Journal of Ideas in Health

e ISSN: 2645-9248 Journal homepage: www.jidhealth.com Open Access

Review Article

The use of mHealth solutions in active and healthy ageing promotion: an explorative scoping review

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Abstract

The global population aged 60 years and over is expected to almost double between 2015 and 2050 from 12.0% to 22.0%, which will directly impact countries' labor market composition and increase the economic pressure on their healthcare systems. One way to address these challenges is to promote Active and Healthy Ageing (AHA) using mobile Health (mHealth). This research aims to provide an initial overview of the width and the depth of contemporary preventive mHealth solutions that promote AHA among healthy, independent older adults (individuals aged 60 years and over). To do so, an explorative scoping review was applied to search online databases for recent studies (March 2015 - March 2020) addressing the promotion of mHealth solutions targeting healthy and independent older adults. We identified 31 publications that met the inclusion criteria. Most of them utilized either mobile (n=25) and/or wearable (n=11) devices. mHealth solutions mostly promoted AHA by targeting older adults' active lifestyles or independence. Most of the studies (n=27) did not apply a theoretical framework on which the mHealth promotion was based. User-experience was positive (n=12) when the solution was easy to use but negative (n=11) when the participants were resistant or faced challenges using the device and/or technology. The review concludes that mHealth offers the opportunity to combat the issues faced by an unhealthy and dependent ageing population by promoting AHA through focusing on older adults' Lifestyle, Daily functioning, and Participation. Future research should use multidisciplinary integrated approaches and strong theoretical and methodological foundations to investigate mHealth solutions' impact on AHA behavioral change.

Keywords: mHealth, Active and Health Ageing, Health Promotion, Ageing Society, Older Adults, Netherlands

Background

The world's population is experiencing delayed mortality and a lower fertility rate due to improvements in education, healthcare, sanitation, nutrition, and economic well-being [1]. The prevailing point of view among experts is that we will face an ageing society, where older adults (individuals aged 60 years and over) in the world relatively increase from 12% in 2015 to 22.0% in 2050 [2]. The increasing older population impacts the old-age dependency ratio, where there will be fewer working-age individuals to provide for the older generation, which will increase the pressure on countries' economy, labor market composition, and healthcare system [3]. To avoid that these changes turn into challenges requires new approaches to prevent that ageing comes with ill health and dependency [4], here promoting Active and Healthy Ageing (AHA) could be key. The concept of AHA refers to delaying the onset of morbidity, improving quality of life, and increasing well-being [5,6]. However, besides the medical definition, at the core of AHA is the awareness regarding the subjective nature of what is considered healthy and active ageing, meaning that the older adult themselves should have both autonomy and independence in defining their interpretation [7,8]. Thus, the primary goal is to support the empowerment of older adult persons in independently caring for their health [9]. Central in AHA is the shift from treatment-based healthcare to prevention by using innovative solutions which can be used to create the needed changes in the older adults' lifestyle, social participation, daily functioning, and environment. One of the means widely suggested to potentially stimulate AHA is mobile Health (mHealth) [9,10]. mHealth refers to the usage of mobile communication and computing technologies in healthcare and public health [11]. These interventions are based on mobile electronic devices, such as smartphones, mobile phones, tablets, wearables, and medical devices connected to phones [11-13]. They carry out disease management by tracking health information, such as falls, heart rate, steps, sleep quality, and blood glucose [14], and create behavioral health changes such as motivating particular lifestyles, dietary choices, and exercises. Although the adoption of mHealth and other electronic health technology among older adults has increased, generally, the adoption rate is slow, which could be due to the

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low digital literacy skills among this population [15,16]. Also, the efficacy of mHealth solutions is still limited due to a general lack of sufficient methodology in the intervention and/or product development, as well as a lack of relevant theory, its one-dimensionality in addressing merely one aspect of health, and its lack of suitability in the older adults' lifestyle [9,13,15,17-19]. This explorative scoping review aims to gain insights into how contemporary preventive mHealth solutions can be used to promote AHA by providing an overview of recent studies in the field and highlighting their gaps. The results can be used as a foundation for a more comprehensive review, and ultimately by policymakers, developers, and researchers to increase the effectiveness of interventions, avoid duplication, and increase their understanding of AHA as a theoretical concept in mHealth interventions.

Methods

The scoping review methodology allows for insight into the field of mHealth solutions promoting AHA, which is essential as this field has not been comprehensively reviewed yet. Also, the method allows for an iterative process of data collection and redefinition of search terms, which enhances the scope of relevant data. The review followed Arksey and O'Malley's first five stages of their scoping review framework and used the PRISMA flow diagram to visualize the data selection [20,21]. Ultimately, this review method can provide a range of evidence that offers insights into the width and depth of the new field of mHealth solutions promoting AHA.

Search strategy

A search was performed of the PubMed and Scopus databases on March 11th, 2020, for relevant peer-reviewed articles written in English. The search was conducted in merely two databases as this paper aims to provide an explorative scoping review in the field. The inclusion criteria in the final search query (see appendix 1) were based on the study's population and intervention. The AHA aspect was left out due to the risk of missing relevant data if choosing too specific search criteria for this concept already at this stage. Instead, the AHA aspect was assessed during screening; see study inclusion criteria presented in Table 1. Before the data collection, an initial search was conducted on Google Scholar to assess the relevance of the chosen search strategy, which provided eight additional keywords that fit this research's scope. The validity of the process and suitability of the obtained articles were reviewed by an independent investigator that screened all the titles and abstracts using the search string and the inclusion and exclusion criteria.

Inclusion and exclusion criteria

We searched for interventions that used a mHealth device or application specifically developed for people aged 60 years and over and focused on influencing healthcare, public health, health promotion, or healthy lifestyles. The reviewed articles were published between March 2015 and March 2020. This period provided the most up-to-date studies on the topic, which was especially relevant due to the fast pace of technology development, making older mHealth solutions obsolete. Interventions regarding pregnancy, birth control, literacy, human immunodeficiency virus (HIV), sexually transmitted diseases, and sexually transmitted infections were excluded, as these keywords did not match the scope of this review.

To make the AHA concept more tangible, a conceptual model was developed before data collection, based on literature in the field. The model presents eight aspects of AHA. Four constitute the core elements of AHA, namely: Healthy life expectancy, Wellbeing, Quality of life, and Health. The remaining four are regarded as the main factors to achieving the elements of AHA, specifically: Lifestyle, Participation, Daily functioning, and Environment. During the screening, these four main factors were used as inclusion criteria. Eight sub-factors have been identified under these factors (see Figure 1 and appendix 2).

Table 1 Study inclusion criteria, mHealth in active and healthy ageing promotion

Characteristic	Inclusion criterion	Notes
Study population	People aged 60 years and over.	*Old age* is defined as people aged 60 years and older, a benchmark often used by the United Nations [22]. Although a higher age limit for *old age* becomes more common, this review chose a relatively low bar to apply an inclusive and broad definition aiming to take the diversity of retirement ages, national development levels, and life expectancy into consideration.
	Healthy older adults	Refers to older adults not diagnosed with a chronic disease
	Independent older adults	Refers to older adults that live independently and were directly using the mHealth device themselves
Study intervention	The use of mHealth solutions	mHealth is defined as mobile communication and computing technologies supporting public health and health care practices [11,17]
Study outcome	The promotion of AHA	Outcomes are considered to target the concept of AHA if they address: lifestyle, participation, daily function, or environment (see appendix 2 and Figure 1)

Data extraction

All references were recorded in the reference manager Zotero 5.0.81 and exported for the first inspection round to the screening tool Rayyan [23]. Several ad hoc selection criteria were developed based on increased familiarity of the data to determine duplicates and suitability based on title and abstract. The remaining articles were thoroughly read and reported in a data charting form based on the *guidelines for conducting systematic scoping reviews* [24]. The form was piloted on the ten first selected articles, after which more sections were added to match the data set, and those articles were recharted. Finally, the data was charted into the following sections: literature characteristics (author, title, year of publication, reference, location), study characteristics (the aim of the study, sample size, age, technology proficiency, mean age, gender, control group, device tested on older adults, data from elderly used in device development, methodology, duration of the study, theory), mHealth details (name of the device, type of device, technology used, device and software description), AHA details (AHA target, AHA main and sub-factor) and literature findings (results).

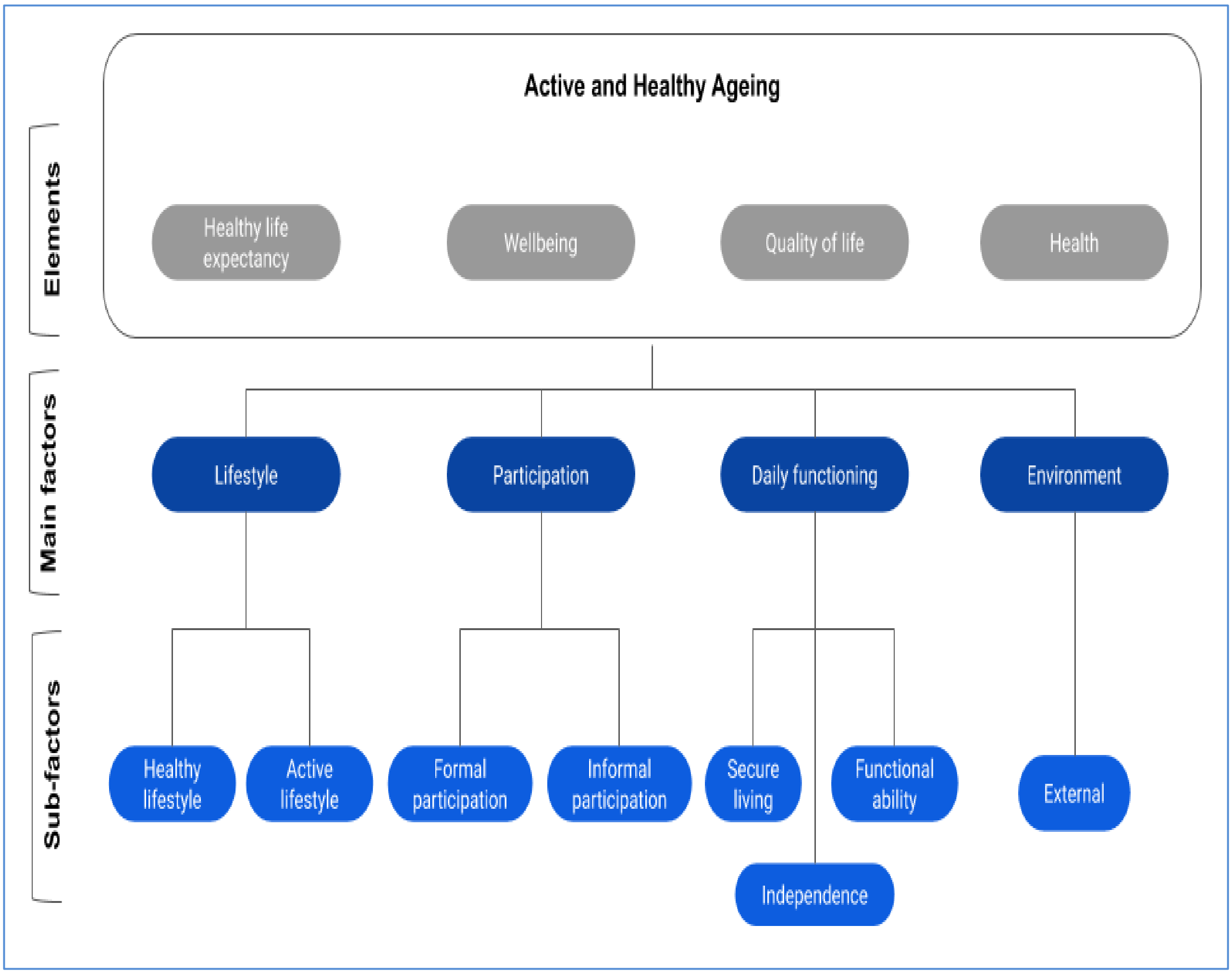

Figure 1 Conceptual model

Note. Conceptual model of active and healthy ageing elements and factors developed for this research.

Analyses

On the final data sample, numerical analysis and a qualitative thematic construction based on the conceptual model (see Figure 1) were conducted with attention to nature, extent, and type of studies included in this scoping review. To do this, the intended and unintended outcomes of each mHealth device were assessed and compared with the literature findings as portrayed in appendix 2, which forms the base of the conceptual model. Finally, to portray the use of mHealth on different AHA functions, a cross-tabulation was created.

Table 2 Exclusion criterion for articles

Reason for exclusion	Notes
Wrong population	mHealth device was not directly used by the elderly, and no age group mentioned, sample younger than 55 years, older adult diagnosed with chronic disease
Could not download the article	Full article not accessible
Wrong methodology	mHealth device not tested on older adults or older adults not consulted in the design
Not mHealth device	Devices not mobile or possessing communication/computing technologies, for example, hearing aids and mounted cameras.
Reviews	When their eligibility criteria either did not match this study's criteria or was unavailable
Other	The devices were supposed to be used at the clinic; when there were multiple studies about the same device, only the most recent paper was included; the device focused on diagnosis, treatment, or surgical recovery.

Results

In total, 2,912 references were generated on PubMed and 1,437 on Scopus. After the first round, 699 duplicates were removed, and 3,370 articles were excluded due to not meeting the inclusion criteria based on their title and abstract. The second-round assessed the body of 280 articles and concluded that 249 of them were not in line with this study's scope, mainly due to the wrong population (n = 73) and wrong methodology (n = 65) (find more details in Table 2). Finally, 31 articles remained for the final numeric and qualitative thematic analysis (see Figure 2).

Study Characteristics

The selected articles had a total of 534 participants. These studies were conducted in five continents – Asia (n = 6), Europe (n = 13), North America (n = 8), Oceania (n = 1), and South America (n = 2) – and one study was multicontinental between Asia and Europe. Most of the studies were published in 2018 (n = 10) and 2019 (n = 7), and there were no studies published in 2020 (see Table 3). When focused on the different mHealth solutions, eleven types of mHealth tools were identified, which could be grouped into four types of devices and technologies. By far, the most prominent type of mHealth device was a mobile device (n = 25), and the most popular mHealth technology was a mobile application (n = 25) (see Table 4). For the different studies' design, predominantly quantitative (n = 15) or mixed methods (n = 11) were used, whereas qualitative methods were less common (n = 5). Moreover, it became apparent that 27 studies did not have a theoretical framework on which the mHealth promotion was based.

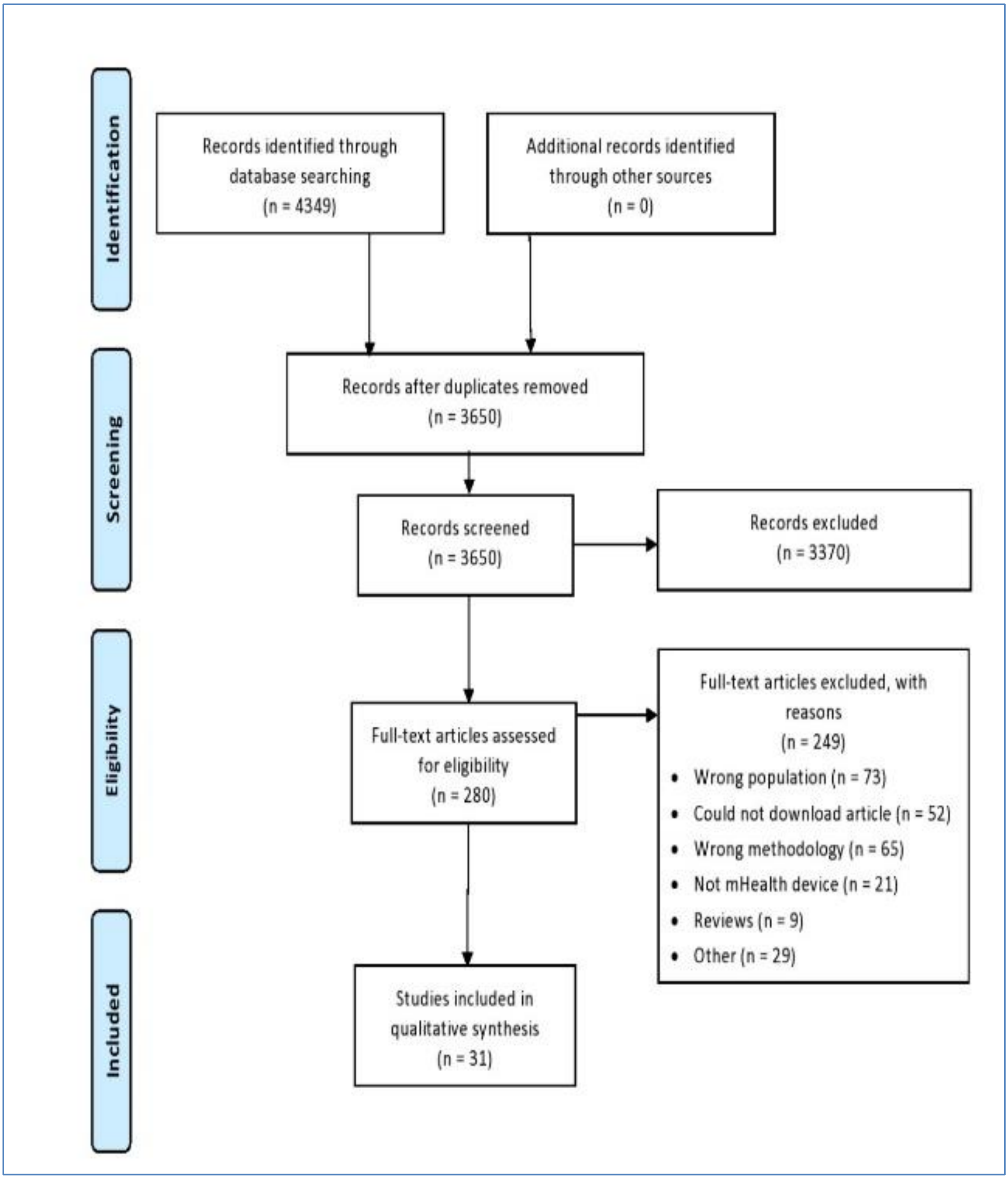

Figure 2 PRISMA flow diagram of included studies

Table 3 Characteristics of included studies in the scoping review

Author	Function	mHealth device	Intervention description	AHA main factor	AHA sub-factor	Country	Age Target population	Sample gender	Sample size	Duration of intervention
Hsieh et al., 2018 [25]	Fall risk application	Smartphone & tablet	The '*steady*' app was developed to determine the usability of fall risk apps among healthy older adults. The app contained a self-reported 13 item questionnaire of health history & progressive posture stability tests. The usability was measured using **semi-structured interviews**. Overall, the usability on smartphones had a higher mean score than the usability on tablets & instructions should be clear and straightforward.	Daily functioning	Independence & secure living	USA	70≤	Mixed	11	NA
Li et al., 2019 [26]	PA and sleeping promoter	Smartwatch, tablet & activity tracker	The pilot study evaluates the feasibility of using an activity tracker and application to improve PA (physical activity) and sleeping based on the self-efficacy theory. The feasibility was tested using **quasi-experimental** pre-and post-test without a control group**.** The study found that mHealth technology helped motivate and achieve PA goals, decreasing sedentary time, but no difference in sleep. However, the sustainability of the behavioral change is unknown as well a lack of usability was reported.	Lifestyle	Active lifestyle	USA	65-85	Mixed	8	6 weeks
Lutze et al., 2015 [27]	Ambient assisted living monitoring	Smartwatch	The created application (containing communication, orientation, localization, and detection of health hazards) for smartwatches aims at supporting and securing everyday life. The **systematic architecture assessment** found that the app's practical utility was positive but that the lack of fine motoric skills regarding the smartwatch raised concerns.	Daily functioning	Independence	Germany	younger and older seniors	Mixed	NA	a couple of weeks
Steinert et al., 2018 [28]	Activity tracker	Activity tracker & smartphone	The ´*Mooc @ home*' uses a tracking device and smartphone application to motivate PA and gain user behavior insights. The pilot study's **validated usability test, interviews, and physical tests** found that PA, balancing ability, and subjective parameters (sleep, fitness level, endurance) increased. There was no difference in BMI and subjective health.	Lifestyle	Active lifestyle	Germany	60≤	Mixed	20	4 weeks
Hill et al., 2018 [29]	Attention training	Tablet	The mobile cognitive attention training application was assessed on their usability and acceptability in home-based use. The **mixed methods (survey and interview)** showed that, on average, the participants rated the app positively and enjoyed the experience. However, they also reported a lack of engagement, confusion with use, and technical difficulties.	Daily functioning	Functional ability	USA	60≤	Mixed	12	Two weeks
Hsieh, 2015 [30]	Virtual pet	Smartphone	The mobile application *'Pet Cure'* aims to use virtual pets as communication media to assist in using medical mobile applications that observe physical and mental conditions. Based on a **group interview and questionnaire**, it was found that the virtual pets enhanced the older adults' willingness to use the medical application.	Lifestyle	Active lifestyle	Taiwan	60<	Mixed	12	1 day
Lin et al., 2016 [31]	Smart clothing	Wearable instrumented vest	The wearable instrument vest was developed to improve posture due to real-time monitoring and emergency warnings through a mobile application. The **TAM usability verification** showed a positive relationship between perceived ease of use, usefulness, attitude, and behavioral intent. However, technological anxiety towards the vest leads to a lack of willingness and difficulty with use.	Daily functioning	Independence & secure living	Taiwan	60<	Mixed	50	30 min

Stara et al., 2018 [32]	Fall risk detection via soles	Instrumented insoles & smartphone	The study reports the usability and user experience between countries with the fall-risk connected health system *'WISEL'*. The system uses foot soles and a smartphone app to measure gait and balance parameters to detect falls. The **User-Centred Design** found no major differences between countries and that safety and security were rated as highly successful.	Daily functioning	Independence & secure living	Ireland, Italy, Israel	60<	Mixed	15	3 days
Lee et al., 2016 [33]	PA promoter application	Tablet	The tablet application for on-demand exercise programs was examined for its effect on function, health status, and efficacy. The effect was tested using a **Quasi-experimental** pre-and post-test with a control group. It showed that the application combined with weekly group-based exercises is associated with increased self-efficacy, cognitive functioning, and outcome expectancy. No difference was found between the two groups on ADL and PHS measures.	Lifestyle	Active lifestyle	Korea	65≤	Females	16	4 months
Bao et al., 2018 [34]	Balance trainer	Smartphone & wearable device	This study assessed long-term balance training efficacy with sensory augmentations using an iPod and an elastic belt. The **preliminary RCT** showed that all participants completed the training without physical complaints or injuries and that the users had increased balance performance and SOT scores compared to the control group.	Daily functioning	Independence & functional ability	USA	65-85	Mixed	6	8 weeks
Shake et al., 2018 [35]	Bingo with PA and education	Tablet	The game-centered mobile application *'Bingocize'* was examined if its combination of bingo and healthy activities and education can increase PA and cognitive performance. The **quasi-experimental design** containing two groups (health education & health education + activity), showed that both groups had increased program adherence and attendance rate, but both did not show improvement in cognitive performance. The group with both health exercise and education had higher functional and physical performance than the only education group.	Lifestyle & Participation	Active lifestyle, informal participation, formal participation	USA	NA	Mixed	46	10 weeks
Deepak et al., 2018 [36]	Healthy eating application	Smartphone	The smartphone application *'ElderEat'* was evaluated on its effect on the user's daily food consumption based on their energy requirements. The **questionnaire** showed that the users had increased knowledge of the Thai Nutrition Flag and dietary guidelines. However, more than half continued to misunderstand the guidelines regarding drinking water.	Lifestyle	Healthy lifestyle	Thailand	60-80	Mixed	14	30 min
Sunghoon et al., 2019 [37]	Monitoring solution	Smartphone	The monitoring tool *'ECA'* (for the older adult) was assessed on its usability to provide an older adult with solutions for ageing problems (fall detection, pill assistance, chat, allergy, emotion, and activity log service). Based on **surveys**, it was found that the interface was not user-friendly, and it could cause a disturbance in daily routine. However, it did facility communication between children and older adults and suitability to remind mediation. However, testing was limited; thus, the system could not be evaluated properly.	Daily functioning & lifestyle	Independence, functional ability & active lifestyle	Switzerland	56-69	Mixed	9	28 h
Handojo et al., 2017 [38]	Monitoring solution	Smartphone	The study examines the mobile phone application's usability to monitor the self-health of the older adult (containing medication reminders, medical records, emergency assistance, and GPS). The **questionnaire** showed that the participants rate the information, ease of use, benefits of the applications as good.	Daily functioning	Independence & secure living	Indonesia	60≤	NA	20	NA
Zimmermann et al., [39]	PA promoter application	Smartwatch & smartphone	The PA promoter application '*EPARS*' suitability to monitor activities using smartphone and wearable sensors were examined. The study found that the app had 98.63% accuracy but that some members had false-positive occurrences due to confusion and that the notification to do exercises caused an unwelcome disturbance in their life.	Lifestyle	Active lifestyle	Brazil	60-75	Mixed	32	2 weeks
Huq et al., 2016 [40]	Fall detection application	Smartphone	The study evaluates the suitability to use axial accelerometer data through smartphones to detect falls, where detection of falls would be monitored and assisted by an operator.	Daily functioning	Independence & secure living	Australia	65≤	Mixed	57	6 months

			The pilot **data** from Raw Movement Data System and InspectLife Surveillance Web System showed that the accelerometer was suitable to measure falls. However, there are too many false fall registrations. The **feedback** from the participants shows that they are generally positive, but they did not have an increased sense of security.							
Alsager & Chatterjee, 2017 [41]	PA and cognitive training application	Smartphone	The persuasive mobile app *'Adherence Booster'* was examined on its suitability to boost older adult adherence to exercise to prevent cognitive decline. The app encourages PA and memory activities among older adult based on social cognition theory, The **RCT** shows that the amount of exercise and adherence is higher and that short-term memory was improved among the individuals who used the app; however, the number of exercises per adherent was not higher.	Lifestyle	Active lifestyle	USA	55-64, 65-74, and 75 or above)	Mixed	20	30 days
Paul et al., 2017 [42]	PA promotion via gamification (fish)	Smartphone	The interactive smartphone application '*STARFISH*' acceptability and usability to increase PA based on behavior change techniques are assessed. The **pilot BCT mapping** showed that participants outweighed the benefits above the app's difficulties, found the app easy to use, and reported positive health development (physically and psychologically). However, the layout of the app could be made more suitable to the target population and certain features of the app.	Lifestyle	Active lifestyle	United Kingdom	65<	Mixed	15	6 weeks
Santos et al., 2015 [43]	PA promoter application via gamification	Smartphone	The study describes the development of interactive games for fall prevention and rehabilitation and tests their usability. The mixed methods (**observation and validation dataset)** showed that participants found the system easy to use and that they were enthusiastic and motivated to use the app. However, they faced frustration with correctly positioning the devices as well as with inaccuracy of the algorithms.	Daily functioning & lifestyle	Independence & active lifestyle	Portugal	60<	Mixed	5	NA
Demiris et al., 2016 [44]	Fall detection device	Wearable device	The study investigates the usability of a typical automatic fall detection device with an accelerometer, magnetometer, and microphone. The **longitudinal usability study and interviews with participants** found that the participants were enthusiastic, doing it beneficial, and felt more secure. However, some subjects saw the device as a burden, had troubles maintaining the device, displeased the aesthetic, or would not take the device with them in fear of losing it.	Daily functioning	Independence	USA	62≤	Mixed	8	4 months
Davis et al., 2016 [45]	Bidirectional ambient display platform	Smartphone & Ultrabook display	The study investigates the perception of activity levels that help improve social connectedness through human activity-based ambient displays. The experimental **human activity recognition system and feedback from users** showed that participants had a sense of peace of mind, did not find wearing a phone around their waist obtrusive, increase the feeling of closeness, and increased awareness of activity levels. However, participants expressed the feeling of social distance during periods of inactivity, and some had privacy issues.	Lifestyle	Active lifestyle	Canada	72≤	Female	6	2 weeks
Sucerquia et al., 2018 [46]	Fall detection device	Wearable device	The real-time fall detection device called '*SisFall*' effectiveness is examined. The device uses a microcontroller, sensor, and GRPS transmitter to active when a fall has been detected. The pilot study's data showed that the older adult has the same ADL as the youngster, that the device registers to main false falls, and that it is not strong enough to withstand bumping or falls.	Daily functioning	Independence	Colombia	60≤	Mixed	17	1 week
Papagiannaki et al., 2019 [47]	Activity tracking application	Wearable sensors	The activity classification scheme for detecting movement patterns called the '*FrailSafe project'* effective was examined. The **experimental cross-validation** based on the deep-learning approach shows that the schema was able to unobtrusive monitor movement patterns among older adults.	Lifestyle	Active lifestyle	Greece	70-92	Mixed	20	NA

Steinert et al., 2016 [48]	Self-monitoring	Smartphone	The <u>effectiveness and suitability</u> of the self-monitoring health goals through a smartphone application called '*MyTherapy'* was examined. The **questionnaire** showed that adherence to medication guidelines, fruit intake, and fish intake improved. However, no increase was found in water intake, no PA, no weight loss, and no increase in social contacts.	Lifestyle	Active lifestyle & healthy lifestyle	Germany	60<	Mixed	30	4 weeks
Miura et al., 2015 [49]	Activity tracking	Smartphone	The smartphone-based fait measurement application for exercise '*AyuLog*' <u>effectiveness was measured, which measure daily acceleration and GPS location</u>. The **focus group, surveys, and health measurements** found that the GPS's success rate was 97.6%, and it helped maintain walking activity. Almost all participants indicated that they found using the app easily and continue using it. The app. However, no significant relationship was found among changes of walking velocity and number of walking days and distance.	Lifestyle & Participation	Active lifestyle & informal participation	Japan	60≤	Mixed	50	3 months
Ribeiro et al., 2018 [50]	Healthy eating application	Activity tracker & smartphone	The meal recommender system '*SousChef*' was developed to study <u>barriers in adopting healthier eating habits and explore new ideas to promote these habits</u>. The **individual semi-structured interviews** showed that the system allows individuals to adhere to nutrition guidelines well choosing alternative dishes than initially suggested.	Lifestyle	Active lifestyle & healthy lifestyle	Portugal	65<	NA	9	NA
Matthies et al., 2018 [51]	Activity tracker	Smartwatch	The study assesses the <u>effectiveness of step counting alerting for wrist-worn accelerometers</u>. The preliminary field study showed that a 90% recognition rate, which is way higher than other smartwatches (10%)	Lifestyle	Active lifestyle	Germany	75-82	Mixed	5	1 day
Mehra et al., 2019 [52]	PA promoter application	Tablet	The study <u>assesses a tablet-based app's usability to support an older adult in doing exercises at home</u>. Based on **user performances and interviews**, the app showed that participants successfully use it. Most of the participants were satisfied with the app use. However, some participants would prefer more extensive instructions.	Lifestyle	Active lifestyle	The Netherlands	69-99	Mixed	14	1 day
Orso et al., 2019 [53]	Food monitoring application	Smartphone	The mobile app '*Salus*' uses mobile assistance to monitor food intake. The a**pp's data and focus group**'s assessment showed that 89% of the actions were correctly targeted. The AP also received a positive evaluation of the user. However, the frequency of access decreased during the trial, lower the amount of use.	Lifestyle	Healthy lifestyle	Italy	60<	Mixed	22	1 week
Thilo et al., 2019 [54]	Fall detection device	Wearable sensor & smartphone	The study assesses the usability of the Pwearable fail detection prototype through community-dwelling involvement, based on Medical Device Technology Development Process. The focus **group** showed that the device was comfortable and easy to use. However, the battery was of low quality, needing frequent recharging and the wireless function had very limited reach. The participants also preferred more training.	Daily functioning	Independence & secure living	Switzerland	75-92	Mixed	15	9 days
Kolakowski et al., 2015 [55]	Fall detection device	Wearable & stationary node	The study assesses the effectiveness of wireless mobility and behavioral measurement system. The **mobile phone appointment, client satisfaction, and waiting list management system** showed many technical issues regarding not correctly measuring body movements and location information.	Daily functioning	Independence & secure living	Poland	65≤	NA	N/A	5 days

Table 4 Types of mHealth devices and technologies

Type of mHealth device	*n*	Type of mHealth technology	*n*
Mobile device [22, 23, 25, 27, 29, 31-40, 42, 45-47, 49, 50, 51]	25	Application [22-30, 32-40, 45-51]	25
Wearable device [23, 24, 28, 31, 36, 41, 43, 44, 48, 51, 52]	11	Movement recognition [29, 31, 36, 42, 51, 52]	6
Activity tracker [25, 29, 47]	3	Algorithm [33, 43, 44]	3
Non-wearable device [42, 52]	2	Location tracking [28, 41]	2

The sum of n per category could exceed or not reach 31 as papers can be classified in multiple sub-categories or none if the item was not reported.

AHA factors in mHealth Solutions

The articles' composition outcome showed that mHealth solutions used three main overarching factors in AHA: Lifestyle, Participation, and Daily functioning. Most of the articles focused on the AHA-related Lifestyle (n = 19) and Daily functioning (n = 14) of the older adult, with their most addressed subfactors being active lifestyle (n = 17) and independence (n = 13) (see Table 5). The studies used 21 different mHealth functions. However, only a few were reoccurring between the studies and AHA factors. The most reoccurring was activity tracking (n = 4), physical activity (PA) promoter applications (n = 4) and fall detection devices (n = 4) (see Table 5).

Table 5 Cross-tabulation of AHA domains and mHealth functions.

Main domain	Sub-domain	mHealth function	*n*	Reference index
Lifestyle	Healthy lifestyle	Healthy eating application	3	[33, 47, 50]
		Self-monitoring	1	[45]
	Active lifestyle	Active bingo	1	[32]
		Activity tracking	4	[25, 44, 46, 48]
		Bidirectional ambient display platform	1	[42]
		Healthy eating application	2	[47, 50]
		Monitoring solution	1	[34]
		PA and cognitive training application	1	[38]
		PA promoter application	4	[23, 30, 36, 49]
		PA promoter application via gamification	2	[39, 40]
		Self-monitoring	1	[45]
		Virtual pet	1	[37]
Participation	Formal participation	Active bingo	1	[32]
	Informal participation	Active bingo	1	[32]
		Activity tracking	1	[46]
Daily functioning	Independence	Ambient assisted living monitoring	1	[24]
		Balance training	1	[31]
		Fall detection application	1	[37]
		Fall detection device	4	[41, 43, 51, 52] [22]
		Fall risk application	1	[29]
		Fall risk detection via soles	1	[34, 35]
		Monitoring solution	2	[40]
		PA promoter application via gamification	1	[28]
		Smart clothing monitoring	1	
	Functional ability	Attention training	1	[26]
		Balance training	1	[31]
		Monitoring solution	1	[34]
	Secure living	Fall detection application	1	[37]
		Fall detection device	2	[51, 52]
		Fall risk application	1	[22]
		Monitoring solution	1	[35]
		Smart clothing monitoring	1	[28]

The sum of n per category could exceed or not reach 31 as papers can be classified in multiple sub-categories or none if the item were not reported on

Implementation Evaluation of mHealth Solutions for AHA Promotions

The outcome of the implementation of mHealth solutions can facilitate understanding of how mHealth can promote AHA. Many solutions address multiple AHA factors; thus, to avoid duplication and a skewed perspective of the outcomes, the solutions are not explored per factor. Instead, three evaluation themes were identified during data analysis, which is: Outcome evaluation, Participatory satisfaction evaluation, and Technical process evaluation. Based on the studies' results, almost one-third (n = 13) reported specific unsuccessful outcomes. These were mainly on the theme's satisfaction/enthusiasm of participants, improved physical activity, or general health improvements. Twenty studies reported general successful outcomes; the reasons of the studies' success generally conceded with the opposite that caused unsuccessful outcomes of the other studies (see Table 6). However, most studies did not offer specific explanations of how the (lack) of success was measured and determined. The participatory satisfaction evaluation provided insights into how the participants experienced the mHealth solution, which can be a prerequisite for successful implementation. The reasons for positive (n = 12) and negative experiences (n = 11) were concurrent: the device's usability. Individuals had a negative experience when they were met with resistance or faced challenges in using the device but a positive experience when it was easy to use (see Table 6). Several studies indicated a need for more age-appropriate designs or multiple versions of the same device to address the heterogeneity in the population and a cultural change among older adults to reduce the stigma around fall detection devices [44, 54]. It was visible that most studies focused less on user experience and more on their mHealth solution's technical development. Eleven studies reported positively, and nine studies negatively on this aspect. The most common reasons for technical challenges were that the devices/applications issued off too many false alarms, and the data was not accurate enough to support the older adult in their everyday life sufficiently. These outcomes highlight that not all mHealth solutions have sufficiently developed technical systems, especially fall detection devices appear to require improvement (see Table 6).

Table 6 Implementation evaluation of mHealth solutions for AHA promotions

Evaluation	Classification Category	Reason	*n*	Reference
Outcome evaluation	Successful outcome	Improved PA	9	[23, 25, 31, 32, 38, 45, 46]
		Increased health consciousness	5	[25, 30, 39, 46, 49]
		Increased social engagement	4	[37, 39, 42, 46]
		Increased feeling of security	3	[22, 37, 41
		Improved cognitive functioning	3	[26, 30, 42]
		Boosted high adherence to the intervention	2	[32, 38]
		Overall satisfied and/or enthusiastic	9	[26, 29, 32, 35, 37, 40, 41, 49, 50]
		Increased knowledge	2	[22, 23]
	Unsuccessful outcome	None or modest PA improvements	5	[25, 30, 32, 39, 45]
		None or modest general health improvements	4	[23, 31, 45, 46]
		No perceived need of a device	1	[41]
		Device disturbing	2	[35, 41]
		No increased feeling of safety	1	[37]
		Lack of engagement	2	[26, 40]
		No knowledge increase	1	[33]
Participatory satisfaction evaluation	Positive user experience	High usability	6	[22, 24, 33, 35, 38, 50]
		Easy to use	9	[22, 28, 31, 35, 39, 40, 49, 50, 51]
	Negative user experience	Challenging to use device	11	[22, 23, 24, 28, 33, 37, 39, 41, 46, 49, 51]
		Resistance to using the device	4	[28, 37, 41, 51]
Technical process evaluation	Technical benefits	Specific technology proved useful	6	[23, 27, 31, 34, 44, 46]
		Positive technological outcomes	3	[36, 46, 48]
		Not feeling limited by wearing the device	3	[37, 42, 50]
	Technical challenges	Negative influence on everyday life	1	[51]
		Poor accuracy	2	[30, 52]
		False fall alarms	5	[36, 37, 41, 43, 51]

The sum of n per category could exceed or not reach 31 as papers can be classified in multiple sub-categories or none if the item were not reported

Conclusion

The conducted explorative scoping review aimed at providing a first overview of contemporary preventive mHealth solutions that promote AHA among healthy, independent older adults.

Main findings

The 31 reviewed articles showed that most studies were conducted in either Europe or North America and that the most prevalent mHealth solutions were activity trackers, fall detection devices, and physical activity (PA) promoter applications. Regarding AHA factors, the most addressed were Lifestyle and Daily functioning. Only two studies targeted the factor of Participation, and none focused on the Environmental factor. Regarding the methods to achieve AHA, the studies generally aimed at improving an active lifestyle and increasing/maintaining independence.

The scoping review also showed that the mHealth promotion studies mainly focused on the technical development of the device or application and lacked focus on the effects the mHealth solution had on AHA behavioral change. The causation might be due to both a deficiency of methodological rigor and the absence of theoretical foundations.

According to user experiences, many studies reported a lack of ease of use and suitability to the target population. The leading cause was that the mHealth solutions were disrupting older adults' life. Even though the older adults were at the center of these mHealth devices' development process, often the tools were not adapted appropriately for their everyday life. Highlighting, once again, the importance of increased inclusion of older adults in the design and development of mHealth solutions and repeated usability tests before final implementation. In general, more negative remarks were recorded regarding the devices' user experience than the technological capabilities of the solutions, which indicates that the lack of technical development is less of an issue than the usability of the solution.

Strengths and limitations

This scoping review was able to screen a broad scope of references, providing new insights into the width and depth the field of mHealth solutions has for AHA. The methodology allowed for the inclusion of a wide variety of study designs as it did not exclude references based on quality [20]. The review shows the importance of high technology standards, understanding users' perspectives regarding both their needs and specific solutions' usefulness, and what type of health behavior the devices can influence.

Nevertheless, the research was limited as only published, and peer-reviewed articles were included, which led to the exclusion of publications on commercial mHealth solutions. Besides, scoping reviews are naturally limited due to their secondary data, which only shows what the original authors reported on and not the entire data set. Finally, this method does not aim to synthesize evidence [18]; thus, this research was unable to generalize the effectiveness of mHealth solutions among healthy older adults.

Interpretation

To create, adapt, and adopt successful mHealth solutions for the promotion of AHA behaviors, we propose that future studies could benefit from being grounded in a rigorous methodological and theoretical foundation by using an integrated multidisciplinary approach and focusing on the effects of mHealth solutions on AHA behavioral change. To increase the chance of successful implementation and adoption by older adults, new studies should aim to target a wider variety of AHA factors instead of trying to improve only one.

This research provides intervention developers, healthcare professionals, and mobile tech developers with an initial overview of AHA promotion's mHealth field. It offers information to facilitate investment, implementation, and scaleup of successful mHealth solutions. These suggestions can be used to avoid duplicating mistakes and create new effective mHealth solutions. Ultimately, integrating these suggestions could empower older adults to autonomously care for their health and increase their amount of independent, healthy life years, thus decreasing the pressure on healthcare systems and the working-age population caused by the increasing old-age dependency ratio.

Conclusions

mHealth can promote older adults' AHA behavior by targeting their Lifestyle, Participation, and Daily functioning. More specifically, addressing older adults' independence and an active lifestyle are the most common ways of AHA promotion, mainly materialized through activity tracking, PA promotion, and fall detection.

This review focused on mHealth solutions developed specifically for older adults. However, many older individuals experienced challenges when using the devices—underlining the importance of using an integrated approach where the target population is heavily involved in the design, implementation, and maintenance of the mHealth solutions. Besides, the reviewed studies showed a lack of methodological rigor and theoretical foundation and concentration on the effects that mHealth solutions have on AHA behavioral changes. By applying multidisciplinary approaches, improvements could be made, where both social scientists for behavioral change and mobile technology engineers work together.

In conclusion, this research provides an initial overview of contemporary mHealth solutions promoting AHA among healthy and independent older adults. Through further development and upscaling of mHealth solutions, more will be known about their viability to empower older adults and decrease the pressure on the healthcare system caused by an ageing population.

Abbreviation

mHealth: mobile Health; AHA: Active and Healthy Ageing; HIV: Human Immunodeficiency Virus; PA: Physical Activity; RCT: Randomized Control Trial; BCT: Behavior Change Techniques

Declaration

Acknowledgment

The authors would like to acknowledge the support that was received from dr. Cha-Hsuan Liu. Her guidance and knowledge on social science methodology and healthcare is highly appreciated.

Funding

The authors received no financial support for their research, authorship, and/or publication of this article.

Availability of data and materials

Data will be available by emailing Lina Marcussen: lina.marcussen@gmail.com

Authors' contributions

Authors are equally participated in this work. All authors have read and approved the final manuscript.

Ethics approval and consent to participate

We conducted the research following the Declaration of Helsinki. However, the Review Article needs no ethics committee approval.

Consent for publication

Both authors declare to have provided substantial contributions to the conception or design of the work, including the acquisition, analysis, and interpretation of data. They have both participated in drafting the work and revising. Lina Marcussen's contribution is weighted in the

collection of the data and Jesse David Marinus had a prominent role in the revision.
Both authors have given final approval of the version to be published and agreement to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

Competing interest
The authors declare that they have no competing interest.

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Article Info
Received: 28 November 2020
Accepted: 08 February 2020
Published: 20 March 2021

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Appendix 1 Final search query

Search ((((((((((mobile applications[MeSH Terms]) OR wearable electronic devices[MeSH Terms]) OR microcomputers[MeSH Terms]) OR cell phones[MeSH Terms]) OR (mHealth[Title/Abstract] OR Mobile health[Title/Abstract] OR Mobile application*[Title/Abstract] OR Mobile health application*[Title/Abstract] OR mHealth app[Title/Abstract] OR health app[Title/Abstract] OR cell phone[Title/Abstract] OR cell phones[Title/Abstract] OR mobile phone[Title/Abstract] OR mobile phones[Title/Abstract] OR microcomputer[Title/Abstract] OR microcomputers[Title/Abstract] OR desktop computer[Title/Abstract] OR desktop computers[Title/Abstract] OR laptop[Title/Abstract] OR laptops[Title/Abstract] OR personal computer[Title/Abstract] OR personal computers[Title/Abstract] OR wearable electronic device[Title/Abstract] OR wearable electronic devices[Title/Abstract] OR iPad[Title/Abstract] OR iPads[Title/Abstract] OR smartphone[Title/Abstract] OR smartphones[Title/Abstract] OR smartwatch[Title/Abstract] OR smartwatches[Title/Abstract] OR mobile device[Title/Abstract] OR mobile devices[Title/Abstract] OR mobile technology[Title/Abstract] OR text messaging[Title/Abstract]))) **AND** ((((Health[MeSH Terms]) OR (Health Care Quality, Access, and Evaluation[MeSH Terms])) OR Public health[MeSH Terms]) OR (health[Title/Abstract] OR public health[Title/Abstract] OR health care[Title/Abstract] OR healthcare[Title/Abstract] OR Health management[Title/Abstract] OR health promotion[Title/Abstract] OR healthy lifestyle[Title/Abstract] OR healthy lifestyles[Title/Abstract]))) **AND** (((Aged[MeSH Terms]) OR (Aged, 80 and over[MeSH Terms])) OR (older adult[Title/Abstract] OR "old aged"[Title/Abstract] OR old-aged[Title/Abstract] OR "older adults"[Title/Abstract])))) **AND** "last 5 years"[PDat] AND English[lang])) **NOT** (Pregnant[Title/Abstract] OR pregnancy[Title/Abstract] OR birth control[Title/Abstract] OR Literacy[Title/Abstract] OR HIV[Title/Abstract] OR sexual transmitted diseases[Title/Abstract] OR sexual transmitted infections[Title/Abstract]) Filters: published in the last 5 years; English

Appendix 2 References for conceptual model

Elements	Health	Wellbeing	Healthy life expectancy	Quality of life
Aspects	Optimizing opportunities for health [7]	Well-being [social, mental, and physical] [56]	Increased average healthy lifespan [56]	Quality of life [7]
	People are able to live healthy lives [57]	Enable well-being [6]	Increased healthy life expectancy [5]	Quality of life [domain] [56]
	Optimizing opportunities for health and social care [5]	Well-being [domain] [56]	Increased healthy life years [5]	Increase quality of life [5]
	Functioning of underlying physiological systems across the life course [domain] [56]	Well-being [mental, social, physical] [5]		
	Reduced disability [5]			

Main factor	Lifestyle		Participation		Daily functioning			Environment
Sub-factor	Healthy lifestyle	Active lifestyle	Formal participation	Informal participation	Independence	Functional ability	Secure living	External
Aspects	Lifetime lifestyles [factor] [56]	Physical active [7]	Participation in labour market [7]	Optimising opportunities for participation [7]	Maintained autonomy and independence [7]	Functional ability [developing and maintaining] [7]	Optimising opportunities for security [7]	Environment [social, physical and policy] [6]
	Adoption of healthy lifestyles [behavioural change] [9]	Activity [cognitive, social, and physical] [9]	Continued participation in the formal labour market [57]	Participation in economic-, spiritual-, cultural-, civic- and social-affairs [7]	Reduced dependency [5]	Capacities [mental and physical] [6]	People are able to live secure lives [57]	Lifetime physical, economic, and social environment [factor] [56]
			Working and caring, lifelong learning, education [factor] [56]	Engagement in unpaid productive activities [57]	People are able to live independent lives [57]	Capabilities across the life course [physical and cognitive] [domain] [56]		Capacity and enabling environment [domain] [57]
				Working and caring, lifelong learning, education [factor] [56]	Prolonging the number of independent and healthy years during old age [9]	Remain functional abilities [9]		