness	Gardening (increase)	(J. Guo et al., 2022; Machida, 2019; Scott et al., 2015, 2020; Sia et al., 2020)
	Sense of independence	Gardening (increase)	Scott et al. (2015)
	Health adaptation	Dancing (increase)	(Chen, 2018; Zeng and He, 2023)
	Feeling safety	Walking (increase)	Evenson et al. (2013)
Social and lifestyle health	Social connections ability	Dancing (increase)	(Chen, 2018; Zeng and He, 2023)
		Gardening (increase)	(Brawley, 2007; Frost and Murtagh, 2023; J. Guo et al., 2022; Machida, 2019; S.-A. Park et al., 2016)
		Walking (increase)	Brawley (2007)
	Sense of belongings	Singing (increase)	Cai et al. (2023)
		Dancing (increase)	Chen (2018)
		Gardening (increase)	(Leaver and Wiseman, 2016; Scott et al., 2020; Tsai et al., 2020)
	Role transition adaptation	Dancing (increase)	(Sheng, 2022; Zeng and He, 2023)
		Gardening (increase)	Scott et al. (2020)
	Social change adaptation	Dancing (increase)	(Chen, 2018; Sheng, 2022; Zeng and He, 2023)
	Balanced meals habit	Gardening (increase)	Machida (2019)

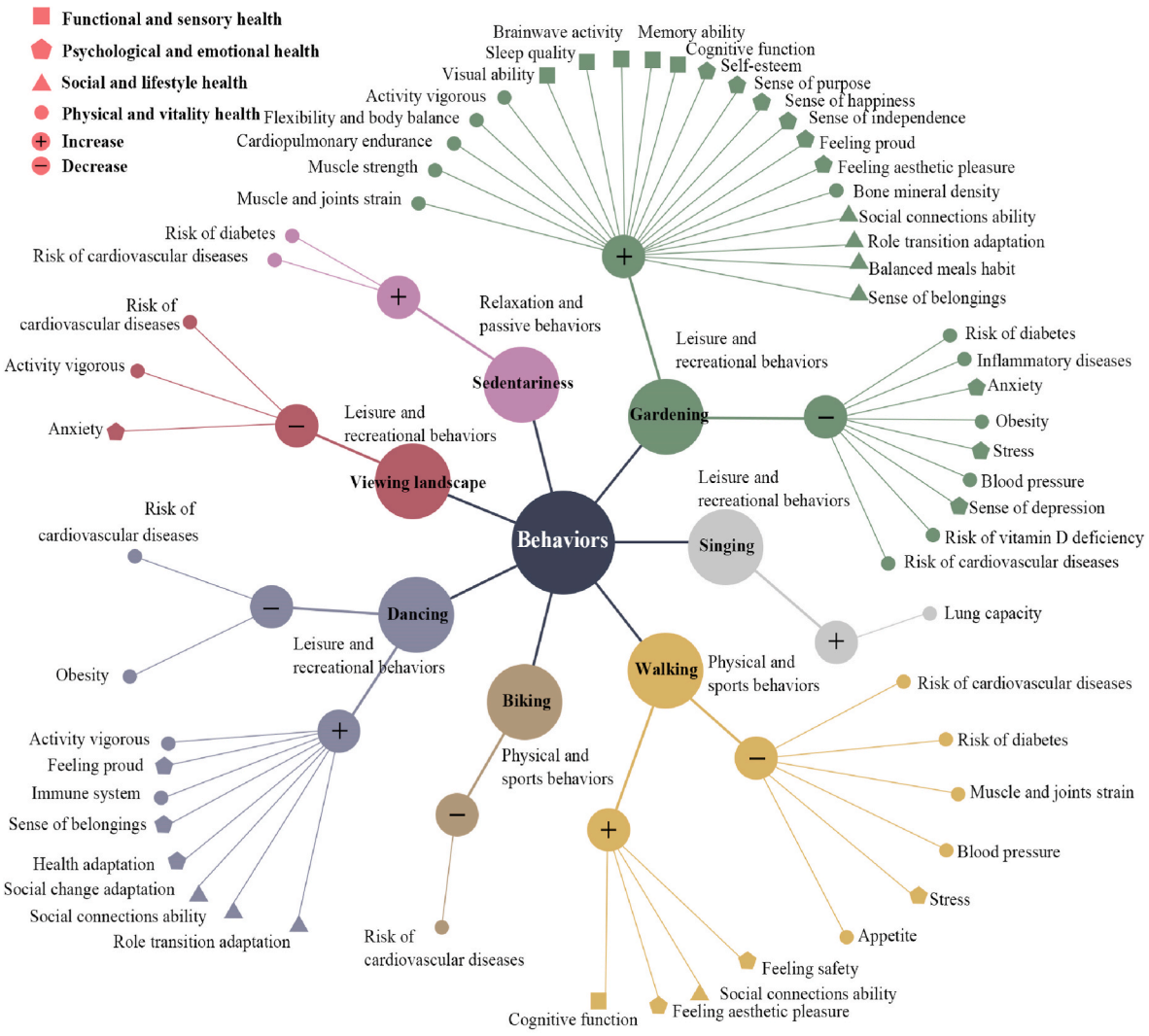


Fig. 7. Different influences of 7 behaviors for seniors.

environmental conditions and behavior, such as pavement and facilities, while sensors examine behavior's impact on health, prioritizing human health monitoring.

Urban nature behaviors significantly influence health, including physical and mental well-being and the aging process (Cai et al., 2023; Chen, 2018; Evenson et al., 2013; Pratiwi et al., 2019). Walking is the most common activity for seniors because it is relatively easy, simple, and safe (Leng et al., 2020), it has proven health benefits(Brawley, 2007; Harris et al., 2015; Pratiwi et al., 2020), and it can be easily measured by a variety of tools (Tabatabaie et al., 2019; Vilhelmson and Thulin, 2022; Zhai et al., 2020). The walking can improve the social confidence (Zhai and Baran, 2017), decrease appetite (Brawley, 2007) and increase feeling safety and aesthetic pleasure (Evenson et al., 2013). Gardening is identified as having the most health benefits, such as decreasing the risk of diabetes (S.-A. Park et al., 2016), lowering blood pressure (Hassan et al., 2018), and reducing stress (Scott et al., 2015), as shown in Fig. 4. Gardening involves various activities (e.g., weeding, digging, watering) (Scott et al., 2020; Sun et al., 2020b; Tabatabaie et al., 2019) that can be more easily measured. In addition, gardening behaviors involve both the upper and lower body, covering low and moderate-intensity physical activities. However, it can also increase muscle and joint strain (S.-A. Park and Shoemaker, 2009). Sedentary behavior increases the risk of diabetes and cardiovascular diseases (Storgaard et al., 2013), so reducing the sedentary behavior can reduce the risk of diseases in seniors. This indicates that seniors need to pay attention to the duration of behaviors and choose appropriate activities.

4.2. *Challenges and issues of measuring tools*

In the process of measuring seniors' behaviors in urban nature, we note common challenges and issues that the reviewed studies reveal, which are generic rather than focused on the limitations of a specific service. Fig. 8 illustrates the performance capabilities of the different tools.

Sample size refers to the number of observations or individuals in a study. It is important for quantitative research, and larger sample sizes provide more data for analysis and yield more representative results (H. Park et al., 2024). In contrast, for qualitative research, considering addressing a smaller sample size may provide richer behavioral data. If the sample size is large enough, quantitative analysis can be considered; if the sample size is relatively small, and the behavioral frequency and reasons of seniors need to be explored, qualitative research is more suitable.

Studies with large sample sizes, often exceeding 10,000 samples (Cohen et al., 2016; Hooper et al., 2020; H. Tu et al., 2015), typically use SOPARC or third-party data. Third-party data often provides excellent sample sizes based on institutional long-term outcomes, such as government sources (Vilhelmson and Thulin, 2022). Studies with fewer than 50 samples usually employ wearable sensors or self-reports (Hassan et al., 2018; Leng et al., 2020; S.-A. Park et al., 2011; Pratiwi et al.,

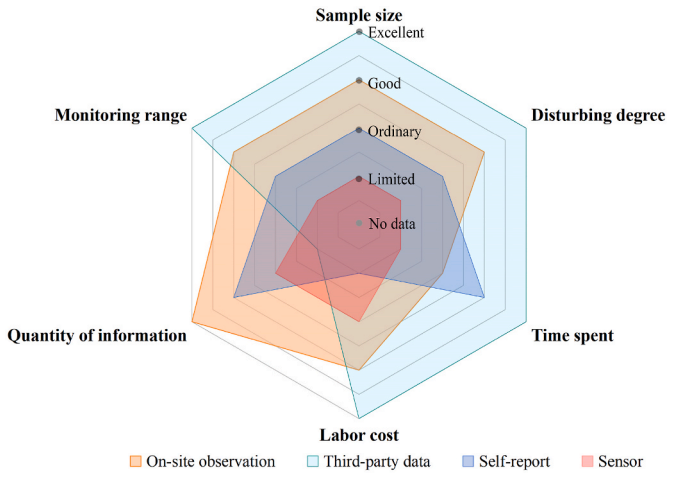


Fig. 8. Challenges and issues of measuring tools.

2019).

Monitoring range refers to the area size where the most samples are located. behaviors (Rupprecht et al., 2015; Wright Wendel et al., 2012) and health benefits of nature (Amano et al., 2018) vary considerably depending on contextual factors (H. Park et al., 2024). Seniors' behavious are diverse and widely distributed, and a larger monitoring area can provide more complete results. If the behavior types in multiple areas are studied, third-party data can be considered, but considering its limitations, some areas need to be selected for qualitative research to verify the accuracy of their data, such as in park corners, under big trees, and on pedestrian paths.

Third-party data, particularly from communication operators, performs best in this regard but may not represent all seniors due to differences in smartphone ownership, signal coverage, and public venue accessibility (S. Guo et al., 2019). Sensors and self-reports are inefficient over larger areas as they focus on individual samples. On-site observation can cover the most frequented sections of the area (Y. Li et al., 2022), but it may neglect some users in some corners.

Time spent refers to the minimum time required for the entire measurement process. Measurement time limits the study area's extent (Hughey et al., 2016; Scott et al., 2020) and the assessment of behaviors over time. If the researcher does not consider the duration of the study, such as the season, and external factors, such as the weather, third-party data has a greater advantage, because it can save a lot of time, but if the researcher wants the data to be more accurate and realistic, other methods need to be combined.

The availability of third-party data has led many researchers to use these for virtual audits, saving time (Vilhelmson and Thulin, 2022; L. Yang et al., 2021; Zeng and He, 2023). However, behavioral data from third-party sources is one-sided and fails to take into account the duration of participants. On-site observation requires significant time (Cohen et al., 2009), as this method demands multiple observations over different days and seasons to be credible. Self-report methods are time-efficient and easy to carry out as they rely on participants' long-term experiences. Sensors are the least time-efficient, needing more time for data collection, result validation, and worker training (Tedesco et al., 2017) to prevent data bias.

Labor cost refers to the minimum number of investigators required. Labor-intensive tools often limit sample size or study scale (Seresinhe et al., 2017). If the number of researchers is small, third-party data collection and on-site observation can be carried out. If self-report and sensor are carried out, a small number of researchers need to spend more time collecting data in order to ensure the accuracy of data.

On-site observation lacks the capability to capture seniors' detailed information (Y. Li et al., 2022; K. Park et al., 2020). Researchers can independently obtain behavior information from third-party data immediately (Hooper et al., 2020; Vilhelmson and Thulin, 2022; Zeng and He, 2023), but the fixed nature of the data makes it difficult to adjust subjectively according to research objectives. On-site observation performs well, requiring only a few investigators with cameras (Sun et al., 2020b), phone cameras (Mu et al., 2021) or unmanned aerial vehicles (Zhai et al., 2021) to record. The labor cost of self-report is high due to the need for surveying a large number of samples to enhance representativeness. Sensors also require more labor because of the research cycles and tedious steps involved.

Quantity of information refers to the maximum number of behavioral types that a tool can obtain in a single measurement. Some qualitative methods can provide comprehensive information, including behavior frequency (He et al., 2020b), time (Witham et al., 2014), forms, and intensity (Storgaard et al., 2013; W. Zhang et al., 2022). These collected data can offer context and meaning, explaining the reasons behind these patterns, and better understand how seniors' behaviors relate to urban nature. According to the quantitative values measured, some qualitative methods were used to ask seniors to recall the behavior types and psychological feelings at a specific time. Combining the measured results of the two methods, corresponding to each other, can make the data more complete.

Specific behaviors of the senior can be measured by self-reports and on-site observation, while sensors and third-party data often yield more generalized data. Given that behavior types vary greatly in urban nature, on-site observation has the advantages of flexibility (Mu et al., 2021), high validity (K. Park et al., 2020), low inference (Sun et al., 2020b), and low subject burden (Y. Li et al., 2022). Although on-site observation closely relates to seniors' daily life, it lacks detailed information. Combining both tools in some studies (Duan et al., 2018; Leng et al., 2020; J. Liu et al., 2021; Mu et al., 2021) compensates for their shortcomings (Bonaccorsi et al., 2020). Sensors vaguely measure a few behaviors, like walking (Amagasa et al., 2019; Evenson et al., 2013) and sitting (Cerin et al., 2023; Müller-Riemenschneider et al., 2020), due to the lack of consensus on algorithms to define various behavior levels (Lee et al., 2018; Sabia et al., 2014).

Disturbing degree refers to the influence of the investigator on the sample during measurement. Minimal observer disturbance ensures behaviors closely resemble daily life (Sun et al., 2020b), making lower-burden tools preferable (Lane et al., 2020). Using tools with less interference, researchers can obtain behavior types more in line with the actual situation, but the data will be single, and the relationship between behavior and environment cannot be obtained.

Privacy is a major concern for most seniors, who must decide which parameters can be shared with the investigator (Tedesco et al., 2017), potentially affecting results, particularly in self-reports (Cai et al., 2023; He et al., 2020a), which requires long-term contact and trust to get the most consistent with the real data. Some wearable sensors cause discomfort, hindering normal activities (Harris et al., 2015; Koohsari et al., 2020; Lee et al., 2018; Togo et al., 2008). However, the radar is non-intrusive that it can be placed in everywhere in the park to acquire continuous gait speed rather than periodic monitoring (Alshamaa et al., 2021). On-site observation can effectively reduce direct contact among people during research (M. Liu et al., 2023) and capture participants' real-time behaviors (Garrod, 2009). However, it allows for the collection of data on a large number of people within a relatively short time period but lack of capturing detailed user information. Also, it rarely involves the influence of spatial environment and behavior time on the physical activity (H. Tu et al., 2015).

4.3. Limitations

The behavior of seniors do not arise in isolation and are also susceptible to other age groups, such as caring for children (Sadruddin et al., 2019). However, we only included papers that focused on seniors, and did not focus on other age groups. In addition, we only pay attention to urban nature, other sites, such as forests, rural parks, these places also

have the generation of seniors' behaviors. Some of the tools for measuring seniors' behavior, and the types of behavior, could be further supplemented.

There are also some limitations of the search strategy. The first, we only use two well-known databases, and there are other databases that we have not mentioned in the article. The second, although we have tried a large number of search terms, the number of word combinations is limited. The third, we only include published English articles, articles in other languages, or papers to be published are not covered, which will cause errors.

4.4. Implications and future study

Future research should develop a weighted measure for different measurement tools to facilitate comparisons and provide a more accurate score for the supportive potential of measurement subtools. Different tools are used in different ways, and the numerical evaluation criteria are different (Duan et al., 2018; Harris et al., 2015; Lee et al., 2018), so the accuracy of the final results cannot be guaranteed. In addition, it is important to verify the effectiveness and representation of some of the latest tools, such as big data and ai tools. While these tools can reduce the researcher workforce, data for senior groups are less accurate than for other groups. Future research should focus more on the combination of tools, the use of a single tool has limitations, but also easy to produce deviations.

Given the growing interest in non-pharmacological interventions that promote positive health outcomes through behaviors in urban nature (Hassan et al., 2018; S.-A. Park et al., 2011; Su et al., 2023), further research is needed to understand how these behaviors impact seniors' health. In addition, some behaviors have different impacts on seniors according to their duration, such as gardening, and future studies can focus on the relationship between the duration of behaviors and the health of seniors.

The types of measured behaviors may be influenced by seniors' age, gender, health status (Matthews et al., 2012), marital status, and length of residency (Chang, 2020). This review focuses solely on seniors, and the characteristics of this population should be considered in future studies. Scoring tools can enhance the results' significance (Rodiek et al., 2016).

5. Conclusions

This review utilized the PRISMA methodology to systematically analyze the relationship between monitoring tools, seniors' behaviors, and influencing factors. Among the 86 included studies, tools were classified into 4 main types and 24 sub-types, used to measure 45 seniors' behaviors categorized into four types. These behaviors produced 36 influencing factors, grouped into four physical and mental health categories. The main contributions of this review are: (1) Self-report and sensor tools pre-select target seniors, while on-site observation selects seniors' data post-measurement. Some third-party data include seniors' information, while others do not. (2) Self-reports capture participants' awareness of their behaviors and detailed local usage patterns. Third-party data focus on objective regional characteristics. On-site observations assess the relationship between internal environmental conditions and behavior types. Sensors examine the influence of behaviors on the human body, emphasizing health impacts. (3) Seniors should consider the duration of behaviors and select appropriate activities, as the same behavior can have both beneficial and harmful effects. Overall, this review's classification and discussion of tools, behaviors, and influences provide valuable insights for engineers, designers, and scientists, offering a solid foundation for future research.

CRediT authorship contribution statement

Fan Yuan: Writing – original draft, Visualization, Software, Resources, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Mingze Chen:** Writing – review & editing, Supervision, Project administration, Conceptualization, Data curation, Investigation, Methodology.

Declaration of interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A

Table 1
Seniors' behaviors measured by sub-tools.

Behavior type	Sub- behavior type	Tools	References
Physical and sports behaviors	Walking	Accelerometer	(Amagasa et al., 2019; Čukić et al., 2019; Evenson et al., 2013; Koohsari et al., 2020; Lee et al., 2018; Müller-Riemenschneider et al., 2020; Witham et al., 2014; Zhai et al., 2021)
		Questionnaire	(Chang, 2020; Duan et al., 2018; Lee et al., 2018; Z. Liu et al., 2021; Tabatabaie et al., 2019; Zhang et al., 2022; Zhou et al., 2020)
		Interview	(Fontán-Vela et al., 2021; Harris et al., 2015; He et al., 2020; Pleson et al., 2014; Van Puyvelde et al., 2023; Yan et al., 2023; Y. Yang et al., 2019)
		SOPARC	(Chow et al., 2016; Duan et al., 2018; Fontán-Vela et al., 2021; Schmidt et al., 2019; Tu et al., 2015)
		Pedometer	(Harris et al., 2013, 2015; Togo et al., 2008; Zhai et al., 2020)
		Shoe-type walking data loggers	(Aznar-Gimeno et al., 2021; Noh et al., 2020; Schlachetzki et al., 2017)
		Manual count	(Leng et al., 2020; Zhai and Baran, 2017)
		Third-party data (government)	(Hooper et al., 2020; Vilhelmson and Thulin, 2022)
		Phone camera	(J. Liu et al., 2021; Mu et al., 2021)
		Carried camera	(Sia et al., 2020)
		Radar	Alshamaa et al. (2021)

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Table 1 (*continued*)

Behavior type	Sub- behavior type	Tools	References
		Third-party data (crowdsourced imageries service)	(L. Yang et al., 2021)
		Unmanned aerial vehicles	(K. Park et al., 2020)
		Third-party data (communication operator)	Guo et al. (2019)
	Playing racket games (tennis, table tennis, badminton)	SOPARC	(Chow et al., 2016; Duan et al., 2018; M. Liu et al., 2023; Tu et al., 2015)
		Questionnaire	(Duan et al., 2018; Tabatabaie et al., 2019)
		Fixed video recording camera	Li et al. (2022)
		Phone camera	Mu et al. (2021)
		Third-party data (government)	Hooper et al. (2020)
		Interview	Pleson et al. (2014)
		Unmanned aerial vehicles	(K. Park et al., 2020)
	Jogging and running	SOPARC	(Chow et al., 2016; Duan et al., 2018; Fontán-Vela et al., 2021; M. Liu et al., 2023; Schmidt et al., 2019)
		Questionnaire	(Chang, 2020; Duan et al., 2018; Tabatabaie et al., 2019; Zhou et al., 2020)
		Interview	He et al. (2020)
		Third-party data (government)	Hooper et al. (2020)
		Unmanned aerial vehicles	(K. Park et al., 2020)
		Accelerometer	Koohsari et al. (2020)
		Phone camera	Mu et al. (2021)
	Fitness training, fitness with equipment (waist twister, air walker, exercise biking, waist/back massager)	SOPARC	(Chow et al., 2016; Duan et al., 2018; M. Liu et al., 2023; Tu et al., 2015)
		Interview	(Fontán-Vela et al., 2021; Pleson et al., 2014; Van Puyvelde et al., 2023)
		Questionnaire	Duan et al. (2018)
		Fixed video recording camera	Li et al. (2022)
		Phone camera	(J. Liu et al., 2021)
	Playing ball games (baseball, football, soccer, golf, basketball, gate ball, volleyball)	SOPARC	(Chow et al., 2016; Duan et al., 2018; Evenson et al., 2019; M. Liu et al., 2023)
		Questionnaire	(Duan et al., 2018; Tabatabaie et al., 2019)
		Fixed video recording camera	Li et al. (2022)
		Third-party data (government)	Hooper et al. (2020)
		Unmanned aerial vehicles	(K. Park et al., 2020)
	Playing wu shu (tail chi, tail chi sword, qigong)	Interview	(He et al., 2020; Pleson et al., 2014; Van Puyvelde et al., 2023)
		SOPARC	(Duan et al., 2018; M. Liu et al., 2023; Tu et al., 2015)
		Questionnaire	(Duan et al., 2018; Z. Liu et al., 2021)
		Fixed video recording camera	Li et al. (2022)
		Phone camera	(J. Liu et al., 2021)
	Biking	Questionnaire	(Chang, 2020; Duan et al., 2018; Lee et al., 2018; Tabatabaie et al., 2019; Zhou et al., 2020)
		Interview	(He et al., 2020; Pleson et al., 2014; Van Puyvelde et al., 2023)
		SOPARC	(Fontán-Vela et al., 2021; Schmidt et al., 2019)
		Third-party data (government)	Hooper et al. (2020)
		Unmanned aerial vehicles	(K. Park et al., 2020)
	Skating, roller skating	Carried camera	(Sia et al., 2020)
		SOPARC	Evenson et al. (2019)
		Interview	Yan et al. (2023)
		Phone camera	Mu et al. (2021)
	Swimming	Questionnaire	Tabatabaie et al. (2019)
		Third-party data (government)	Hooper et al. (2020)
	Gymnastic	Questionnaire	Lau et al. (2021)
		SOPARC	(M. Liu et al., 2023)
	Playing frisbee	Interview	Pleson et al. (2014)
	Jumping rope	SOPARC	(M. Liu et al., 2023)
	Boxing	Phone camera	Mu et al. (2021)
	Shuttlecock kicking	Phone camera	Mu et al. (2021)
Leisure and recreational behaviors	Dancing	Interview	(Chen, 2018; He et al., 2020; Pleson et al., 2014; Yan et al., 2023)
		Questionnaire	(Duan et al., 2018; Z. Liu et al., 2021; Tabatabaie et al., 2019)
		SOPARC	(Duan et al., 2018; M. Liu et al., 2023; Tu et al., 2015)
		Phone camera	(J. Liu et al., 2021; Mu et al., 2021)
		Carried camera	(Sia et al., 2020)

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Table 1 (*continued*)

Behavior type	Sub- behavior type	Tools	References
		Fixed video recording camera	Li et al. (2022)
		Third-party data (government)	Zeng and He (2023)
	Hiking	Third-party data (government)	Vilhelmson and Thulin (2022)
	Watching (books, birds, bulletin board, phone, newspapers, games, landscape)	SOPARC	(Evenson et al., 2019; M. Liu et al., 2023)
		Questionnaire	Chang (2020)
		Fixed video recording camera	Li et al. (2022)
		Phone camera	(J. Liu et al., 2021)
		Interview	Van Puyvelde et al. (2023)
		Carried camera	(Sia et al., 2020)
	Walking the dog	Carried camera	(Sia et al., 2020)
		Questionnaire	Koohsari et al. (2020)
		Third-party data (government)	Vilhelmson and Thulin (2022)
		SOPARC	(M. Liu et al., 2023)
		Interview	Van Puyvelde et al. (2023)
	Music behviors (singing, playing musical instruments, listening opera)	Phone camera	(J. Liu et al., 2021; Mu et al., 2021)
		Carried camera	(Sia et al., 2020)
		Interview	Cai et al. (2023)
		SOPARC	(M. Liu et al., 2023)
	Picnic and camping	SOPARC	Evenson et al. (2019)
		Unmanned aerial vehicles	(K. Park et al., 2020)
		Third-party data (government)	Vilhelmson and Thulin (2022)
	Hunting, fishing	Third-party data (government)	Vilhelmson and Thulin (2022)
		Unmanned aerial vehicles	(K. Park et al., 2020)
	Writing and painting	SOPARC	(M. Liu et al., 2023)
		Interview	Van Puyvelde et al. (2023)
	Taking photographs	SOPARC	(M. Liu et al., 2023)
		Interview	Van Puyvelde et al. (2023)
	Fixing	Carried camera	(Sia et al., 2020)
		Unmanned aerial vehicles	(K. Park et al., 2020)
	Enjoying the scenery	Interview	Van Puyvelde et al. (2023)
		Phone camera	(J. Liu et al., 2021)
	kite flying	Carried camera	(Sia et al., 2020)
		Phone camera	Mu et al. (2021)
	Designing and making the garden (making furrows, making tags, digging, mixing soil, filling soil, fertilizing, raking, tying plants, sowing)	Questionnaire	(Evenson et al., 2013; S.-A. Park et al., 2008, 2016; S.-A. Park and Shoemaker, 2009; Scott et al., 2015; Tabatabaie et al., 2019)
		Third-party data (government)	Vilhelmson and Thulin (2022)
	Maintaining the garden(watering, transplanting, weeding, raking, flower arrangement, pruning)	Questionnaire	(Evenson et al., 2013; S.-A. Park et al., 2008, 2016; S.-A. Park and Shoemaker, 2009; Scott et al., 2015, 2020; Tabatabaie et al., 2019)
		Carried camera	(Scott et al., 2020; Sia et al., 2020)
		Third-party data (government)	Vilhelmson and Thulin (2022)
	Incidental gardening behaviors (attending garden parties, washing the produce, harvesting fruit, flower arrangement)	Questionnaire	(Evenson et al., 2013; S.-A. Park et al., 2016; Scott et al., 2015, 2020; Tabatabaie et al., 2019)
		Third-party data (government)	Vilhelmson and Thulin (2022)
	Local games (playing diabolo, playing game bowl)	SOPARC	(Duan et al., 2018; M. Liu et al., 2023)
	Sweeping	Carried camera	(Sia et al., 2020)
Relaxation and passive behaviors	Sitting to rest	Questionnaire	(Cerin et al., 2023; Lau et al., 2021; Lee et al., 2018; Z. Liu et al., 2021; Müller-Riemenschneider et al., 2020; Storgaard et al., 2013)
		Accelerometer	(Cerin et al., 2023; Koohsari et al., 2020; Müller-Riemenschneider et al., 2020; Perchoux et al., 2023; Vich et al., 2021)
		SOPARC	(Kaczynski et al., 2011; M. Liu et al., 2023; Schmidt et al., 2019; Tu et al., 2015)
		Interview	Van Puyvelde et al. (2023)
		Carried camera	(Sia et al., 2020)
		Fixed video recording camera	Li et al. (2022)
		Unmanned aerial vehicles	(K. Park et al., 2020)
	Standing to rest	SOPARC	(M. Liu et al., 2023; Tu et al., 2015)
		Fixed video recording camera	Li et al. (2022)
		Carried camera	(Sia et al., 2020)
		Unmanned aerial vehicles	(K. Park et al., 2020)

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Table 1 (*continued*)

Behavior type	Sub- behavior type	Tools	References
	Stretching	SOPARC	(Duan et al., 2018; M. Liu et al., 2023)
		Questionnaire	Duan et al. (2018)
		Interview	Pleson et al. (2014)
	Shopping	Carried camera	(Sia et al., 2020)
		Questionnaire	(Z. Liu et al., 2021)
	Lying down	SOPARC	Evenson et al. (2019)
		Unmanned aerial vehicles	(K. Park et al., 2020)
	Sunbathing	Phone camera	(J. Liu et al., 2021)
	Hanging up laundry	Phone camera	(J. Liu et al., 2021)
	Smoking	Carried camera	(Sia et al., 2020)
	Praying	Carried camera	(Sia et al., 2020)
	Eating or drinking	Carried camera	(Sia et al., 2020)
	Squatting to rest	Carried camera	(Sia et al., 2020)
Social and care behaviors	Chatting	Questionnaire	(Chang, 2020; Lau et al., 2021; Z. Liu et al., 2021; Zhou et al., 2020)
		Carried camera	(Sia et al., 2020)
		Fixed video recording camera	Li et al. (2022)
		Interview	Van Puyvelde et al. (2023)
		Unmanned aerial vehicles	(K. Park et al., 2020)
		Phone camera	(J. Liu et al., 2021)
		SOPARC	Schmidt et al. (2019)
	Caregiving (children, seniors)	Questionnaire	(Duan et al., 2018; Lau et al., 2021; Z. Liu et al., 2021)
		Interview	(Pleson et al., 2014; Yan et al., 2023)
		Carried camera	(Sia et al., 2020)
		Fixed video recording camera	Li et al. (2022)
		SOPARC	Duan et al. (2018)
	Playing board games (cards, chess, mahjong)	Questionnaire	(Lau et al., 2021; Z. Liu et al., 2021; Zhou et al., 2020)
		SOPARC	(M. Liu et al., 2023; Tu et al., 2015)
		Carried camera	(Sia et al., 2020)
		Fixed video recording camera	Li et al. (2022)
		Phone camera	Mu et al. (2021)
		Interview	Yan et al. (2023)

Appendix B

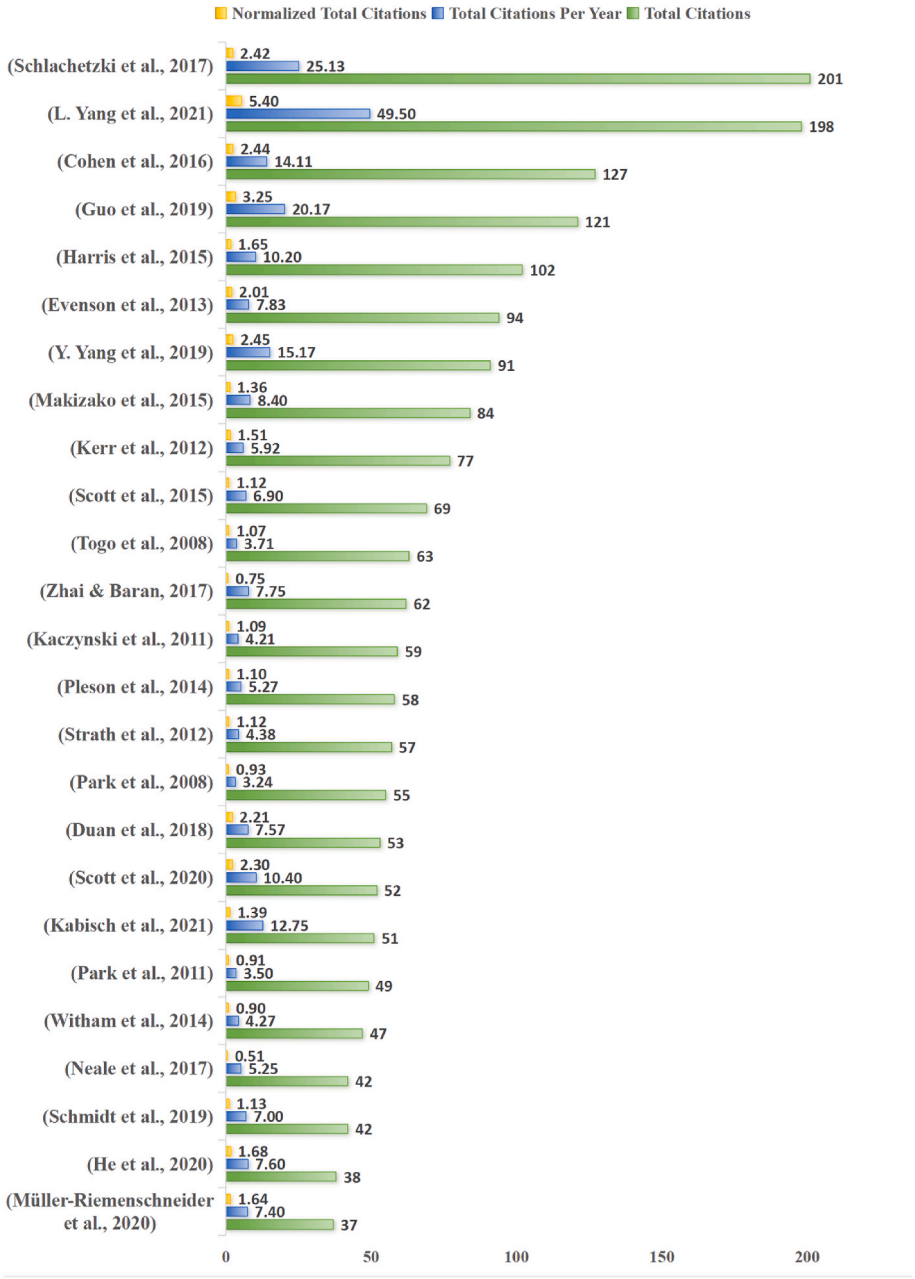

Fig. 1. Most Global Cited Papers.

Appendix C

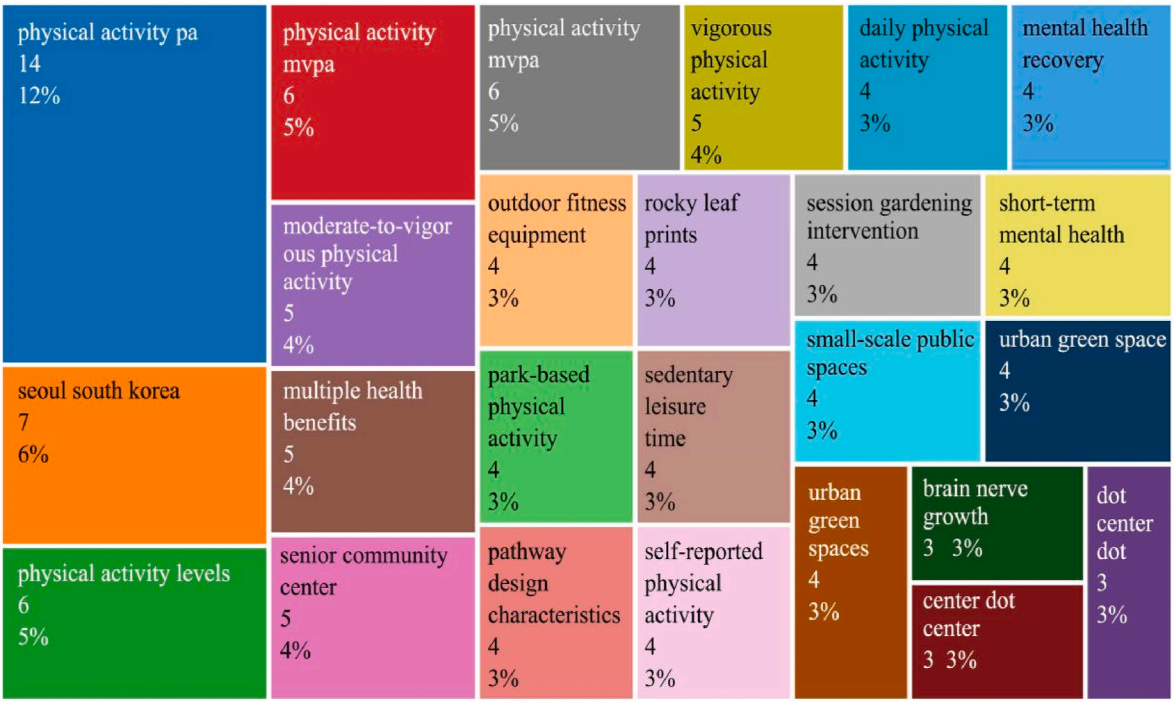

Fig. 1. Terms frequency in abstracts.

Data availability

No data was used for the research described in the article.

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