Utrecht University, Social Policy and Public Health

Promotion of Active and Healthy Ageing through mHealth for Healthy Older Adults: a scoping review

Course: Thesis Based on Existing Data (201800155)

Lina Marcussen, 6663311

2020-06-05

Supervisor: Cha-Hsuan Li

Abstract

Our population is getting older than ever before. Between 2015 and 2050, the number of people aged 60 and over are expected to almost double. Simultaneously, the share of working aged people is decreasing, which highlights the impact of population aging on the labour market and increases the economic pressure on healthcare systems. One strategy to address the challenges faced by an ageing population, is promotion of active and healthy ageing. Mobile health (mHealth) has spread rapidly the past decade and is believed to be able to materialise this strategy.

This paper aims to provide an informed overview and analysis of contemporary mHealth solutions that promote active and healthy ageing among older adults. A scoping review has been conducted, focused on references published between 2015-2020 addressing mHealth devices that targets older adults aged 60 or over. The initial search resulted in 4349 publications, after inclusion and exclusion criteria were applied 31 remained for the review. The majority of the studies were published between 2018 and 2019 in Europe. Most of them utilise either smartphones or tablets, however diverse types of activity trackers and wearables are also registered. mHealth solutions mostly promote active and healthy aging through targeting elderlies' active lifestyle and independence.

The research concludes that mHealth can promote active and healthy ageing among healthy and independent elderly by targeting their lifestyles, participation in society and daily functionings. However, more focus should be put on the development of mHealth solutions specifically for older adults, to make the devices a natural part of the elderly's everyday life. mHealth offers an opportunity to combat the issues faced by an aging population, by empowering elderly to stay independent and healthy as long as possible.

Key words: mHealth, mobile health, active and healthy ageing, prevention, ageing population

Introduction

This research focuses on mobile health (mHealth) solutions that promote active and healthy ageing (AHA) among healthy elderly. Healthy older adults are targeted as the research aims to generate an overview of the contemporary field of mHealth solutions available to prolong good health while ageing and thereby tackle problems related to an ageing population.[1]

Due to improvements in education, healthcare, sanitation, nutrition and economic wellbeing, people are living longer than ever before (UNFPA, 2015). Persons aged 60 years and older make up the fastest growing age group. Between 2015 and 2050, the number of people aged 60 and above in the global population is expected to almost double, from 12 to 22 per cent (see figure 1) (WHO, 2018). With the right sets of policies, individuals and societies would be able to reap the benefits of ageing, however ageing also poses social and economic challenges (UNFPA, 2015).

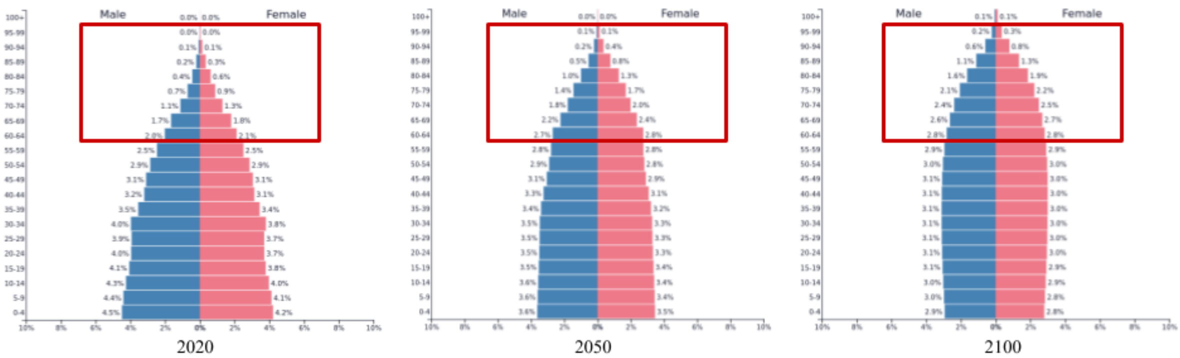
Population ageing will influence the potential support ratio, which can be understood as the number of working age (people aged 25-64) per person aged 65 years and older. In 2019, this ratio stretched between 11.7 in sub-Saharan Africa to 1.8 in Japan. These numbers indicate that in sub-Saharan Africa there is a high support ratio due to a large share of working aged people compared to elderly, while in Japan there are relatively few of working age to care and provide for the older generation. During the coming decades, the ratio is projected to decrease in all regions. Low values will accentuate the impact of population ageing on economic performance and the labour market, and heighten the economic pressure many countries are likely to face in relation to public systems such as healthcare (UN, 2019).

To address the challenges and expenses an ageing population poses to the healthcare sector new approaches are needed (Ureña et al., 2018). For older adults to be able to stay active and healthy for a longer time (Umb-Carlsson, 2020), a shift from treatment based healthcare to *prevention* is required, in combination with innovative solutions able to *empower* old adults to autonomously care for their own health and stay healthy longer (Helbostad et al., 2017). Promotion of AHA is one strategy to deal with the ageing population. The concept of AHA refers to the process of increased healthy life years, quality of life and healthy life expectancy for all people as they age (Bousquet et al., 2019). It builds

[1] The terms elderly and older adults are used interchangeably in the paper to refer to healthy people aged 60 or above.

Figure 1

World population



Note. World population pyramid 2020, 2050 and 2100 (Populationpyramid.net, 2019)

on the maintenance of functional abilities (WHO, 2020) and promotes autonomy and independence among old-aged (WHO, 2002).

One tool that has grown in popularity the last decade and is suggested to be able to offer the means to stimulate active and healthy lifestyles is mHealth (Helbostad et al., 2017). mHealth, mobile devices supporting public health and healthcare practices, can be pedometers for step counting, smartphone applications and many other solutions (Hamine et al., 2015; Kampmeijer et al., 2016). mHealth technologies are believed to offer a promising approach of designing interventions adapted to the changing needs of an individual (Freigoun et al., 2017).

This research investigates how mHealth solutions can be used to tackle the challenges posed by an ageing society. A scoping review is used to be able to understand if ageing actively and healthy by using mHealth solutions can prolong elderlies' number of healthy and independent years and thus potentially decrease the pressure on public systems that an ageing population otherwise causes. The aim of the research is to provide an informed overview and analysis that can be used by policy makers to upscale successful interventions, as well as by researchers and developers to avoid duplication and finally to further the understanding of the use of AHA as a theoretical concept in mHealth interventions.

Active and Healthy Ageing

The theoretical considerations of this thesis are based on the concept of AHA. This concept has been selected due to recurrent suggestions that both active ageing and healthy ageing are viable approaches to tackle the societal challenges faced by an ageing population (Beard et al., 2016; Marsillas et al., 2017; Narushima et al., 2018; WHO, 2020). There is no universal definition of AHA, thus follows a disquisition of contemporary understandings of AHA and its application in this study.

The World Health Organisation (WHO) currently runs a project called “Global strategy on Ageing and Health”. Two different plans have been launched within this strategy, one promoting *active ageing* and the other *healthy ageing* (WHO, 2020). The first one offers a broad understanding of *active ageing* as “the process of optimizing opportunities for health, participation and security in order to enhance quality of life as people age.” (WHO, 2002, p.12). To achieve this, maintaining independence is a key goal when growing older both from an individual and policy perspective. Furthermore, the plan understands *being active* as more than being physically active or labour market participation, but for instance continued participation in economic, spiritual, cultural, civic and social affairs. In the same plan, *health* is referred to as social, mental and physical wellbeing (WHO, 2002). Moreover, the second plan explains *healthy ageing* as “developing and maintaining the functional ability that enables wellbeing in older age” (WHO, 2020, p.3). WHO finds functional ability to be determined by three factors. Firstly, the combination of an individual’s mental and physical capacities; secondly, the environment in which the individual lives, including social, physical and policy environment; and finally, the interaction between factor one and two (WHO, 2020).

On a European level, the European Commission runs the European Innovation Partnership on Active and Healthy Ageing (EIP on AHA) to address the societal challenges a rapidly ageing European population poses to AHA through innovation and digital transformation (European Commission, 2020). The build-up of the EIP on AHA triggered the development of a standard operational definition of AHA. Based on the work of Kuh et al. (2014) a conceptual framework was developed. This framework includes six aspects, firstly three key domains of AHA: 1) capabilities across the life course (physical and cognitive), 2) well-being and quality of life, and 3) functioning of underlying physiological systems across the life course. In addition to these are three key factors influencing AHA: 4) working and caring, lifelong learning, education, 5) lifetime lifestyles, and 6) lifetime physical, economic and social environment (Bousquet et al., 2015). The framework was developed into the following definition “the process of optimizing opportunities for health and social care to increase healthy life expectancy, healthy life years and quality of life for all people as they age" (Bousquet et al., 2019, p.70). From this perspective, AHA allows people to realise their potential for mental, social and physical well-being throughout their life course while simultaneously contributing to the sustainability of social and health systems, while reducing disability and dependency (Bousquet et al., 2019).

Another understanding of AHA is given by Zaidi et al.'s (2017). To measure AHA in Europe, they selected the following domains from the Active Ageing Index, a tool developed by the European Union, namely: employment; participation in society; independent, healthy and secure living; and capacity and enabling environment for active ageing. Their definition of AHA used for the selection was:

> the situation where people are able to live healthy, independent and secure lives as they age and thus continue to participate in the formal labour market as well as engage in other unpaid productive activities (such as volunteering and care provision to family members). (Zaidi et al., 2017, p. 143).

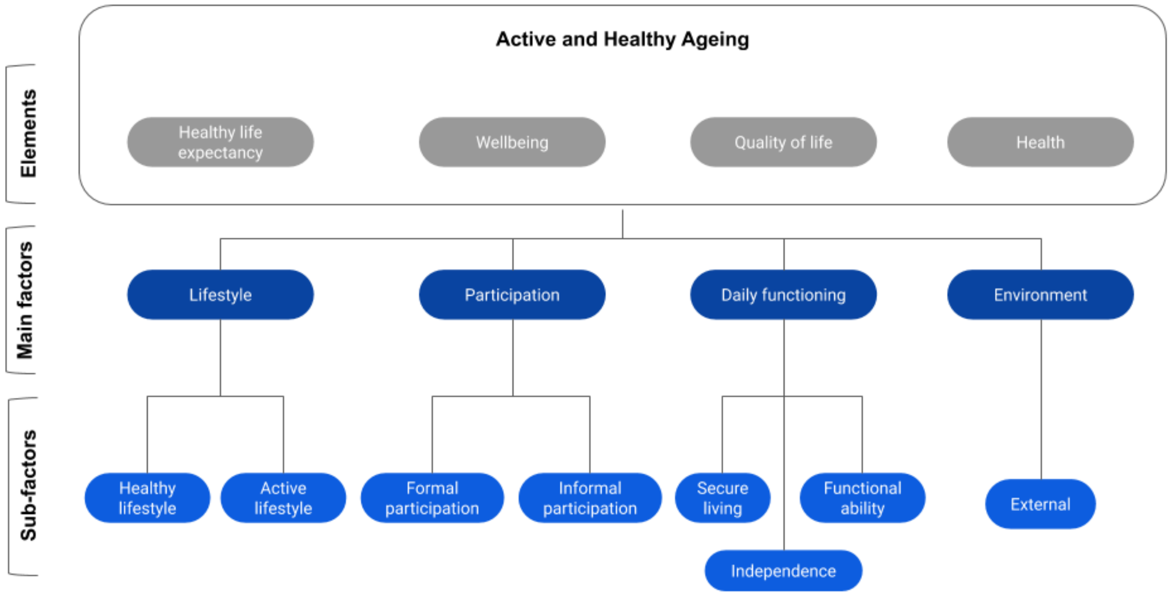
Finally, Helbostad et al. (2017) argue that AHA is necessary for prolonging the number of independent and healthy years during old age for and remaining functional abilities. To promote AHA, they suggest that interventions must be targeted at detecting risk factors related to old age functional decline. They claim that achieving AHA requires adoption of healthy lifestyles, which often builds on behavioural change. Further, they highlight that to be able to promote active and healthy ageing, focus must be put on cognitive, social and physical activity (PA).

There are some differences and similarities in these understandings. Bousquet et al. (2019) focus on opportunities for health and refer to rather abstract concepts such as "quality of life". Zaidi et al. (2017) take a broad perspective on AHA, and include participation in society, which is in line with WHO's definition of *active ageing*. Finally, Helbostad et al. (2017) follow the same line as WHO's definition of *healthy ageing* and focus on functional abilities at old age.

This research compiles the main aspects of AHA suggested from the literature and concludes a concept model to make the concept more tangible. The aspects have been grouped into eight main categories. Four of these constitute the core elements of AHA, namely: *Healthy life expectancy, Wellbeing, Quality of life* and *Health.* The remaining four are regarded as main factors to achieve the elements of AHA, specifically: *Lifestyle, Participation, Daily functioning* and *Environment.* These can be understood as the building

Figure 2

Concept model



Note. Concept model of active and healthy ageing developed for the purpose of this research.

blocks to achieve AHA. Eight sub-factors have been identified under these factors (see figure 2, appendix 1).

mHealth and Ageing

Mobile devices are growing in popularity and have become everyday items for many. The spread of tablets and smartphones in the last decade, offering advanced computing and communication capacities, has led to a strong development of mHealth (Zapata et al., 2015). mHealth is a sub-branch of *electronic health*, known as eHealth, referring to the application of information and communication technology to affect health (Zuehlke et al., 2009). mHealth refers to the usage of *mobile* communication and computing technologies in public health and healthcare (Free et al., 2010). It is used for promotion of healthy lifestyles as well as treatment, diagnosis and prevention of chronic diseases. Central in mHealth is the involvement of patients in the design and implementation of strategies to increase quality of life and improve health (Recio-Rodríguez et al., 2019). mHealth interventions are based on mobile electronic devices, such as mobile phones, smartphones, wearables, tablets, medical devices connected to phones and personal digital assistants. Today, short message service (SMS) is the most frequently used feature of mHealth (Dicianno et al., 2015; Free et al., 2010;

Marcolino et al., 2018). Examples of mHealth solutions targeting older adults are those tracking health information, such as falls, heart rate, steps, sleep quality and blood glucose (Wang et al., 2018).

In a broad sense, mHealth applications can be divided into two subgroups, those aimed at *health behavioural change* and those addressing *disease management.* Applications targeting the former include for example personal digital assistant applications to reduce calorie intake and smoke cessation through text messages. The latter targets depression treatment, adherence to medication and diabetes controls among other things (Helbostad et al., 2017). Faiola et al. (2019) suggests a third category of mHealth solutions, namely those targeting *healthy lifestyle behaviours.* This approach targets both prevention and disease management through health behaviours, such as physical inactivity and dietary habits.

In a systematic review on mHealth, Marcolino et al. (2018) find positive results from mHealth solutions in areas such as chronic disease management, improving quality of life and reducing hospitalisation and deaths, and confirm findings from previous research about the growing popularity of mHealth. However, also in line with previous research, the review states that in general the efficacy of mHealth interventions is still limited (Hamine et al., 2015; Helbostad et al., 2017). Some argue that this is due to lack of sufficient methodology in the development of the interventions (Hamine et al., 2015; Marcolino et al., 2018). Others attribute this to the lack of relevant theory in mHealth interventions, despite its proven benefits (Bull & Ezeanochie, 2016; Dahlke et al., 2015; Helbostad et al., 2017). Another weakness is the one-dimensionality of most applications, addressing merely one function, such as PA (Helbostad et al., 2017).

Regarding the older population, the adoption of health-related digital technology has been slow. However, thanks to the development of easy to use devices this trend is changing (Recio-Rodríguez et al., 2019). mHealth has become frequently more used within the ageing population, due to its convenience and ability to monitor individuals' chronic diseases and wellbeing, as well as provide continued information and support (Fletcher & Jensen, 2015). Positive results have been reported from interventions facilitating behavioural change and increasing PA targeting older people (Helbostad et al., 2017). For example, mobile applications are able to empower older adults by providing the means for PA profiles, social support and goal-setting, among other features (Steinert et al., 2018). On the other hand, most mHealth solutions and devices have not been developed specifically targeting the preferences and needs of elderly, nor involved them in the design process (Dasgupta et al., 2016;

Helbostad et al., 2017). Although current deployment of mHealth is hampered by older adults' low adoption of communication and information devices as well as their low digital literacy (Devos et al., 2015), it is expected that as digital experience increases, there will be an increase of routine integration of digital technology into older adults' health management strategies (Recio-Rodríguez et al., 2019). Helbostad et al. (2017) suggest that there is a need for the development of mHealth interventions specifically for older adults due to growth of this share of the population. For the elderly to accept mHealth tools, they must fit their lifestyle, goals and expectations as well as represent a clear benefit to them (Devos et al., 2015).

Research focus

Through applying a scoping review methodology, this research aims to explore how issues caused by an ageing society, such as increased pressure on public systems, can be prevented by using mHealth solutions to empower elderly to autonomously care for their own health and increase their amount of healthy life years. The research addresses preventative mHealth solutions promoting AHA. Therefore, *health behaviour change*-mHealth interventions targeting healthy and independent older adults are in focus. The objective of the study is to provide an informed overview and analysis of contemporary mHealth solutions with a preventative approach promoting AHA, that can be used by policy makers as well as researchers and developers. On an individual level, this could empower older adults to be in control of their own health and enjoy more independent and healthy years. On a societal level, the goal is to increase the recognition of available mHealth solutions to encourage further employment, investment and support. To achieve this, the research question guiding this scoping review is: *How can active and healthy ageing among healthy older adults be promoted through mHealth solutions?*

Methods

Research design

This research is conducted using a scoping review to get insight into the entire field of mHealth solutions promoting AHA. Scoping reviews are particularly useful when a field of literature not yet has been comprehensively reviewed, which is the case regarding mHealth solutions promoting AHA (Peters et al., 2015). As a too strict data collection process might lead to overlooking relevant references, scoping review has been selected instead of the more prevalent systematic review. Compared to a systematic review, a scoping review allows for an iterative process of data collection and redefinition of search terms throughout the process (Arksey & O'Malley, 2005). Additionally, the scoping review encourages inclusion of a variety of study designs and does not exclude references based on quality (Peters et al., 2015). These characteristics are appreciated as valuable to this study. In short, a scoping review allows for "a process of summarising a range of evidence in order to convey the breadth and depth of a field" (Levac et al., 2010, p. 1).

Arksey and O'Malley (2005) provide a six-stage framework for conducting a scoping review. Stage 1, i*dentifying the research question,* included the process of defining all parameters of the research question, for which the PICO (Population, Intervention, Comparison, Outcome) tool was applied. The P, I and O are used to define key elements of the review question. C was excluded as a comparison group is not relevant to answer this research question (Cooke et al., 2012). *Population* is defined as people aged 60 or over, which is the current benchmark for WHO (UN, 2017; WHO, 2018). This age is used to apply an inclusive and broad definition of ageing aiming to take the diversity of retirement ages, national development levels and life expectancy into consideration. *Intervention* refers to mHealth devices, which are defined as mobile communication and computing technologies in public health and health care (Free et al., 2010). *Outcome* refers to the promotion of AHA. Solutions are regarded as targeting the concept of AHA if they address any of the main factors identified in the literature: *Lifestyle*, *Participation*, *Daily functioning* and *Environment* (see figure 2). What is regarded as AHA in this study can be seen in the concept table developed from the literature study (see appendix 1).

Stage 2, *identifying relevant studies*, entailed developing and applying the search strategy. The first step was to develop the search strategy model (see appendix 2). The model is based on the definitions of the intervention (mHealth) and population (people aged 60 or more). AHA was left out due to the risk of missing relevant data if choosing too specific search criteria for this concept. To still include the health dimension, mHealth was divided into two elements, the *technological* and the *health aspect.* The model consists of two search term sections per concept, one for "controlled vocabulary terms" which were found using PubMed's MeSH term tool (for definitions of the MeSH terms see appendix 3), and one for "free text terms" which were identified during literature studies and using Oxford's online dictionary. Once a draft search strategy was developed, an experienced librarian was consulted to refine the strategy. When refined, a preliminary search on google scholar was conducted with some of the key words to test if they generated relevant references and to find additional keywords. Eight additional keywords were found through this strategy, and a few more by scanning key words in some of the already identified relevant articles. Finally, the strategy was tested to validate the relevance of the references. During this process a "NOT" section was included to limit the amount of irrelevant references. In this section *HIV*, *sexual transmitted diseases*, *sexual transmitted infections*, *pregnant*, *pregnancy*, *birth control* and *literacy* were added.

Field criteria for the review limited the references to studies published in English during the past five years. That five-year period stretches between March 2015 and March 2020, as the latter is when data collection was carried out. This period was selected to generate the most recent references. Two electronic databases were used based on recommendation from the librarian. PubMed was used for biomedical references, and generated 2912 references (see exact search query in appendix 2). Scopus was used for a general search, and generated 1437 references. Both databases include only peer reviewed references. All references were recorded in the reference manager Zotero 5.0.81, and then exported to the screening tool Rayyan where the first screening round was done (Ouzzani et al., 2016).

Stage 3, *study selection*, consisted of two screening rounds. In the first round, duplicates were deleted and titles and abstracts from all references were screened. The methodology of a scoping review allows for an iterative process of data collection (Arksey & O'Malley, 2005), thus based on increased familiarity with the data ad hoc selection criteria was developed to ensure the relevance of the references. In the second round, the full articles were downloaded and assessed. There were no limitations to the region or institution of publication. References were excluded based on the following eligibility criteria: *wrong population* (mHealth device was not directly used by the elderly, no age group mentioned, sample younger than 55 years, elderly diagnosed with chronic disease), *wrong methodology* (the solution was not tested on elderly or elderly was not consulted in the design), *not mHealth device* (for example, hearing aids and mounted cameras), *reviews* (since their eligibility criteria either did not match this study's criteria or was unavailable), *other* (device supposed to be used at clinic; when there were multiple studies about the same device only the most recent paper was included; device focused on diagnosis, treatment or surgical recovery). A PRISMA flow diagram is used to visualise the data selection (see figure 3).[2]

Stage 4, *charting data,* refers to the technique of interpreting data according to key themes (Arksey & O'Malley, 2005). A "data charting form" was developed in Excel inspired by the guidelines from Peters et al. (2015), and data from the selected studies was charted into the following sections: *literature characteristics* (author, title, year of publication, reference, location), *study characteristics* (aim of study, sample size, age, technology proficiency, mean age, gender, control group, device tested on elderly, data from elderly used in device development, methodology, duration of study, theory), *mHealth details* (name of device, type of device, technology used, device and software description), *AHA details* (AHA target, AHA main and sub-factor) and *literature findings* (results).

Stage 5, *collecting, summarising and reporting results.* To report the results a numerical analysis was created to give attention to the nature, extent and type of studies included in the review. To be able to report a narrative account from the studies, a thematic construction based on the theoretical framework was applied (Arksey & O'Malley, 2005). The literature was organised thematically according to the factors identified in the theoretical framework of AHA and a cross-tabulation was developed to portray the relationship between the mHealth solutions and the factors (see results section).

Stage 6, *consultation exercise,* aims to validate and inform findings from the previous stages. Although some regard this stage as a requirement (Daudt et al., 2013), others see it as optional (Arksey & O'Malley, 2005). It has not been included in this study due to the challenge of finding an unbiased expert in regard to the breadth of the field, as well as time limitations.

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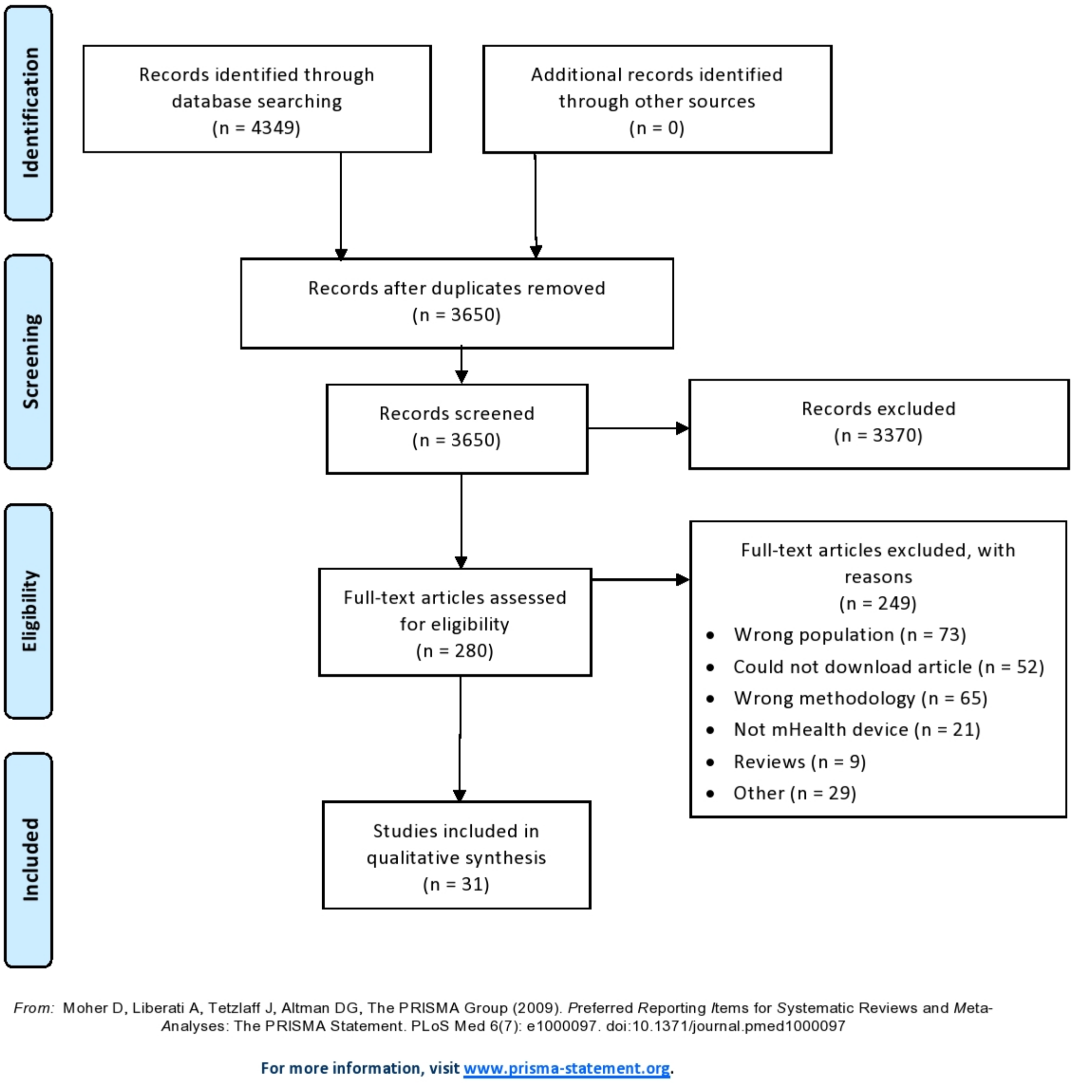
[2] Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA)

Figure 3

PRISMA Flow Diagram



Note. Prisma flow diagram to visualise the data selection process

Ethical considerations

Ethical considerations must be taken also when working with secondary data. Ethical issues common for reviews have been identified and considered in the methodology of this scoping review. Firstly, exhaustive data aggregation has been conducted, in which ethical heterogeneity is prevalent. It is possible that some studies have insufficient ethical consideration (Vergnes et al., 2010). However, scoping reviews do not aim to assess the quality of the reviewed studies (Pham et al., 2014). A second issue among scoping reviews can be the inclusion of unpublished material. While it might widen the scope of the study, it can also result in publishing studies carried out on ethically unacceptable conditions. Therefore, this study chose to only include published literature. Finally, the element of subjectivity may influence selection of studies and interpretation of results. Thus, to reduce the risk for bias, the methodology, appendices and tables transparently show the procedure of data selection and result interpretation (Vergnes et al., 2010).

Results

To answer the research question, the following three elements of the reviewed studies are analysed, general and mHealth characteristics, how mHealth is utilised to promote AHA, and the implementation of mHealth for AHA promotion. When examples of studies are given, they are referred to by using numbers in brackets, the corresponding reference can be found in appendix 4.

General information

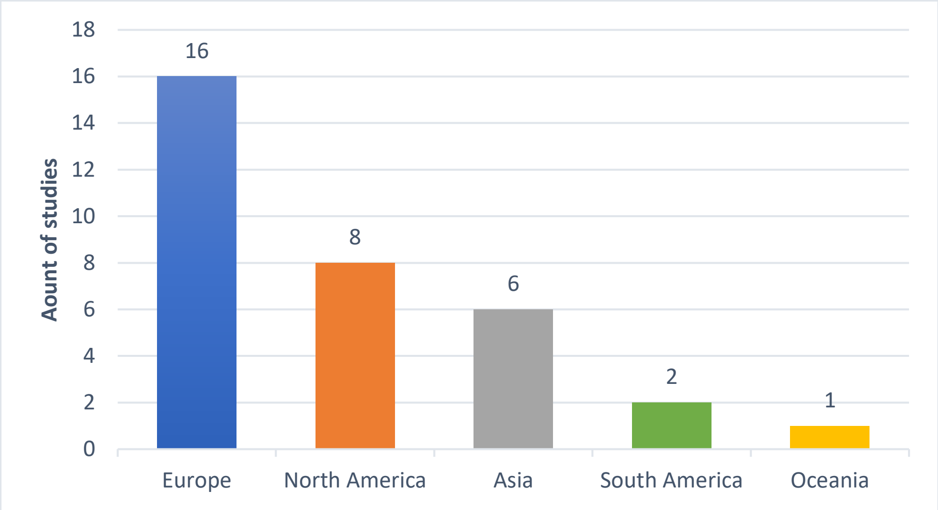
General characteristics. 31 studies on health behaviour change mHealth solutions were selected to be part of this review (see general description of their characteristics in appendix 5). Out of these, the majority were published in 2018 and 2019, indicating an increase in mHealth studies targeting some aspect of AHA. No included studies were published in 2020, which can be explained by the fact that data collection took place in the beginning of March. In line with previous findings, the majority of the mHealth solutions in this review do not apply a theoretical framework, which is argued to be one reason of mHealth interventions' limited efficacy (Bull & Ezeanochie, 2016; Dahlke et al., 2015; Helbostad et al., 2017). About half of the studies are published in Europe, while the United States is the single most represented country with 7 studies (see figure 4). This highlights that mHealth is a recognised tool to promote AHA in most regions, however in Africa where the support ratio is not yet that pressing there appears to be less focus on these types of solutions.

mHealth characteristics. This paragraph outlines the attributes of the mHealth solutions identified in the review (see detailed overview in appendix 6). Eleven types of devises are identified. However, by examining their purpose, they can be categorised into four main groups (illustrated in figure 5). Mobile devices (such as smartphones and tablets) are the most frequently used devices. This is partly due to that many of the mHealth solutions in this review utilise multiple devices, where a mobile device commonly serves as the base, combined with for example an activity tracker. Wearable devices are also rather frequently used, while non wearable devices and activity trackers are less frequent in this research.

Analysing the types of technologies used on the devices show that applications are by far the most prevalent (as seen in figure 6). This can be explained by the fact that

Figure 4

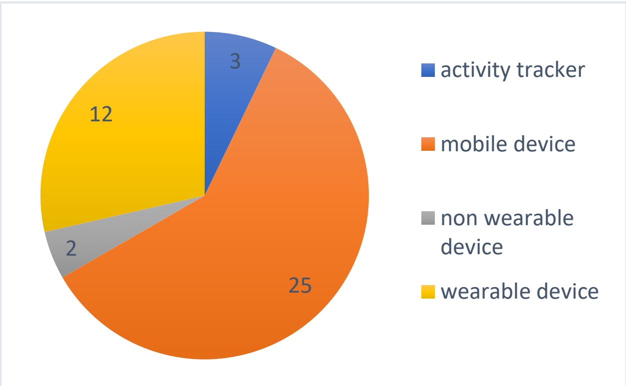
Regions



Note: Display of the regions of study publication

Figure 5

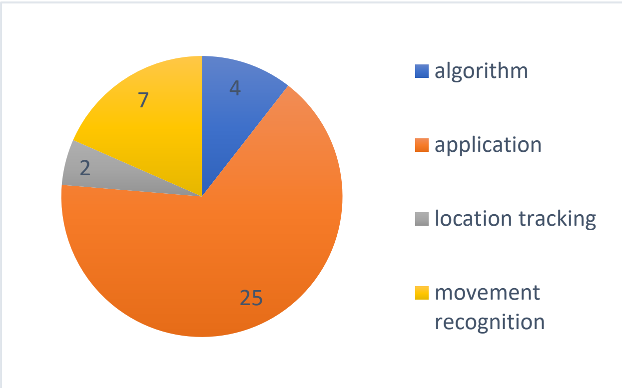
Types of mHealth devices



Note: Types of mHealth devices identified in review.

Figure 6

Types of mHealth technologies



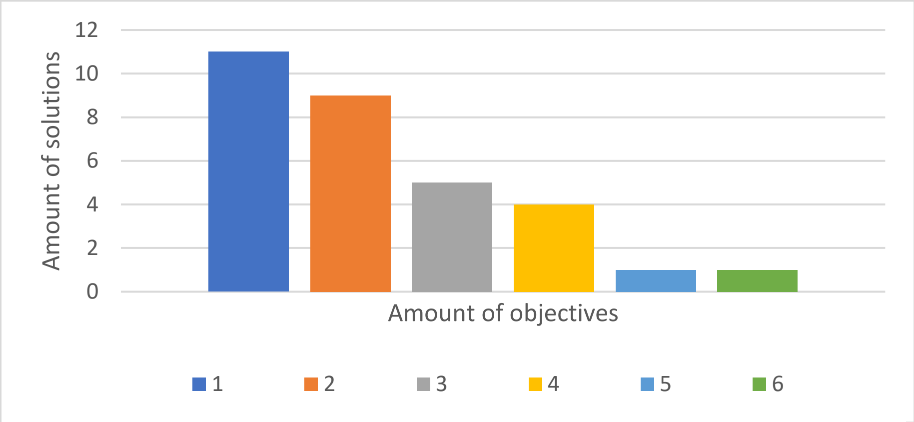
Note. Overview of types of technology used on the mHealth devices

smartphones, tables and smartwatches all can use applications, as well as that an application holds a wide variety of functions which have not been reported separately in this literature study, such as GPS, accelerometers and emergency functions. Thus, the algorithms, location tracking and movement recognition are not integrated in any application, but function independently on for example a wearable device.

Moreover, for each of the solutions, their main function is identified. Compared to the *types of devices* and *technologies*, where each solution can fall into multiple sub-categories, here each solution is classified into one function each. Whereas 18 different functions are

Figure 7

Amount of AHA objectives per solution



Note. The hight of the staples indicate how many studies promote a certain number of objectives. The numbers 1-6 indicates the number of objectives targeted per study.

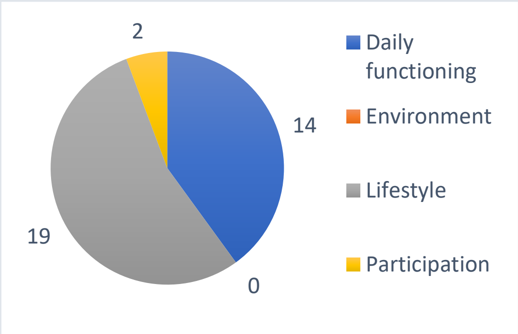
identified, the most recurring ones in this review are *activity tracking*, *fall detection devices* and *PA promoter applications*, all represented in four studies each. *Healthy eating applications*, *monitoring solutions* and *PA promoter via gamification* are also seen in multiple studies, while the remaining functions are only represented by one study each. However, although one main function per solution is identified, most of the solutions still target more than one AHA objective (see figure 7 and appendix 7). Among other, these can be cognitive activity, health education, emergency or medication adherence. Previous research indicates that many solutions only address one objective, which is generally regarded as a weakness of mHealth devices (Helbostad et al., 2017). In this research, 65 per cent of the solutions target more than one objective, which could indicate a decrease in one-dimensionality over the last years.

The utilisation of mHealth to promote Active and Healthy Ageing

Out of the four main factors contributing to AHA identified in the literature study, *Environment* is the only one not seen among any of the reviewed mHealth solutions (see figure 8 and appendix 7 for detailed description). *Lifestyle* and *Daily functioning* are the most identified factors. Among the sub-factors, *active lifestyle* is addressed in 17 of the solutions, while the second most addressed sub-factor *independence* (illustrated in figure 9). Note that

Figure 8

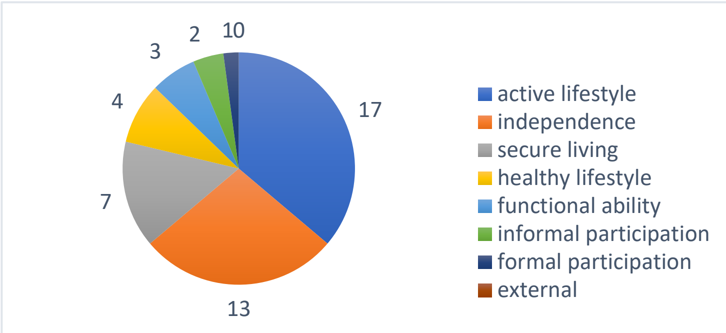
Main factors AHA



Note. Overview of main AHA factors promoted by mHealth solutions.

Figure 3

Sub-factors AHA



Note. Overview of AHA sub-factors promoted by mHealth solutions.

one solution can promote more than one main and sub-factor, which is why the sum of the factors add up to more than 31.

Table 1 presents what mHealth functions are designed to promote which AHA factors. The studies do not directly mention what factor they target, but through application of the AHA concept model developed in this research, categorisation of the functions into factors is possible. Each of the factors is discussed in further detail below.

The Lifestyle factor. More than 60 per cent of the studies promote AHA through the *Lifestyle* factor. Its sub-factor *active lifestyle* is the most prevalent one across all factors. It builds on the promotion of social, cognitive and physical activity (Helbostad et al., 2017; WHO, 2002). Out of the ten different mHealth functions identified fulfilling this sub-factor, activity tracking and PA promoter applications are most common. An example of the latter is an intervention promoting home based training among Korean women by sharing video exercise programmes on a tablet (9).

Healthy eating applications and PA promoter applications via gamification are also seen in more than one study. STARFISH is an example of the latest (18). This smartphone group-application tracks the elderlies' movement via a fish avatar on the background of each group member's phone, to encourage each other to stay active. What these functions have in common is that they all aim to influence the health behaviour of the elderly, mainly through

Table 1:

Cross-tabulation of AHA factors and mHealth functions

Main factors	Sub-factors	mHealth function	N (%)	Reference index
Lifestyle	healthy lifestyle	healthy eating application	3 (9,7)	12, 26, 29
		self-monitoring	1 (3,2)	24
	active lifestyle	active bingo	11 (35,5)	11
		activity tracking	4 (12,9)	4, 23, 25, 27
		bidirectional ambient display platform	1 (3,2)	21
		healthy eating application	2 (6,5)	26, 29
		monitoring solution	1 (3,2)	13
		PA and cognitive training promoter application	1 (3,2)	17
		PA promoter application	4 (12,9)	2, 9, 15, 28
		PA promoter application via gamification	2 (6,5)	18, 19
		self-monitoring	1 (3,2)	24
		virtual pet	1 (3,2)	6
Participation	formal participation	active bingo	1 (3,2)	11
	informal participation	active bingo	1 (3,2)	11
		activity tracking	1 (3,2)	25
Daily functioning	independence	ambient assisted living monitoring	1 (3,2)	3
		balance training	1 (3,2)	10
		fall detection application	1 (3,2)	16
		fall detection device	4 (12,9)	20, 22, 30, 31
		fall risk application	1 (3,2)	1
		fall risk detection via soles	1 (3,2)	8
		monitoring solution	2 (6,5)	13, 14
		PA promoter application via gamification	1 (3,2)	19
		smart clothing monitoring	1 (3,2)	7
	functional ability	attention training	1 (3,2)	5
		balance training	1 (3,2)	10
		monitoring solution	1 (3,2)	13
	secure living	fall detection application	1 (3,2)	16
		fall detection device	2 (6,5)	30, 31
		fall risk application	1 (3,2)	1
		monitoring solution	1 (3,2)	14
		smart clothing monitoring	1 (3,2)	7
Environment	external		0	

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

integrating PA to their everyday life, but also through activation of cognitive abilities and social activities.

The other sub-factor, *healthy lifestyle*, simply refers to the adoption of healthy lifestyles (Bousquet et al., 2015; Helbostad et al., 2017). Two different functions target this sub-factor. Self-monitoring is used in one study, whereas healthy eating application is used in three. Elder Eat, is one of the latter (12). It records the user's food consumption, evaluates it, and offers recommendations about eating in the right way. These functions also aim to impact the elderlies' health behaviour, by creating a sustainable change of lifestyle driven by the old adults themselves.

The Participation factor. This factor is based on the sub-factors *informal participation* and *formal participation*. Informal participation refers to engagement in for instance unpaid productive activities and cultural-, spiritual-, social- and economic affairs, while formal participation covers labour market participation and lifelong learning (Bousquet et al., 2015; WHO, 2002; Zaidi et al., 2017). Two mHealth functions address these sub-factors, namely active bingo and activity tracking. Active bingo is materialised via the mobile app Bingocize, which combines exercises and health education through bingo (11). As the bingo is carried out as a social group activity, it falls into the *informal participation* sub-factor. However, it also counts as *formal participation* due to its health education aspect (Bousquet et al., 2015). The study addressing only *informal participation* presents a smartphone gait measurement application motivating elderly to walk regularly (25). The increased PA that the older adults experienced positively influenced their social involvement in society, some for example got engaged in voluntary work. It appears that both these functions can stimulate opportunities for diverse types of participation among the elderly, which is a central part of ageing actively (WHO, 2002).

The Daily functioning factor. More than a fifth of the papers promote AHA by addressing this factor. It consists of three sub-factors. Firstly, *independence*, aiming to reduce dependence and maintain autonomy. Secondly, *functional ability*, which includes the development and maintenance of capabilities across life. Finally, *secure living*, targeting optimised opportunities for security (Bousquet et al., 2015, 2019; WHO, 2002, 2020). Out of these sub-factors, *independence* is most frequently targeted, mainly by fall detection devices or monitoring solutions. One of the first is a wearable fall detection device with GPS and emergency features (20). An example of the latter is a monitoring application that offers fall detection services, pill assistant features, chat features and live stream radio features among other things (13). Both functions enable elderlies to remain living independently and autonomously take care of their daily tasks.

Secure living is the second most frequently addressed sub-factor. Its most prevalent mHealth function is the fall detection device. One example is a wearable, automatically alerting, waterproof fall detection sensor that is applied on the body of the elderly and connects with a smartphone application (30). These mHealth solutions help old adults to age healthy and actively by supporting them to continue living their lives as normal while feeling secure and cared for. Lastly, *functional ability*, is addressed by three different mHealth functions, monitoring solution, balance training and attention training. The latter is a cognitive training tablet application to improve memory (5). These all aim to assist old adults to maintain their functional abilities while ageing.

The implementation of mHealth for AHA promotion

The outcome of the implementation of mHealth solutions can facilitate understanding in how mHealth can promote AHA. Many of the solutions address multiple AHA factors, thus to avoid duplication and a skewed perspective the outcomes of the solutions are not explored per factor, but according to three themes identified during data analysis. Firstly, successful and unsuccessful implementation, secondly, positive and negative user experience, and finally technical benefits and challenges (see detailed overview in appendix 8).

Successful implementation. Two thirds of the studies have successfully delivered on their AHA aims during implementation of their mHealth solution. Many studies performed PA tests on the participants before and after the intervention, and report improved PA scores. In many of the studies the old adults comment that they are overall satisfied or enthusiastic over the device they tested. Many also became more conscious about their health and felt a greater desire to be active. One of the participants testing the STARFISH application comment:

> I think you sort of realise as well, how little you do some days. Before we had those phones I could do nothing sitting on the couch all the afternoon before, whereas after I felt I need to get up from here and actually do something. (18, p.6)

Social engagement is another factor that many solutions successfully increased, as well as a feeling of security, cognitive functioning and health knowledge. In two of the studies the authors find that the mHealth devices resulted in high adherence rates compared to the control group. These fruitful implementations indicate that some of the reviewed mHealth solutions are able to promote AHA through targeting the lifestyle, participation and daily functionings of elderly.

Unsuccessful implementations. Roughly one third of the reviewed studies report unsuccessful results concerning the implementation of their mHealth solution. The most recurring outcomes are that the participants achieved none or modest improvements on PA, or health in general (such as improved sleeping patterns). Other less favourable remarks regard that the device was disturbing or that the elderly did not perceive a need for it. One of the studies notes a decrease in usage of their application throughout the test period, indicating that not all types of mHealth solutions boost adherence (29). These outcomes imply that not all mHealth solutions are successful in promoting AHA. However, there may be some successful and some unsuccessful aspects of the same solution, which underlines the danger of addressing only one objective.

Positive user experience. It appears that many of the studies have been able to develop devices suiting the user level of older adults, which may be a prerequisite to reach successful implementation. Almost 40 per cent of the studies document that the older adults find the device user-friendly and/or easy to. One elderly participant states the following regarding one of the fall detection devices ‘‘It [the application] was very positive, with big writing and touch buttons, and "change sensor" was clearly written in the lower part." (30, p.315). Another study digs deeper into the perceived ease of use and finds that it positively correlates with perceived usefulness as well as attitude towards their suggested smart clothing (7).

Negative user experience. On the other hand, although all studies were selected on the criteria of developing a mHealth solution specifically for older adults, it appears that many have not adapted the devices and their technology enough for the target group to comfortably be able to use it. About 40 per cent of the studies report that the elderlies experience challenges when using the device or its technology. Most of these experiences evolve around difficulties using the device or need for further explanations prior to usage. For example, the same fall detection device that received positive feedback on the usability of is technology receive this feedback on the device itself "They [the elderlies] added that most of their generation would need extensive training and coaching regarding handling a smartphone, to be able to deal with it on a day to day basis." (30, p.315). One of the studies declare that giving clear and simple instructions is one of their "lessons learned" regarding developing mHealth devices (1). Issues are also raised regarding charging of the devices. Some struggle remembering to charge the device, and others were unable to find an electrical output where they intended to charge it. Charging was also an issue regarding one of the smartwatches, as the action required fine motoric skills which many struggled performing (3). The remaining negative user experiences evolve around resistance to use the device, either due to its size or functions, or because the user was afraid of losing it.

Many of the studies comment on the poor user experience outcomes suggesting the need for a cultural change to reduce the stigma around fall detection devices (20), more age-appropriate designs (20) or multiple versions of the same device to address the heterogeneity of elderlies (30).

Technical benefits. Many studies focus less on user experience and more on the technical development of their mHealth solution, several deliver positively on this aspect. Multiple of the studies' mHealth solutions prove to be specifically useful to reach their aim, such the monitoring solution that appeared to be a highly efficient communication tool between elderly parents and their children (13). Some of the solutions report higher accuracy levels than similar devices, especially the smartwatch developed to be worn when walking with a rollator (27). The elderlies express that some of the devices were developed in such a way that they did not limit their everyday life, in one of the interventions the participants eventually even forgot that they were wearing the device (30). These results indicate that the technology developed for older adults holds a high standard and is suitable to promote AHA.

Technical challenges. There are also studies in which the technology did not deliver as planned. The most common issue is that the fall detection devices/applications give off too many false alarms. Another issue is that the device is not accurate enough to sufficiently support the elderly in their everyday life. Finally, one of the mHealth solutions was seen as a burden on everyday life, due to for example the device´s limited battery life (30). These outcomes contradict the previous section and point to that not all mHealth solutions have sufficiently developed technical systems, and especially fall detection devices appear to require improvement.

Overall, these outcomes point to that there are some characteristics that influence the success of implementation. Firstly, the devices and their technology must be easy to use, which can be influenced by an interface adapted to elderly or sufficient explanations prior to usage. Secondly, the solutions shall not constrain elderlies' everyday life due to factors such as battery time, too many false fall alarms, device size and charging difficulties. Finally, older adults must see the need of the device and perceive it as useful.

Discussion

Main findings

This research aims to answer the question: *How can active and healthy ageing among healthy older adults be promoted through mHealth solutions?* The scoping review used to investigate this presents a large share of input to answer the question. However, what the review does not present is equally relevant to consider.

Utilisation of mHealth to promote AHA. Among the reviewed studies, 18 different mHealth functions promoting AHA are identified, where the most prevalent are activity tracking, fall detection devices and PA promoter applications. However, the frequency of these functions does not answer for their effectiveness in promoting AHA, it simply shows that among the studies, these are the most prevailing. Examining the cause of the frequency goes beyond the scope of this review.

In the initiating literature study, the concept of AHA was broken down into the four core elements *Health, Wellbeing, Healthy life expectancy* and *Quality of life.* To be able to achieve these, four main factors were identified, namely *Lifestyle, Participation, Daily functioning* and *Environment.* When analysing which of these factors the health behaviour change mHealth solutions of this review are targeting, and their frequency, it becomes apparent that the levels of behavioural change varies. The two most frequently promoted factors, *Lifestyle* and *Daily functionings,* both involve behavioural changes on an intrapersonal level. Thus, only the individual herself is required to make adaptions to her lifestyle or daily functioning. *Participation,* however, requires a setting for the elderly to participate in, and thus represents a more interpersonal level, merely two studies address this factor. Finally, *Environment* involves social, physical, policy and economic environment, which are aspects on a community level (Bousquet et al., 2015; WHO, 2020). This is the only factor not targeted by any of the reviewed solutions. This points to that health behaviour change mHealth solutions are best suitable to promote AHA on an intrapersonal level, they are able to do so on an interpersonal level, however less common, but research is yet to prove if mHealth can promote AHA on a community level.

The most common way among the reviewed solutions to promote AHA is via the *Lifestyle* factor, and more specifically targeting an *active lifestyle.* Mainly via activity tacking and PA promotion functions, mHealth solutions strive to influence the elderlies' health behaviour, by adopting an active lifestyle stimulated by physical, social and cognitive activities. *Healthy lifestyle* also builds up to the *Lifestyle* factor. Healthy eating applications and self-monitoring solutions are identified to enable older adults to create a sustainable healthy lifestyle driven by themselves.

AHA is also promoted via the *Participation* factor, targeted by merely two solutions, namely an active bingo programme and an activity tracking intervention. Besides the fact that this factor is categorised as an interpersonal level factor, its comparably low prevalence can be a result of that a separation has been made in the theoretical framework between social activity (which falls into active lifestyle) and social participation (which falls informal participation). Relevant to consider regarding *formal participation* is that as all solutions in this study target older adults, mainly in retirement age. Thus, most are no longer part of the formal labour market. However, the reviewed solutions that did to promote *informal participation,* seem to have been successful when combining it with some type of PA. These studies thus imply that *Participation* is not commonly promoted among health behaviour change mHealth solutions for elderly. However, mHealth is able to stimulate opportunities for participation among elderly, especially when combining it with PA.

Many mHealth solutions promote AHA via the *Daily functioning* factor. This review indicates that focusing on *independence* is the most common way to do so. This aspect is a central part of the AHA concept, to be able to empower older adults to stay in charge of managing their wellbeing. Many of the solutions promoting this sub-factor also target *secure living*, understandable as fall detection applications/devices and diverse monitoring solutions make up the majority of these products, which conjointly promotes autonomy and security. Together with the final sub-factor, *functional ability,* the reviewed mHealth solutions support elderly to remain independent and uphold their functional abilities while living securely – thus promoting the maintenance of elderlies' daily functioning.

Implementation of mHealth solutions. A majority of the studies indicate that the implementation of the mHealth solutions were successful on one or several aspects. However, about one third of the studies report unsuccessful implementation outcomes. Vital to acknowledge is the baseline of the study participants. It may be that no improvements are recorded due to the high baseline of the study participants regarding for example their daily PA levels. However, also worth noting is that some studies report both successful and unsuccessful results. This underlines the importance of not developing one-dimensional solutions, but products with more than one AHA objective to increase the chance of successful implementation. For the solutions that do not report any successful implementation aspects, this is mainly due to that they focused on technical development instead of user outcome, have not yet done an extensive testing of the solution, or simply did not achieve any positive outcomes.

An inclusion criterion for the review was that the mHealth solution is designed specifically for older adults and includes this target group in the design and/or development of the product. Yet, user experience differs greatly among the solutions, indicating that even when elderlies are at the centre of the development process of mHealth devices, many times the tool is still not adapted enough for convenient everyday use. This highlights 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, it appears that there are more negative comments about the user experience of the devices than the technological capabilities of the solutions, which may indicate that lack of technical development is less of an issue than the usability of the solution.

What is not there. The two most prevalent reasons for exclusion during the second screening are “wrong methodology” and “wrong population”. These refer to studies where older adults are not integrated in the design of the device, the device has not been tested on elderly, or the device is not developed specifically for elderly (such as standard activity trackers). These exclusion amounts point to the large share of mHealth devices that do not place elderly at the centre of product development. Moreover, including a global scope of studies brings insight into that utilising mHealth to address AHA is most prevalent in Europe and North America. Despite low support ratios in Eastern Asia, comparably few studies in this review are published in that region. However, many studies from Asia were excluded from this review as they targeted either a younger population, or used technology not defined as mHealth, such as robots.

Strengths, limitations, implication

AHA is an internationally recognised concept to tackle social issues caused by an ageing society and mHealth is one of the suggested tools to materialise this. Yet, prior to this research there were no studies mapping the mHealth landscape within the field of AHA. This research provides an overview of the contemporary mHealth solutions developed specifically for older adults promoting AHA.

Although the review methodically thoroughly follows the recommended stages of a scoping review, some limitations must be acknowledged. A certain bias may be present regarding inclusion of studies, as only published and peer-reviewed articles are included in the research, which may exclude publications on commercial mHealth solutions. In addition, only one person carried out the screening process of studies despite recommendations that two or more researchers perform this process (Pham et al., 2014). However, to reduce bias, other researchers have continuously been consulted during the process. Another limitation is that this review addresses the use of mHealth in a preventative manner, and therefore only includes studies on healthy and independent older adults. Finally, scoping reviews do not aim to “synthesise” evidence, thus is this research unable to explore the effectiveness of mHealth solutions among healthy older adults (Arksey & O’Malley, 2005).

Nevertheless, this research has been able to screen a large scope of references, providing insights to the topic both from included and excluded publications. The study maps solutions in a quickly developing field of technology and reviews them from the perspective of the contemporary AHA concept in a way that has not been done before. The interdisciplinarity of the review highlights the multiplicity of the topic by shedding light on the importance of high technology standards, understanding users’ perspectives regarding needs and solutions’ usefulness, as well as what health behaviour the devices can influence. This review suggests that mHealth is able to prolong the number of healthy and independent years among the elder population. The reviewed studies indicate that this can be done mainly through focus on elderlies’ *Lifestyle, Participation* and *Daily Activities*, and that mHealth solutions may have a higher chance of reaching their goal if more than one AHA objective is targeted. Additionally, aspects influencing implementation appears to be mHealth solutions’ user-friendliness and influence on everyday life, as well as elderlies’ perceived need for the solution. To ensure appropriateness to the target group, elderly should be at the centre of design and development of mHealth solutions.

These suggestions can be used by researchers and developers to avoid duplication and improve available solutions, and more importantly provide policy makers and healthcare professionals with an overview of the field to facilitate investment, implementation and scaleup successful mHealth solutions. Ideally this will result in multiple outcomes for older adults, such as prevention of onset of chronic disease, reduction of risk factors for functional decline, maintaining good health and wellbeing, prolonging independent lifestyles, and finally the increase of healthy life years and quality of life. Ultimately, besides empowering elderlies, these changes could decrease the pressure on the healthcare system and the working age population as the support ratio is expected to continue to decrease.

However, few mHealth studies apply any theoretical framework. More theory based-research is needed, especially on AHA to fully understand its impact on the support ratio and public systems, as well as explore why some factors are targeted more than others and if some are more likely to lead to sustainable behavioural change. Further, future reviews could add value by researching the treatment side of mHealth solutions, as well as include a younger age group to be able to compare user experience and types of solutions. Additional advances to the field could be made by exploring what makes a mHealth solution successful. Finally, society needs to normalise usage of mobile devices among elderly and support them to confidently handle the devices daily and independently.

Main insights

AHA among healthy older adults can be promoted through mHealth solutions targeting their *Lifestyle*, *Participation* and *Daily functions*. Addressing elderlies' *independence* and *active lifestyle* are the most common ways, mainly materialised through activity tracking, PA promotion and fall detection. These mHealth functions, among others, can improve old adults' *Health, Wellbeing, Healthy life expectancy* and *Quality of life*.

This research focuses on solutions developed specifically for older adults, yet many elderlies experience challenges when using the devices. This underlines the importance of problem- and user driven development, as well as real setting testing and consultation of elderlies in the design of solutions. However technically advanced a mHealth solution may be is irrelevant if the elderly does not find a need for the solution or is unable to use it properly.

In conclusion, this research provides an overview of contemporary mHealth solutions promoting AHA among heathy and independent elderly. Through further development and upscaling these solutions may be able to empower older adults and decrease the pressure on the healthcare system as the population is ageing further.

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Appendices

Appendix 1 – Concept table AHA

Elements	Health	Wellbeing	Healthy life expectancy	Quality of life
Aspects	Optimising opportunities for health (WHO, 2002)	Well-being (social, mental and physical) (WHO, 2002)	Increased average healthy lifespan (Bousquet et al., 2015)	Quality of life (WHO, 2002)
	People are able to live healthy lives (Zaidi et al., 2017)	Enable well-being (WHO, 2020)	Increased healthy life expectancy (Bousquet et al., 2019)	Quality of life (domain) (Bousquet et al., 2015)
	Optimizing opportunities for health and social care (Bousquet et al., 2019)	Well-being (domain) (Bousquet et al., 2015)	Increased healthy life years (Bousquet et al., 2019)	Increase quality of life (Bousquet et al., 2019)
	Functioning of underlying physiological systems across the life course (domain) (Bousquet et al., 2015)	Well-being (mental, social, physical) (Bousquet et al., 2019)		
	Reduced disability (Bousquet et al., 2019)			

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) (Bousquet et al., 2015)	Physical active (WHO, 2002)	Participation in labour market (WHO, 2002)	Optimising opportunities for participation (WHO, 2002)	Maintained autonomy and independence (WHO, 2002)	Functional ability (developing and maintaining) (WHO, 2020)	Optimising opportunities for security (WHO, 2002)	Environment (social, physical and policy) (WHO, 2020)
	Adoption of healthy lifestyles (behavioural change) (Helbostad et al., 2017)	Activity (cognitive, social and physical) (Helbostad et al., 2017)	Continued participation in the formal labour market (Zaidi et al., 2017)	Participation in economic-, spiritual-, cultural-, civic- and social-affairs (WHO, 2002)	Reduced dependency (Bousquet et al., 2019)	Capacities (mental and physical) (WHO, 2020)	People are able to live secure lives (Zaidi et al., 2017)	Lifetime physical, economic and social environment (factor) (Bousquet et al., 2015)
			Working and caring, lifelong learning, education (factor) (Bousquet et al., 2015)	Engagement in unpaid productive activities (Zaidi et al., 2017)	People are able to live independent lives (Zaidi et al., 2017)	Capabilities across the life course (physical and cognitive) (domain) (Bousquet et al., 2015)		Capacity and enabling environment (domain) (Zaidi et al., 2017)
				Working and caring, lifelong learning, education (factor) (Bousquet et al., 2015)	Prolonging the number of independent and healthy years during old age (Helbostad et al., 2017)	Remain functional abilities (Helbostad et al., 2017)		

Appendix 2 – Scoping Review Search Strategy Model- PubMed

	Concept 1a	Concept 1b	Concept 2	Exclude
Key concepts	**mHealth (technology)**	**mHealth (health)**	**Ageing**	**NOT**
Definition	Mobile devices, mobile communication or mobile computing technologies supporting public health and healthcare [3]	Mobile devices, mobile communication or mobile computing technologies supporting public health and healthcare	Any person aged 60 or older [4]	
Controlled vocabulary terms / Subject terms (MeSH terms)[5]	mobile applications OR cell phones OR microcomputers OR wearable electronic devices	Health OR Public health OR Health Care Quality, Access, and Evaluation	Aged OR Aged, 80 and over	
Free text terms / natural language terms	mHealth OR Mobile health OR Mobile application* OR Mobile health application* OR mHealth app OR health app OR cell phone OR cell phones OR mobile phone OR mobile phones OR microcomputer OR	health OR public health OR health care OR healthcare OR Health management OR health promotion OR healthy lifestyle OR healthy lifestyles	elderly OR “old aged” OR old-aged OR “older adults”	Pregnant OR pregnancy OR birth control OR Literacy OR HIV OR sexual transmitted

[3] Free, C., Phillips, G., Felix, L., Galli, L., Patel, V., & Edwards, P. (2010). The effectiveness of M-health technologies for improving health and health services: A systematic review protocol. *BMC Research Notes*, *3*(1), 250. https://doi.org/10.1186/1756-0500-3-250 and Hamine, S., Gerth-Guyette, E., Faulx, D., Green, B. B., & Ginsburg, A. S. (2015). Impact of mHealth chronic disease management on treatment adherence and patient outcomes: A systematic review. *Journal of Medical Internet Research*, *17*(2), e52. https://doi.org/10.2196/jmir.3951

[4] WHO. (2018, February 18). *Ageing and Health* https://www.who.int/news-room/fact-sheets/detail/ageing-and-health

[5] https://www-ncbi-nlm-nih-gov.ludwig.lub.lu.se/

(synonyms, UK/US terminology, medical/laymen's terms, acronyms/abbreviations, drug brands, more narrow search terms)[6]	microcomputers OR desktop computer OR desktop computers OR laptop OR laptops OR personal computer OR personal computers OR wearable electronic device OR wearable electronic devices OR iPad OR iPads OR smartphone OR smartphones OR smartwatch OR smartwatches OR mobile device OR mobile devices OR mobile technology OR text messaging			diseases OR sexual transmitted infections

Search 1 result (#1) = **AND** Search 2 result (#2) = **AND** Search 3 result (#3) = **NOT** Search 4 result (#4) =

[6] https://www.thesaurus.com/ (oxford)

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 (elderly[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 3 – Tree overview of aspects of MeSH terms and their definitions

Concept	Initial term	Initial term	MeSH term
		Mobile applications	**Mobile applications** mobile electronic devices which support a wide range of functions and uses which include television, telephone, video, music, word processing, and Internet service.
		Text messaging Communication between CELL PHONE users via the Short Message Service protocol which allows the interchange of short written messages.	**Cell phone** Analog or digital communications device in which the user has a wireless connection from a telephone to a nearby transmitter. It is termed cellular because the service area is divided into multiple "cells." As the user moves from one cell area to another, the call is transferred to the local transmitter.
		Mobile phone	
	Smartphone	**Computers, handheld**	**Microcomputers**

	A cellular phone with advanced computing and connectivity capability built on an operating system.	A type of MICROCOMPUTER, sometimes called a personal digital assistant, that is very small and portable and fitting in a hand. They are convenient to use in clinical and other field situations for quick data management. They usually require docking with MICROCOMPUTERS for updates.	Small computers using LSI (large-scale integration) microprocessor chips as the CPU (central processing unit) and semiconductor memories for compact, inexpensive storage of program instructions and data. They are smaller and less expensive than minicomputers and are usually built into a dedicated system where they are optimized for a particular application. "Microprocessor" may refer to just the CPU or the entire microcomputer.
	Personal digital assistant		
	handheld computers		
	Tablet computers		
	Smart glasses		
		Smart glasses	**Wearable electronic devices** Electronic implements worn on the body as an implant or as an accessory. Examples include wearable diagnostic devices, wearable ACTIVITY TRACKERS, wearable INFUSION PUMPS, wearable computing devices, SENSORY AIDS, and electronic pest repellents

<table>
<tr><td rowspan="3">mHealth (health)</td><td rowspan="2"></td><td>Health care</td><td>Health Care Quality, Access, and Evaluation

The concept concerned with all aspects of the quality, accessibility, and appraisal of health care and health care delivery.</td></tr>
<tr><td>Public Health</td><td>Public Health

Branch of medicine concerned with the prevention and control of disease and disability, and the promotion of physical and mental health of the population on the international, national, state, or municipal level.</td></tr>
<tr><td></td><td>Health & Wellbeing</td><td>Health

The state of the organism when it functions optimally without evidence of disease.</td></tr>
</table>

<table>
<tr><td rowspan="3">Ageing</td><td></td><td>Ageing</td><td>Ageing
The gradual irreversible changes in structure and function of an organism that occur as a result of the passage of time.</td></tr>
<tr><td>Old aged</td><td>Aged, 80 and over
A person 80 years of age and older</td><td rowspan="2">Aged
A person 65 through 79 years of age</td></tr>
<tr><td></td><td>Aged</td></tr>
</table>

Appendix 4 – Reference index

Study number	Reference
1	Hsieh, K. L., Fanning, J. T., Rogers, W. A., Wood, T. A., & Sosnoff, J. J. (2018). A Fall Risk mHealth App for Older Adults: Development and Usability Study. JMIR Aging, 1(2), e11569.
2	Li, J., Hodgson, N., Lyons, M. M., Chen, K.-C., Yu, F., & Gooneratne, N. S. (2019). A personalized behavioural intervention implementing mHealth technologies for older adults: A pilot feasibility study. Geriatric Nursing (New York, N.Y.).
3	Lutze, R., Waldhör, K., Fu W.-T., Balakrishnan P., Harabagiu S., Wang F., & Srivatsava J. (2015). A smartwatch software architecture for health hazard handling for elderly people (rayyan-60370878). 356–361. https://www.scopus.com/inward/record.uri?eid=2-s2.0-84966430735&doi=10.1109%2fICHI.2015.50&partnerID=40&md5=5813ded0ae3ec33b89848869a00aa80f
4	Steinert, A., Buchem, I., Merceron, A., Kreutel, J., & Haesner, M. (2018). A wearable-enhanced fitness program for older adults, combining fitness trackers and gamification elements: The pilot study fMOOC@Home. Sport Sciences for Health, 14(2), 275–282. https://www.scopus.com/inward/record.uri?eid=2-s2.0-85040370847&doi=10.1007%2fs11332-017-0424-z&partnerID=40&md5=d524daf24074ae15641fe4c7a7236346
5	Hill, N. L., Mogle, J., Wion, R., Kitt-Lewis, E., Hannan, J., Dick, R., & McDermott, C. (2018). App-based attention training: Incorporating older adults' feedback to facilitate home-based use. International Journal of Older People Nursing, 13(1).
6	Hsieh, H. C. L. (2015). Developing Mobile Application Design of Virtual Pets for Caring for the Elderly. In J. Zhou & G. Salvendy (Eds.), Human Aspects of IT for the Aged Population. Design for Everyday Life (pp. 269–277). Springer International Publishing. https://doi.org/10.1007/978-3-319-20913-5_25
7	Lin, W.-Y., Chou, W.-C., Tsai, T.-H., Lin, C.-C., & Lee, M.-Y. (2016). Development of a Wearable Instrumented Vest for Posture Monitoring and System Usability Verification Based on the Technology Acceptance Model. Sensors (Basel, Switzerland), 16(12).

8	Stara, V., Harte, R., Di Rosa, M., Glynn, L., Casey, M., Hayes, P., Rossi, L., Mirelman, A., Baker, P. M. A., Quinlan, L. R., & ÓLaighin, G. (2018). Does culture affect usability? A trans-European usability and user experience assessment of a falls-risk connected health system following a user-centred design methodology carried out in a single European country. Maturitas, 114, 22–26.
9	Lee, J., Jung, D., Byun, J., & Lee, M. (2016). Effects of a Combined Exercise Program Using an iPad for Older Adults. Healthcare Informatics Research, 22(2), 65–72.
10	Bao, T., Carender, W. J., Kinnaird, C., Barone, V. J., Peethambaran, G., Whitney, S. L., Kabeto, M., Seidler, R. D., & Sienko, K. H. (2018). Effects of long-term balance training with vibrotactile sensory augmentation among community-dwelling healthy older adults: A randomized preliminary study. Journal of Neuroengineering and Rehabilitation, 15(1), 5.
11	Shake, M. C., Crandall, K. J., Mathews, R. P., Falls, D. G., & Dispennette, A. K. (2018). Efficacy of Bingocize®: A Game-Centred Mobile Application to Improve Physical and Cognitive Performance in Older Adults. Games for Health Journal, 7(4), 253–261.
12	Meephak, N., Tepbanchaporn, M., Jarupaibul, A., Mitrpanont J.L., & Sawangphol W. (2018). Elder eat: A smartphone application for recording and monitoring food consumption for Thai elderly (rayyan-60370040). https://www.scopus.com/inward/record.uri?eid=2-s2.0-85058149245&doi=10.1109%2fICT-ISPC.2018.8524004&partnerID=40&md5=b1d73773028c93b7e2fbbaf656e4f70c
13	Sunghoon, K., Parasuraman, G. M., & Jaunbuccus, S. (2019). Elderly Care Assistant: A Discreet Monitoring Tool. In P. Fleming, B. M. Lacquet, S. Sanei, K. Deb, & A. Jakobsson (Eds.), Smart and Sustainable Engineering for Next Generation Applications (pp. 287–301). Springer International Publishing. https://doi.org/10.1007/978-3-030-18240-3_27
14	Handojo, A., Sutiono, T. J. A., Purbowo, A. N., Palit H.N., & Santoso L.W. (2017). Elderly healthcare assistance application using mobile phone (rayyan-60370464). 2018, 292–296. https://www.scopus.com/inward/record.uri?eid=2-s2.0-85049313446&doi=10.1109%2fICSIIT.2017.69&partnerID=40&md5=097230fe51419cbda3d53b7a086ca323

15	Zimmermann, L. C., Da Hora Rodrigues, K. R., & Da Graça Campos Pimentel, M. (2019). EPARS: Elderly physical activity reminder system using smartphone and wearable sensors (rayyan-60369710). 1139–1145. https://www.scopus.com/inward/record.uri?eid=2-s2.0-85072894813&doi=10.1145%2f3341162.3350845&partnerID=40&md5=59ee1410b1ea86fe1ffbfa1f61981186
16	Huq, G. B., Basilakis, J., & Maeder, A. (2016). Evaluation of Tri-axial accelerometery data of falls for elderly through smart phone (rayyan-60370780). 1. https://www.scopus.com/inward/record.uri?eid=2-s2.0-84962574024&doi=10.1145%2f2843043.2843385&partnerID=40&md5=2ba940a075f5c77c027519d0b9bd510d
17	Alsaqer, M., & Chatterjee, S. (2017). Helping the elderly with physical exercise: Development of persuasive mobile intervention sensitive to elderly cognitive decline (rayyan-60370377). 2017, 1–6. https://www.scopus.com/inward/record.uri?eid=2-s2.0-85048553308&doi=10.1109%2fHealthCom.2017.8210790&partnerID=40&md5=1e9caceef369fb3e728917af2f8194a6
18	Paul, L., Brewster, S., Wyke, S., McFadyen, A. K., Sattar, N., Gill, J. M., Dybus, A., & Gray, C. M. (2017). Increasing physical activity in older adults using STARFISH, an interactive smartphone application (app); a pilot study. Journal of Rehabilitation and Assistive Technologies Engineering, 4, 2055668317696236.
19	Santos, A., Guimaraes, V., Matos, N., Cevada, J., Ferreira, C., & Sousa, I. (2015). Multi-sensor exercise-based interactive games for fall prevention and rehabilitation (rayyan-60370879). 65–71. https://www.scopus.com/inward/record.uri?eid=2-s2.0-84963747510&doi=10.4108%2ficst.pervasivehealth.2015.259115&partnerID=40&md5=8545a966d094012c89d018247fe2f05a
20	Demiris, G., Chaudhuri, S., & Thompson, H. J. (2016). Older Adults' Experience with a Novel Fall Detection Device. Telemedicine and E-Health, 22(9), 726–732. https://www.scopus.com/inward/record.uri?eid=2-s2.0-84986890473&doi=10.1089%2ftmj.2015.0218&partnerID=40&md5=2c972ad120f34d5d236557e35124546a

21	Davis, K., Marcenaro, L., Owusu, E., Regazzoni, C., Hu, J., & Feijs, L. (2016). Promoting social connectedness through human activity-based ambient displays (rayyan-60370663). 64–76. https://www.scopus.com/inward/record.uri?eid=2-s2.0-85014838284&doi=10.1145%2f2996267.2996274&partnerID=40&md5=8f349a2c8e3e4854e074c5b1fa8cfe6f
22	Sucerquia, A., López, J. D., & Vargas-Bonilla, J. F. (2018). Real-Life/Real-Time Elderly Fall Detection with a Triaxial Accelerometer. Sensors (Basel, Switzerland), 18(4).
23	Papagiannaki, A., Zacharaki, E. I., Kalouris, G., Kalogiannis, S., Deltouzos, K., Ellul, J., & Megalooikonomou, V. (2019). Recognizing Physical Activity of Older People from Wearable Sensors and Inconsistent Data. Sensors (Basel, Switzerland), 19(4).
24	Steinert, A., Haesner, M., Tetley, A., & Steinhagen-Thiessen, E. (2016). Self-Monitoring of Health-Related Goals in Older Adults with Use of a Smartphone Application. Activities, Adaptation and Aging, 40(2), 81–92. https://www.scopus.com/inward/record.uri?eid=2-s2.0-84976340326&doi=10.1080%2f01924788.2016.1158569&partnerID=40&md5=4c3eb001fab4742b655a87b0421a64e5
25	Miura, T., Yabu, K., Hiyama, A., Inamura, N., Hirose, M., & Ifukube, T. (2015). Smartphone-Based Gait Measurement Application for Exercise and Its Effects on the Lifestyle of Senior Citizens. In J. Abascal, S. Barbosa, M. Fetter, T. Gross, P. Palanque, & M. Winckler (Eds.), Human-Computer Interaction – INTERACT 2015 (pp. 80–98). Springer International Publishing. https://doi.org/10.1007/978-3-319-22698-9_7
26	Ribeiro, D., Ribeiro, J., Vasconcelos, M. J. M., Vieira, E. F., & de Barros, A. C. (2018). SousChef: Improved Meal Recommender System for Portuguese Older Adults. In C. Röcker, J. O'Donoghue, M. Ziefle, L. Maciaszek, & W. Molloy (Eds.), Information and Communication Technologies for Ageing Well and e-Health (pp. 107–126). Springer International Publishing. https://doi.org/10.1007/978-3-319-93644-4_6
27	Matthies, D. J. C., Haescher, M., Nanayakkara, S., & Bieber, G. (2018). Step detection for rollator users with smartwatches (rayyan-60370061). 163–167. https://www.scopus.com/inward/record.uri?eid=2-s2.0-85055658002&doi=10.1145%2f3267782.3267784&partnerID=40&md5=0363fc366bbd48bedfac5135d35a1edc

28	Mehra, S., Visser, B., Cila, N., van den Helder, J., Engelbert, R. H., Weijs, P. J., & Kröse, B. J. (2019). Supporting Older Adults in Exercising With a Tablet: A Usability Study. JMIR Human Factors, 6(1), e11598.
29	Orso, V., Spagnolli, A., Viero, F., & Gamberini, L. (2019). The Design, Implementation and Evaluation of a Mobile App for Supporting Older Adults in the Monitoring of Food Intake. In A. Leone, A. Caroppo, G. Rescio, G. Diraco, & P. Siciliano (Eds.), Ambient Assisted Living (pp. 147–159). Springer International Publishing. https://doi.org/10.1007/978-3-030-05921-7_12
30	Thilo, F. J. S., Hahn, S., Halfens, R. J. G., & Schols, J. M. G. A. (2019). Usability of a wearable fall detection prototype from the perspective of older people-A real field testing approach. Journal of Clinical Nursing, 28(1), 310–320.
31	Kolakowski, J., Berezowska, M., Michnowski, R., Radecki, K., & Malicki, L. (2015). Wireless system for elderly persons mobility and behaviour investigation (rayyan-60370890). 2, 833–837. https://www.scopus.com/inward/record.uri?eid=2-s2.0-84957550802&doi=10.1109%2fIDAACS.2015.7341420&partnerID=40&md5=6ed1ecce2ff2157e296f46bca2532633

Appendix 5 – General description of publications included in the review

Classification category	Sub category	N (%)	Reference index
Year of publication	2015	5 (16,1)	3, 6, 19, 25, 31
	2016	6 (19,4)	7, 9, 16, 20, 21, 24
	2017	3 (9,7)	14, 17, 18
	2018	10 (32,3)	1, 4, 5, 8, 10, 11, 12, 22, 26, 27
	2019	7 (22,6)	2, 13, 15, 23, 28, 29, 30
	2020	0	
Research design	Qualitative	5 (16,1)	2, 4, 20, 26, 30
	Quantitative	15 (48,4)	7, 9, 10, 12, 13, 14, 15 17, 22, 23, 24, 25, 27, 29, 31
	Mixed methods	11 (35,5)	1, 3, 5, 6, 8, 11, 16, 18, 19, 21, 28
Theoretical framework	Usage of theoretical framework	4 (12,9)	2, 17, 21, 30
	Not used/clearly stated	27 (87,1)	1, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 18, 19, 20, 2, 23, 24, 25, 26, 27, 28, 29, 31
Duration of study	Less than 1 week	8 (25,8)	6, 7, 8, 12, 13, 27, 28, 21
	1 to 4 weeks	10 (32,3)	3, 4, 5, 15, 17, 21, 22, 24, 29, 30
	5 to 8 weeks	3 (9,7)	2, 8, 10
	9 to 12 weeks	2 (6,5)	11, 25
	13 to 16 weeks	2 (6,5)	9, 20
	17 to 20 weeks	0	
	21 to 24 weeks	1 (3,2)	16
Country location	Asia	6 (19,4)	6, 7, 9, 12, 14, 25
	Europe	14 (45,2)	3, 4, 8, 13, 18, 19, 23, 24, 26, 27, 28, 29, 30, 31
	North America	8 (25,8)	1, 2, 5, 10, 11, 17, 20, 21
	Oceania	1 (3,2)	16
	South America	2 (6,5)	15, 22

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

Appendix 6 – Characteristics of mHealth solutions

Classification category	Sub category	Detailed category	N (%)	Reference index
Type of mHealth device	activity tracker	activity tracker	2 (6,5)	4, 26
		instrumented insoles	1 (3,2)	8
	mobile device	smartphone	19 (61,3)	1, 4, 6, 8, 10, 12, 13, 14, 15, 16, 17, 18, 19, 21, 24, 25, 26, 29, 30
		tablet	6 (19,4)	1, 2, 5, 9, 11, 28
	non wearable device	ultrabook display	1 (3,2)	21
		stationary node	1 (3,2)	31
	wearable device	smartwatch	4 (12,9)	2, 3, 15, 27
		wearable device	3 (9,7)	10, 20, 22
		wearable instrumented vest	1 (3,2)	7
		wearable node	1 (3,2)	31
		wearable sensor	2 (6,5)	23, 30
Technology	algorithm	machine learning	2 (6,5)	12, 23
		algorithm	1 (3,2)	22
		deep learning	1 (3,2)	23
	location tracking	accelerometer	1 (3,2)	7
		GPS	1 (3,2)	20
	movement recognition	human activity recognition system	2 (6,5)	15, 21
		pattern recognition	1 (3,2)	21
		recording nodes	1 (3,2)	31
		sensor technology	2 (6,5)	8, 30
		vibrotactile sensory augmentation	1 (3,2)	10
	application	application	25 (80,6)	1, 2, 3, 4, 5, 6, 7, 8, 9, 11, 12, 13, 14, 15, 16, 17, 18, 19, 24, 25, 26, 27, 28, 19, 30
Function	active bingo		1 (3,2)	11
	activity tracking		4 (12,9)	4, 23, 25, 27
	ambient assisted living monitoring		1 (3,2)	3
	attention training		1 (3,2)	5
	balance training		1 (3,2)	10
	bidirectional ambient display platform		1 (3,2)	21
	fall detection application		1 (3,2)	16
	fall detection device		4 (12,9)	20, 22, 30, 31
	fall risk application		1 (3,2)	1
	fall risk detection via soles		1 (3,2)	8
	healthy eating application		3 (9,7)	12, 26, 29
	monitoring solution		2 (6,5)	13, 14
	PA and cognitive training promoter application		1 (3,2)	17
	PA promoter application		4 (12,9)	2, 9, 15, 28
	PA promoter application via gamification		2 (6,5)	18, 19
	self-monitoring		1 (3,2)	24
	smart clothing monitoring		1 (3,2)	7
	virtual pet		1 (3,2)	6
Sample age	55≤		2 (6,5)	13, 17
	60≤		14 (21,4)	4, 5, 6, 7, 8, 12, 14, 15, 19, 20, 22, 24, 25, 29
	65≤		8 (25,8)	2, 9, 10, 16, 18, 26, 28, 31
	70≤		3 (9,7)	1, 21, 23
	75≤		2 (6,5)	27, 30
Sample gender	Mixed		26 (83,9)	1, 3, 4, 5, 6, 7, 8, 10, 11, 12, 13, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 27, 28, 20, 30
	Females		2 (6,5)	2, 9
	Men		0	
Samples' proficiency with the relevant	Yes		5 (16,1)	1, 5, 6, 13, 17
	No		8 (25,8)	4, 7, 18, 24, 25, 28, 29, 30

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

Appendix 7 – AHA characteristics of mHealth solutions

Classification category	Sub category	N (%)	Reference index
Main factor AHA	Daily functioning	14 (21,4)	1, 3, 5, 7, 8, 10, 13, 14, 16, 19, 20, 22, 30, 31
	Environment	0	
	Lifestyle	19 (61,3)	2, 4, 6, 9, 11, 12, 13, 15, 17, 18, 19, 21, 23, 24, 25, 26, 27, 28, 29
	Participation	2 (6,5)	11, 25
Sub-factor AHA	active lifestyle	17 (54,8)	2, 4, 6, 9, 11, 13, 15, 17, 18, 19, 21, 23, 24, 25, 26, 27, 28,
	external	0	
	formal participation	1 (3,2)	11
	functional ability	3 (9,7)	5, 10, 13
	healthy lifestyle	4 (12,9)	12, 24, 26, 29
	independence	13 (41,9)	1, 3, 7, 8, 10, 13, 14, 16, 19, 20, 22, 30, 31
	informal participation	2 (6,5)	11, 25
	secure living	7 (22,6)	1, 7, 8, 14, 16, 30, 31
AHA objective	activity tracking	11 (35,5)	2, 4, 7, 15, 17, 18, 21, 23, 25, 26, 27
	balance training	1 (3,2)	10
	cognitive activity	5 (16,1)	5, 6, 11, 13, 17
	emergency	5 (16,1)	3, 7, 14, 16, 31
	fall detection	8 (25,8)	7, 8, 13, 16, 20, 22, 30, 31
	fall prevention	1 (3,2)	19
	fall risk assessment	1 (3,2)	1
	fall risk monitoring	1 (3,2)	8
	health education	1 (3,2)	11
	healthy eating	4 (12,9)	12, 24, 26, 29
	medication adherence	2 (6,5)	13, 24
	monitoring	7 (22,6)	3, 6, 7, 13, 14, 23, 31
	PA promotion	11 (35,5)	2, 4, 6, 9, 11, 15, 17, 18, 19, 24, 25, 28
	recreational activity	1 (3,2)	24
	self-monitoring	4 (12,9)	2, 14, 18, 24
	social interaction	6 (19,4)	6, 11, 13, 18, 21, 24
	volunteering	1 (3,2)	25

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

Appendix 8 – Description of implementation of mHealth solutions for AHA promotion

Classification category	Sub category	Detailed category	N (%)	Reference index
Successful	Improved PA	improved and/or increased PA	3 (9,7)	2, 4, 17
		increased steps	1 (3,2)	24
		increased walking speed	1 (3,2)	25
		improved balance	1 (3,2)	10
		decreased sedentary behaviour	1 (3,2)	2
		improved functional performance	1 (3,2)	11
	Increased health consciousness	experienced a higher level of fitness	2 (6,5)	4, 18
		increased health consciousness	2 (6,5)	28, 25
		greater motivation to be active and take care of their health	3 (9,7)	4, 9, 18
	Increased social engagement	feeling cared for by someone	1 (3,2)	16
		feeling more socially active	1 (3,2)	25
		increased peace of mind & closeness	1 (3,2)	21
		social comparison	1 (3,2)	18
	Increased feeling of security	increased feeling of security	3 (9,7)	1, 16, 20
	Improved cognitive functioning	improved cognitive functioning	3 (9,7)	5, 9, 21
	Boosted high adherence to the intervention	boosted high adherence to the intervention	2 (6,5)	11, 17
	Overall satisfied and/or enthusiastic	overall satisfied and/or enthusiastic	9 (29,0)	5, 8, 11, 13, 16, 19, 20, 28, 29
	Increased knowledge	increased knowledge about health topics	1 (3,2)	11
		increased knowledge about food guidelines	1 (3,2)	12
Unsuccessful	None or modest PA improvements	no difference in BMI	1 (3,2)	4
		no direct ADL difference	1 (3,2)	9
		limited PA improvements	1 (3,2)	11
		moderate step increase	1 (3,2)	18
		No increase in water intake or physical activity	1 (3,2)	24
		no weight loss among overweight	1 (3,2)	24
	None or modest general health improvements	limited cognitive performance improvements	1 (3,2)	11
		no improvements in sleep	1 (3,2)	2

		no difference in "quality time for one self"	1 (3,2)	24
		limited positive effect on nutrition awareness (tobacco and alcohol)	1 (3,2)	25
	No perceived need of device	experience no risk of falling	1 (3,2)	20
	Device disturbing	embarrassing when fall alarm goes off in public	1 (3,2)	20
		occasionally inconvenient to receive the PA reminders	1 (3,2)	15
	No increased feeling of safety	no increased feeling of safety	1 (3,2)	16
	Lack of engagement	decrease of usage over time	1 (3,2)	29
		lack of engagement	1 (3,2)	5
	No knowledge increase	did not understand how many glasses water to drink per day	1 (3,2)	12
Positive user experience	High usability	user friendly	6 (19,4)	1, 3, 12, 14, 17, 29
		solution can be applied in daily life	1 (3,2)	12
	Easy to use	device easy to use	6 (19,4)	1, 7, 14, 18, 19, 30
		independently able to use the device	3 (9,7)	10, 29, 28
Negative user experience	Challenging to use device	device difficult/ confusing to use	7 (22,6)	1, 2, 5, 7, 16, 25, 30
		more extensive explanations required	2 (6,5)	12, 28
		difficulties with charging the device	2 (6,5)	3, 20
		too small text	2 (6,5)	18, 20
	Resistance to using the device	afraid of losing it	1 (3,2)	20
		annoying to constantly have to wear it	1 (3,2)	20
		barrier to always carry two devices	1 (3,2)	30
		discomfort of having two functions in one smartphone	1 (3,2)	16
		anxious attitude towards intelligent wearables	1 (3,2)	7
Technical benefits	Specific technology proved useful	technology useful in PA motivation	1 (3,2)	2
		device design enhances willingness to use application	1 (3,2)	6
		technology facilitate communication between elderly and child	1 (3,2)	13
		activity recognition scheme possible to use for unobtrusive monitoring of older	1 (3,2)	23
		application led to less resistance of using novel ICTs	1 (3,2)	25

		possible to use same tool for medication reminder and communication	1 (3,2)	13
		feasibility of smartphone as balance trainer proved as all elderly were able to successfully complete training	1 (3,2)	10
	Positive technological outcomes	high accuracy for activity recognition	1 (3,2)	15
		GPS high success rate	1 (3,2)	25
		significantly higher recognition than normal smartwatches	1 (3,2)	27
	Not feeling limited by wearing the device	not feeling limited by wearing the device	3 (9,7)	16, 21, 30
Technical challenges	Negative influence on everyday life	short distance required between phone and sensor not doable	1 (3,2)	30
		too short battery time	1 (3,2)	30
	Poor accuracy	poor accuracy when having device in front pocket	1 (3,2)	19
		inaccurate location information	1 (3,2)	31
	False fall alarms	too many false alarms	3 (9,7)	15, 16, 22
		false alarms when the device was dropped or manually activated	1 (3,2)	30
		dropout due to, device too large/too many false alarms/inability to control the device	1 (3,2)	20

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