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Review

Review

Mobile health applications for older adults: a systematic review of interface and persuasive feature design

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ABSTRACT

Objective: Mobile-based interventions have the potential to promote healthy aging among older adults. However, the adoption and use of mobile health applications are often low due to inappropriate designs. The aim of this systematic review is to identify, synthesize, and report interface and persuasive feature design recommendations of mobile health applications for elderly users to facilitate adoption and improve health-related outcomes.
Materials and Methods: We searched PubMed, Embase, PsycINFO, CINAHL, and Scopus databases to identify studies that discussed and evaluated elderly-friendly interface and persuasive feature designs of mobile health applications using an elderly cohort.
Results: We included 74 studies in our analysis. Our analysis revealed a total of 9 elderly-friendly interface design recommendations: 3 recommendations were targeted at perceptual capabilities of elderly users, 2 at motor coordination problems, and 4 at cognitive and memory deterioration. We also compiled and reported 5 categories of persuasive features: reminders, social features, game elements, personalized interventions, and health education.
Discussion: Only 5 studies included design elements that were based on theories. Moreover, the majority of the included studies evaluated the application as a whole without examining end-user perceptions and the effectiveness of each single design feature. Finally, most studies had methodological limitations, and better research designs are needed to quantify the effectiveness of the application designs rigorously.
Conclusions: This review synthesizes elderly-friendly interface and persuasive feature design recommendations for mobile health applications from the existing literature and provides recommendations for future research in this area and guidelines for designers.

Key words: mobile application, user-centered design, interface design, persuasive features, healthy aging

INTRODUCTION

The aging population is increasing rapidly all over the world. The proportion of people aged 65 or above is expected to reach 12% and 23% worldwide by 2030 and 2100, respectively,[1] which would put enormous pressure on health and social service systems.[2] To alleviate this pressure, healthcare providers are considering designing mobile-based interventions to promote healthy lifestyles, support disease prevention and management, and improve access to health services.[3] The global mobile health market was estimated at $35.1 billion in 2020 and is expected to increase to $145.7 billion by 2027.[4] However, acceptance and continued use of mobile health (mHealth) applications are often low among the elderly, significantly plaguing their utility.[5] One important reason is that most mHealth applications available in the market do not carefully consider the unique needs, preferences, and capabilities of elderly users, resulting in low usability.[5,6]

Compared with younger populations, older adults often face additional challenges in using mHealth applications due to limited perceptual, motor, and cognitive capabilities.[7,8] In particular, the aging process will negatively affect visual and hearing abilities, hand-motor functions, and information processing capacity.[9–12] Moreover, elderlies tend to experience reduced motivational orientation,[6] further hampering the adoption and sustainable use of mHealth applications. Indeed, older adults will not adopt a technology if they do not perceive the benefits of using it.[13]

It is therefore essential to provide sufficient support for older adults when designing mHealth applications for them. Several review articles have focused on evaluating the benefits of mHealth applications for chronic disease management and healthy lifestyle promotion in older adults,[14–17] and some have discussed practical challenges in application design.[15,16,18] However, none of these reviews have compiled and reported mHealth application design recommendations for older adults. On the other hand, some articles have analyzed aging barriers for mHealth application usability and proposed several interface guidelines.[6,19–21] However, these studies neither summarized the current evidence of the effectiveness of interface design nor investigated persuasive feature design. This review aims to address these gaps by identifying, synthesizing, and reporting recommended mHealth application designs that facilitate application adoption and promote healthy aging. Specifically, we seek to identify elderly-friendly interface designs that increase mHealth application acceptability and usability and persuasive features that increase adherence to the delivered mobile interventions.

METHODS

Data sources and searches

We followed the guideline of the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) statement.[22] With the help of a librarian, 2 reviewers (JY and NL) searched PubMed, Embase, PsycINFO, CINAHL, and Scopus databases (Jan 01, 2010, to Apr 30, 2021) to identify articles with a focus on the design of mHealth applications for older adults. We chose 2010 as the start period because mHealth applications for older adults have only grown exponentially in the last decade.[23]

We searched the title and abstract of the articles using 3 groups of keywords that were combined using an AND operator: (a) mHealth application-related terms, (b) application design-related terms, and (c) older adult-related terms. The detailed search strategy can be seen in Supplementary Appendix A.

Study selection

We structured our inclusion and exclusion criteria based on the PICOS (Population, Interventions, Comparisons, Outcomes, Study) framework (see Table 1). Two members of the research team (JY, NL) independently screened the titles and abstracts of the retrieved articles and assessed the full texts of all potentially eligible studies against the inclusion criteria. Interrater reliability of the screening based on the title and abstract resulted in high agreement (Cohen's kappa = 0.74), while the interrater reliability of the screening based on the full text resulted in moderate agreement (Cohen's kappa = 0.67). Disagreements were resolved through group discussion with a third investigator (SST) until 100% agreement was achieved.

Data extraction and analysis

Two team members (JY, NL) extracted and synthesized information using a piloted data extraction form. Specifically, they individually extracted the following items: study characteristics (ie, participant characteristics, country, study design, mHealth application descriptions, and health domain), application design features (ie, user interfaces, persuasive features, theory), mobile interventions, comparison or control groups, evaluation outcomes (ie, end-user perceptions, health-related outcomes), and key findings. Disagreements were resolved through group discussion with another 2 investigators (HHT and KYN) until 100% agreement was achieved.

RESULTS

Study inclusion

We identified a total of 6337 articles using the initial search strategy (Figure 1). We removed 1569 duplicate records using Endnote's automatic duplication finder, leaving 4768 unique articles. After screening titles and abstracts, 175 articles were eligible for full-text review. We excluded 104 articles because the studies did not focus on mHealth applications or did not evaluate the applications with an elderly cohort, leaving 71 included articles. We included 3 studies identified through searching the reference lists of included studies. Thus, 74 articles were kept in the final analysis.

Study characteristics and quality

Table 2 presents details of study characteristics. All of the included studies enrolled participants aged 60 years or more. Four studies did not report participants' gender. 38 studies did not reveal participants' educational background, and 39 studies did not reveal their experience with mobile devices and digital technologies. Sample sizes ranged from 1 to 503, in which 46 studies had a sample size smaller than 30.

Of the 74 included studies, a variety of quantitative ($N = 47$), qualitative ($N = 9$), and mixed-methods designs ($N = 18$) were used to evaluate mHealth applications (see Table 1 for details). We further assessed the quality of the 12 RCT studies based on the Cochrane Risk of Bias Assessment Tool (see Supplementary Appendix B for details).[99] Nine studies reported random sequence generation.[46,48,52,54,59,69,71,74,90] Only 3 studies explicitly stated that the allocation was concealed.[54,59,69] Only 2 studies were double-blinded,[54,74] and 1 study was blinded to neither researchers nor participants.[71] Using 80% completed participants as a threshold, 7 studies had a low risk of incomplete outcome data.[34,46,54,58,69,74,90] One study had a high risk of selective reporting bias.[38] Nine studies suffered from other sources of bias, such as a small sample size,[34,46,48,52,54,58,69,71] a biased sample,[54,59,71,90] and a lack of baseline data.[54]

The mHealth applications described in the 74 included studies were mainly designed for disease prevention and self-management ($N = 28$), physical and cognitive function improvement ($N = 27$), social inclusion and well-being ($N = 6$), healthy dieting ($N = 5$), and health monitoring and reporting ($N = 5$). The remaining 3 articles covered more than 1 health domain, such as using a conversational

Table 1. Inclusion and exclusion criteria based on the PICOS model

	Inclusion and exclusion criteria
Population	An older cohort. An older person can be defined as one whose chronological age is 60 years or above, or 65 years or above.[24] In this review, we used 60 years as a more conservative threshold.
Interventions	Any mHealth applications with any mobile devices, such as mobile phones and tablets. We excluded health-related interventions that only used mobile devices (eg, short messages), wearables, and smart home devices without mobile apps.
Comparisons	No specific comparisons were excluded.
Outcomes	Studies were excluded if they only described the design and development of mHealth applications without testing them using an elderly cohort.
Study designs	We restricted our search to English-written, peer-reviewed journal articles and excluded conference abstracts, non-human studies, theoretical articles, reviews, commentaries, editorials, proposal papers, and protocol papers.

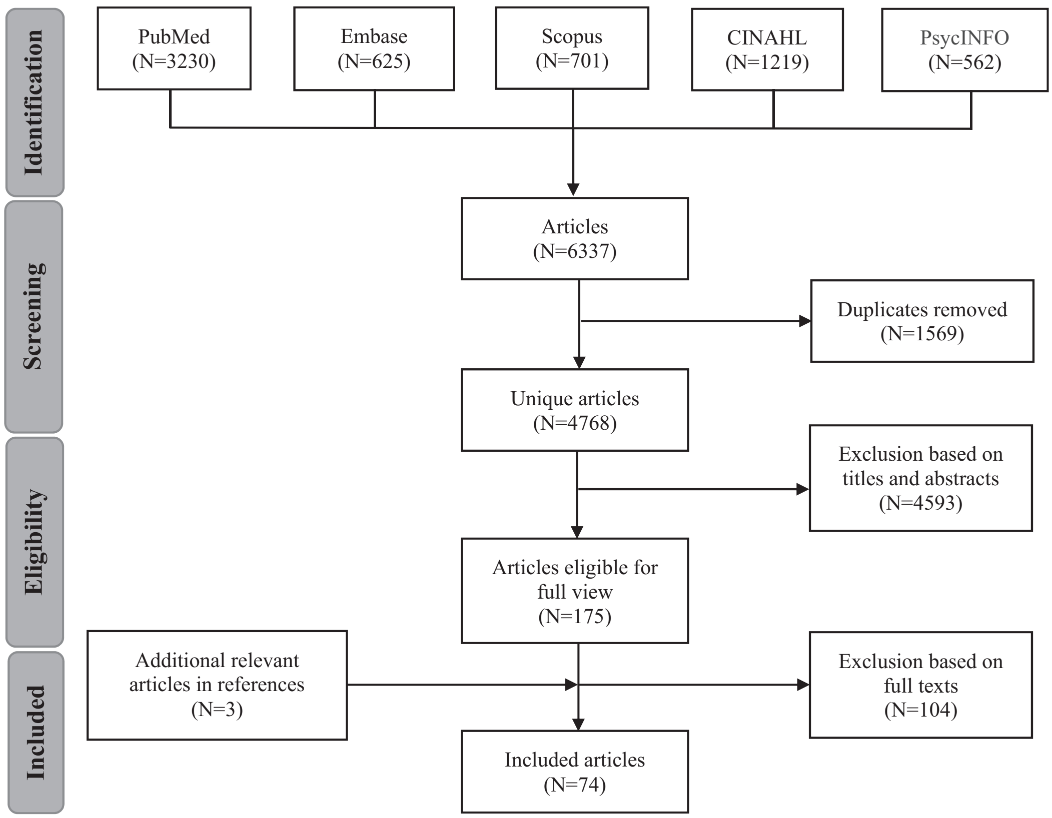

Figure 1. Flowchart of the literature search and selection processes.

agent to offer training modules for healthy dieting, physical health, and cognitive health.[97]

Evaluation outcomes for design effectiveness

The mHealth application designs were mainly assessed along 2 dimensions: end-user perceptions and health-related outcomes (see Supplementary Appendix C for details). Examples of end-user perceptions included usability, feasibility, acceptability, adherence, compliance, engagement, satisfaction, adoption and use, and other self-reported usage experience such as facilitators, barriers, and suggestions for future improvement. On the other hand, health-related outcomes included health-related behavior changes, physical and cognitive functions, psychosocial and emotional well-being, quality of life, and health knowledge.

Recommendations for interface designs

Our analysis identified a total of 9 elderly-friendly interface design recommendations (see Box 1). We grouped these designs into 3 categories based on the addressed needs of elderly users: perceptual limitations, motor coordination problems, and cognitive and memory deterioration.

Perceptual limitations

Font design. Fifteen studies emphasized the importance of font design to improve application readability.[25,37–39,41–43,46,50,53,63,67,81,86,87] One often-mentioned design aspect is *using large font size*.[25,38,39,41–43,46,50] For example, Goumopoulos et al[81] recommended using a font size of 36 to 48 points on mobile phones. Other specific font design recommendations included *using Sans Serif family font style*,[67,81] *using bold*

Box 1. Recommended interface designs

Vision impairment

Font design
- Large font size
- Use Sans Serif family font style (eg, Arial, Verdana)
- Use bold font for key points
- Avoid special font styles (eg, italics, underline, all caps)
- Enable users to customize the font and text properties

Color choice
- Ensure high contrast (eg, use dark texts on a light interface background, use differentiated button color from the interface background)
- Limit number of colors
- Use basic and distinctive colors
- Use consistent background colors
- Use culturally appropriate colors (eg, use Arabic basic colors for Arabian users)
- Color coding of buttons

Provision of audio alternatives
- Provide audio options
- Ensure loud audio volume
- Add vibrations during each auditory tone

Motor coordination problems

Gestural interactions
- Use simple touchscreen gestures (eg, swiping, tapping, dragging, dropping)
- Avoid complex touchscreen gestures (eg, scrolling, zooming)
- Use large and structured buttons

Minimize text entry
- Support voice control
- Button-only interface (eg, use buttons and sliders to answer questions)

Cognitive and memory deterioration

Simple and consistent layout
- Provide a simple and consistent layout
- Ensure adequate white space between lines and buttons
- Adaptive layout based on the screen size
- Avoid large blocks of texts
- Avoid texts over images
- Use culturally appropriate layout (eg, use right to left reading for Arabian users)

Simple and clear navigation
- Flat navigation structure
- Place main functions in the home screen
- Reduce menu options
- Provide a clear return button and a static menu on every page

Multimedia presentation
- Present information in the form of texts, pictures, and videos

Easy-to-understand content
- Use labeled buttons
- Organize related topics into groups
- Use age-appropriate and common languages

font for key points,[53] *avoiding special font styles*,[53] and *enabling users to customize font and text properties*.[53]

Color choice. Designers emphasized the importance of choosing an appropriate color to cater to older adults. One suggestion is to *ensure high contrast* to enhance the content readability for the aging population, such as using dark texts on a light interface background.[26,40,43,46,50,51,67,81,86] Another suggestion is to keep it simple, such as *limiting the number of colors*,[29,43] *using basic and distinctive colors*,[38] *using consistent background colors*,[81] and *using culturally appropriate colors*.[25] Finally, it is suggested to employ *color-coding*, such as assigning appropriate and unique colors for each button.[27,33,43,50,53,63,66,88,91] For example, Harte et al[63] used red for the "I have fallen" button and green for the "I am OK" button.

Audio alternatives.. Applications should provide audio alternatives to ease the burden on vision-impaired elderly users. One suggestion is to *read out texts* to avoid misinterpretation and ensure accessibility to elderly users.[28,62,81] Designers can also *use loud audio volume* and *add vibrations during each auditory tone* for older adults with hearing difficulty.[55,67]

Table 2. Study characteristics

Study	Study design	Age (range, mean)	Gender (female)	Education (college degree or higher)	Computer-related experience	Sample size	Country	Application descriptions	Health domain
Disease prevention and self-management (N = 28)									
Alsswey et al[25]	Quantitative research (Survey)	60+, Mean (M): not reported.	15.70%	23.90%	All had at least 1 year of experience in using mobile applications.	134	Not reported	A mobile app designed to manage physical health needs for Arab elderly users (eg, medication-related information and instructions)	Medication adherence
Alvarez et al[26]	Quantitative research (Pilot study: usability study, feasibility study)	Usability: 65+, M = 73.2; Feasibility: 65+, M = 76	Usability: 67.6%; Feasibility: 59.5%	Usability: 9 years of education; Feasibility: 10.53 years of education	Usability: 32.3% had previous experience with technology.	Usability: 34; Feasibility: 62	Chile	A mobile app that provides interventions to prevent delirium for bedside use for hospitalized elderly patients	Delirium prevention
Bakogiannis et al[27]	Quantitative research (Usability study, pilot study)	Usability: M = 64.9; Pilot: M = 68.7	Usability: 21%; Pilot: 13%	Not reported.	Not reported.	Usability: 14; Pilot: 30	Greece	ThessHF app, a mobile app that supports heart failure self-care for elderly patients with heart failure	Heart failure self-management
Balsa et al[28]	Quantitative research (Usability study)	67–80, M = 70.91	72.2%	63.6%	Not reported.	11	Portugal	VASelfCare, a mobile-based intelligent assistant (in the form of an anthropomorphic virtual assistant) that supports older adults with Type 2 Diabetes Mellitus (T2DM) in medication adherence and lifestyle changes	T2DM self-management
Baric et al[29]	Qualitative research (Focus groups)	66–85, M = 73	45%	40%	55% had daily or weekly computer use; 85% had daily or weekly phone use.	20	Sweden	RemindMe, an interactive digital calendar that provides active reminders for senior people with cognitive impairment	Cognitive impairment self-management
Chen et al[30]	Qualitative research (Usability study)	64	100%	Not reported.	Not reported.	1	China	Win-Win aSleep (WWAS), a mobile app to assist cognitive behavioral therapy for older adults with insomnia	Insomnia self-management
Chen et al[31]	Quantitative research (Pre-post intervention study)	60+, M = 86.68	77%	Not reported.	Not reported.	57	Hong Kong	Lok Chi, a home-based tablet-based intervention designed to improve cognitive and emotional health for community-dwelling older adults with mild cognitive impairment (MCI)	MCI self-management
Chung et al[32]	Quantitative research	65–78, M = 71.56	100%	0%	38 had Android smartphones; 2 had feature phones on which mobile apps were not available.	40	South Korea	MIND MORE, a mobile app for insomnia self-management in community-dwelling older adults	Insomnia self-management

(continued)

Table 2.. continued

Study	Study design	Age (range, mean)	Gender (female)	Education (college degree or higher)	Computer-related experience	Sample size	Country	Application descriptions	Health domain
	(Pre-post intervention study)								
Cunningham et al[33]	Quantitative research (Cohort study)	69–97, M = 84.6	64%	Not reported.	Not reported.	14	United Kingdom	Memory Tracks, a music mobile platform that provides song-task association training for elderly people with dementia	Dementia self-management
Djabelkhir et al[34]	Quantitative research (RCT)	60+, M = 79	60%–70%	44.4%–60%	Not reported	14	France	Two tablet-based cognitive training apps (cognitive stimulation, cognitive engagement) for elderly patients with MCI	MCI self-management
Fortuna et al[35]	Quantitative research (Feasibility study)	60+, M = 68.8	87.50%	12.50%	62.5% had smartphones.	8	United States	PeerTECH, a tablet-delivered psychiatric self-management intervention for older adults with mental illnesses	Psychiatric self-management
Hackett et al[36]	Quantitative research (Pilot study, within-subject, cross-over experiment)	65+, M = 80.3	70%	Not reported.	Participants were able to use computers and had positive attitudes toward computers.	10	United States	SmartPrompt, a mobile reminder app for older adults with dementia and MCI	Self-management of dementia and MCI
Holden et al[37]	Quantitative research (Usability study)	60–85, M = 67.6	61.00%	23.00%	Some participants had never used a smartphone before.	23	United States	Brain Buddy, a mobile app to reduce unsafe medication use by older adults	Medication use
Jongstra et al[38]	Quantitative research (RCT)	65+, M = 69	56%	29%	Not reported.	41	Finland, France, The Netherlands	An interactive counseling platform for healthy aging (ie, cardiovascular risk profiling and prevention)	Cardiovascular diseases prevention
Jung et al[39]	Qualitative study (Usability study, interviews)	65–80, M: not reported.	78.57%	57.14%	All participants had experience with smartphones.	14	United States	FRADA, a food record app that provides dietary assessments for older adults with Type 2 Diabetes	Diabetes self-management
Kim et al[40]	Mixed methods research (Pilot study)	65+, M = 75.7	91%	18.2%	Participants had 3.5 years of smart device usage experience on average.	11	South Korea	365 Healthy Swallowing Coach, a mobile app that delivers swallowing training for elderly dysphagia patients	Swallowing training
Loh et al[41]	Mixed methods research (Pilot study)	68–87, M = 76.8	17%	67%	44% (17%) had access to a mobile phone (a tablet or iPad).	18	United States	TouchStream, a mHealth app that provides geriatric assessment-	Cancer treatment

(continued)

Table 2.. continued

Study	Study design	Age (range, mean)	Gender (female)	Education (college degree or higher)	Computer-related experience	Sample size	Country	Application descriptions	Health domain
								driven interventions for older adults with cancer	
Madill et al[42]	Quantitative research (Usability study)	60+, M = 75.5	23.30%	Not reported.	Not reported.	30	United States	"Take Back Your Back", an iPad-based educational tool for older adults with chronic lower back pain	Back pain treatment
Manca et al[43]	Quantitative research (Between-subject experiment)	69–84, M = 75.3	64.3%	7.14%	50% were familiar with technologies and devices.	14	Italy	A music-based game (robot version and tablet version) for older adults with MCI	MCI self-management
Manera et al[44]	Quantitative research (Pilot study)	60–90, M = 78.3	71%	Not reported.	Not reported.	21	Not reported.	"Kitchen and cooking", a tablet-based serious game for elderly people with MCI and Alzheimer's Disease (AD)	Self-management of MCI and AD
Mertens et al[45]	Quantitative research (Crossover design)	60+, M = 73.8	50%	25%	16.7% expert in computer literacy	24	Germany	Medication Plan, a mobile app designed to improve therapy adherence for elderly patients undergoing rehabilitation	Rehabilitation self-management
Mira et al[46]	Quantitative research (RCT)	65+, M = 72.9	Not reported.	Not reported.	45% had smartphone experience.	99	Spain	ALICE, a tablet-based app for medication self-management	Medication self-management
Portz et al[47]	Quantitative research (Pilot study)	60+, M = 66	60%	Not reported.	Not reported.	30	United States	HF app, a mobile app that tracks heart failure symptoms in elderly users	Heart failure self-management
Puig et al[48]	Quantitative research (RCT)	60+, Median = 66	28%	Not reported.	Not reported.	100	Finland	+Approp, a mobile app for HIV prevention and self-management for older HIV-infected patients	HIV prevention and self-management
Quinn et al[49]	Quantitative research (Pilot study)	65+ M = 70.3	57%	Not reported.	71.4% had Internet at home.	7	United States	Patient coaching system (PCS), a mobile software for diabetes management for older adults	Diabetes management
Reading Turchioe et al[50]	Quantitative research (Feasibility study)	60+, M: not reported.	37%	47%	30.4% did not have a computer and 26.2% did not have the internet.	168	United States	mi.Symptoms, a mobile app that facilitates symptom reporting and patient outcome reporting in older adults	Chronic disease self-management
Scase et al[51]	Qualitative research (Focus groups)	65–80, M = 75.0	88%	Not reported.	Not reported.	25	United Kingdom	4 tablet-based cognitive games (ie, "Find it," "Match it," "Solve it," and "Complete it") for older adults with mild cognitive impairment	MCI self-management
Sun et al[52]		66–72	59.34%	Not reported.	Not reported.	91	China		T2DM self-management

(continued)

Table 2.. continued

Study	Study design	Age (range, mean)	Gender (female)	Education (college degree or higher)	Computer-related experience	Sample size	Country	Application descriptions	Health domain
	Quantitative research (RCT)	M = 68						A mobile-based telemedicine app for T2DM self-management for older adults	
Physical and cognitive function improvement (N = 27)									
Albergoni et al[53]	Quantitative research (Pilot study)	70–78, M = 73.8	40%	Not reported.	Not reported.	10	The Netherlands	PACE, a mobile app that visualizes user adherence to physical activity programs	Physical activities
Baez et al[54]	Quantitative research (RCT)	65–87, M = 71.5	70%–75%	Not reported.	Not reported.	40	Italy	Gymcentral, a tablet-based app for home-based online group exercises under the supervision of a human coach	Home-based exercises
Bergquist et al[55]	Mixed methods research (Usability study)	60–80, M = 66.4	48%	Not reported.	83% had mobile experience.	343	Norway, Germany, The Netherlands	3 mobile apps that deliver physical function self-tests (ie, Self-TUG, Self-STS, Self-Tandem) for older adults	Physical function self-tests
Compernolle et al[56]	Mixed methods research (Usability study)	60–76, M = 64.3	54%	57%	Not reported.	28	Belgium	Activator, a mobile self-monitoring tool designed to reduce older adults' sedentary behavior	Sedentary behavior change
Daly et al[57]	Quantitative research (Pilot study)	65–81, M = 70	50%	60%	Not reported.	20	Australia	PhysiApp, a tablet-based app that delivers tailored, home-based exercise programs for community-dwelling older adults	Home-based exercises
Dekker-van Weering et al[58]	Quantitative research (RCT)	65–75, M = 70.2	61.1%	8.3%	Not reported.	36	The Netherlands	A tablet or computer-based portal that provides home-based exercise programs for pre-frail older adults	Physical activities
Delbaere et al[59]	Quantitative research (RCT)	70+, M = 77.4	67.4%	Not reported.	85% (88.4%) in the intervention (control) group owned computers.	503	Australia	StandingTall, a tablet-based mobile app that delivers home-based, balance exercises to older adults	Balance exercises
Geerds et al[60]	Mixed methods research (Usability study)	M = 80.5	71.80%	Not reported.	93.8% had more than 5 years of smartphone experience.	48	The Netherlands	A mobile app designed to monitor postoperative functional recovery after hip fracture	Functional recovery after hip fracture
Geraedts et al[61]	Quantitative research (Feasibility study)	70+, M = 81	62.5%	Not reported.	62.5% had computer experience; 2.5% had a smartphone.	21	The Netherlands	A tablet-based app that provides home-based exercise programs for pre-frail old adults	Home-based exercises
Haeger et al[62]	Quantitative research (Feasibility	70+, M = 76.5	50%	Not reported.	Not reported.	10	Germany	MIT App Inventor 2, a mobile app that plans trips in hometowns to increase mobility in older adults	Mobility

(continued)

Table 2.. continued

Study	Study design	Age (range, mean)	Gender (female)	Education (college degree or higher)	Computer-related experience	Sample size	Country	Application descriptions	Health domain
	study, controlled trial)								
Harte et al[63]	Mixed methods research (Usability study)	61–85, M: not reported.	Not reported.	Not reported.	Not reported.	12	Ireland	A mobile app that integrates fall risk detection for older adults	Fall risk detection and fall prevention
Hawley-Hague et al[64]	Qualitative research (Usability study, focus groups, interviews)	64–92, M = 77.1	Not reported.	Not reported.	Not reported.	7	United Kingdom	Two mobile apps that support falls rehabilitation exercises (ie, My Activity Programme for patients, Motivate Me for professionals)	Fall rehabilitation exercises
Hill et al[65]	Mixed methods research (Feasibility study)	60+, M = 78.8	78%	56%	Not reported.	9	United States	A tablet-based attention training app designed to improve cognitive functioning in older adults	Cognitive training
Hill et al[66]	Mixed methods research (Usability study)	60+, M = 79	58%	50%	Not reported.	12	United States	A modified tablet-based attention training app designed to improve cognitive functioning in older adults	Cognitive training
Hsieh et al[67]	Mixed methods research (Usability study)	70+, M = 80.3	81.8%	27.2%	54.5% used tablets and 81.1% used smartphones.	11	United States	Steady, a mobile app for fall risk screening for older adults	Fall risk screening and prevention
Kang et al[68]	Quantitative research (Pre-post experiment)	65–75, M = 70	50%	Not reported.	Not reported.	4	South Korea	A mobile app that provides exercise suggestions for older adults with chronic disorders	Exercise suggestions
Kwan et al[69]	Quantitative research (RCT)	60+, Median = 71	85.00%	Not reported.	Not reported.	33	Hong Kong	Samsung Health, a mobile app that monitors walking behaviors	Walking activities
Li et al[70]	Quantitative research (Pre-post between-subjects experiment)	65+, M = 71.3	70%	Not reported.	Not reported.	30	Singapore	5 exergames (ie, Skiing, Hiking, Pikkuli, Chinatown Race, RehaMed Volleyball) that promote physical activities in older adults	Physical activities
Li et al[71]	Quantitative research (RCT)	60+, M = 79.3	19.4%	4.6 years on average	Not reported.	31	Hong Kong	Caspar Health e-system and a mobile app designed to provide occupational therapy rehabilitation for	Physical and functional ability

(continued)

Table 2.. continued

Study	Study design	Age (range, mean)	Gender (female)	Education (college degree or higher)	Computer-related experience	Sample size	Country	Application descriptions	Health domain
								elderly outpatients after hip fracture surgery	
Mehra et al[72]	Mixed methods research (Usability study)	69–99 M: not reported.	73.3%	Not reported.	Not reported.	15	The Netherlands	VITAMIN app, a tablet-based app that supports older adults in home-based exercises	Exercise training
Pettersson et al[73]	Qualitative research (Feasibility study)	70+, M = 76	52.6%	Not reported.	71% (72%) had access to tablet/smartphone (computer).	28	Sweden	Safe Step, a mHealth app that supports self-managed exercises and behavior changes for older adults with impaired balance	Self-managed exercises and behavior changes
Shake et al[74]	Quantitative research (RCT)	65+, M = 73.4	86%	20%	Not reported.	105	United States	Bingocize, a mobile game app designed to provide exercise and health education for older adults	Exercises and health education
Silveria et al[75]	Quantitative research (Pre-post intervention study)	65+, M = 75.2	64%	54.% had trades or professional diploma	52.3% frequently used cellphones; 68.2% used computers; 59.1% used the Internet.	44	Switzerland	ActiveLifestyle, a tablet-based app that delivers home-based strength-balance training to independently living older adults	Strength-balance training
Tabak et al[76]	Mixed methods research	65–75, M = 71	50%	Not reported.	40% had daily technology use.	20	United States	WordFit, a game-based mobile coaching app that stimulates daily physical activities among older adults	Physical activities
Taylor et al[77]	Quantitative research (Feasibility study)	60+, M = 83	53.3%	11 years of education on average	33% owned a computer, 20% used a computer.	15	Australia	StandingTall, a tablet-based app that delivers tailored exercise programs to elderly people with dementia	Exercise programs
Van Het Reve et al[78]	Quantitative research (Pre-post intervention study)	65+, M = 75	63.6%	13.6%	Not reported.	44	Switzerland	ActiveLifestyle, a tablet-based app that delivers strength-balance training to independently living older adults	Strength-balance training
Zhong and Rau[79]	Quantitative research (Usability test, mixed design experiment)	60–90, M = 69.8	73%	18.9%	73.6% had a smartphone and 60.1% had Internet access.	148	China	Pocket Gait, a mobile app designed to provide gait assessment and fall prevention for older adults	Fall prevention
Social inclusion and well-being (N = 6)									
Chi et al[80]	Mixed methods research (Pilot study)	68–89, M = 78.3	100%	Not reported.	70% felt comfortable using technology.	10	United States	Digital Pet, a tablet-based conversational agent in the form of an avatar for older adults	Social connectedness

(continued)

Table 2.. continued

Study	Study design	Age (range, mean)	Gender (female)	Education (college degree or higher)	Computer-related experience	Sample size	Country	Application descriptions	Health domain
Goumopoulos et al[81]	Mixed methods research (Pilot study)	60+, M = 65.7	59%	Not reported.	Not reported.	22	Greece	Senior App Suite, a mobile app designed to improve the social well-being and independence of senior people	Social connectedness
Jansen-Kosterink et al[82]	Quantitative research (Usability study)	60+, M = 73.4	80%	41%	22%, 66%, and 12% of participants had positive, neutral, and negative attitudes toward technology.	91	The Netherlands	GezelschApp, a mobile app that encourages social participation in community-dwelling older adults	Social connectedness
Judges et al[83]	Mixed methods research	68–92, M = 80.6	70%	Not reported.	Most of them had no experience with computers.	10	Canada	InTouch, a tablet-based communication app that reduces loneliness and social isolation in the elderly	Social connectedness
Neves et al[84]]	Mixed methods research (Feasibility study)	74–95, M = 82.5	66.7%	Not reported.	Digital literacy: 4 (no); 3 (low); 5 (medium).	12	Canada	InTouch, a tablet-based communication app that reduces loneliness and social isolation in the elderly	Social connectedness
Similä et al[85]	Mixed methods research (Feasibility study)	66–82, M = 73	100%	Not reported.	5 participants had Internet access; 4 had used a computer in the previous year; 1 had used a smartphone or tablet.	7	Finland	Oiva, a mobile app that provides mental wellness training for older adults	Mental wellness training
Healthy dieting (N = 5)									
Aure et al[86]	Qualitative research (Interviews)	68–95, M = 81	66.7%	Not reported.	44.4% had experience with touch technology (eg, tablet, smartphone).	18	Norway	Appetitus, a mobile nutrition app that supports weight gain or weight maintenance for older adults	Self-monitoring of dieting
Aure et al[87]	Mixed methods research (Feasibility study)	68–95, M = 79.48	72%	Not reported.	40% had experience using tablet or smartphone; 48% used the Internet daily, 16% used Internet weekly, and 36% never used Internet.	25	Norway	Appetitus, a mobile nutrition app that supports weight gain or weight maintenance for older adults	Self-monitoring of dieting
Farsjø and Moen[88]	Qualitative research (Pilot study, focus group)	69–76 M: not reported.	100%	Not reported.	Not reported.	4	Norway	APPETITT, a tablet-based app designed to prevent malnutrition and weight loss in the elderly	Guidance for dieting
Franco et al[89]	Quantitative research (Usability study)	60–85 M: not reported.	79.60%	74.38%	Not reported.	50	United Kingdom	eNutri, a mobile app that provides graphical food frequency assessment for older adults	Healthy dieting
Liu et al[90]	Quantitative research (RCT)	60–90, M = 73.9	79%	58%	68% had used mobile phones or tablets; 7% had used nutrition-related apps.	57	Taiwan	Two mobile apps (ie, voice-only reporting, voice-button reporting) for food intake reporting for elderly people	Food intake reporting

(continued)

Table 2.. continued

Study	Study design	Age (range, mean)	Gender (female)	Education (college degree or higher)	Computer-related experience	Sample size	Country	Application descriptions	Health domain
Health monitoring and health concern reporting (N = 5)									
Algilani et al[91]	Mixed methods research (Feasibility study)	67–90, M = 77	62.50%	Not reported.	Not reported.	8	Sweden	A tablet-based app for early assessment and management of elderly patients' reported concerns	Health concern reporting
Göransson et al[92]	Qualitative research (Interviews)	65+, M = 86	64.7%	23.5%	Not reported.	17	Sweden	A mobile app designed to report health concerns	Health concern reporting
Göransson et al[93]	Quantitative research (Quasi-experimental study)	65+, M = 86	64.7%	23.5%	Not reported.	17	Sweden	A mobile app designed to report health concerns	Health concern reporting
Göransson et al[94]	Quantitative research (Quasi-experimental study)	65+, M = 86	64.7%	23.5%	Not reported.	17	Sweden	A mobile app designed to report health concerns	Health concern reporting
Quinn et al[95]	Quantitative research (Usability study)	65+, M = 77.8	66.7%	100%	25% are skillful with technology and electronics.	12	United States	A mobile app designed to improve engagement of the patient-informal caregiver team	Health recording and monitoring
General (provides more than 1 type of functions) (N = 3)									
Bott et al[96]	Quantitative research (Quasi-experiment)	65+, M: Not reported.	54.7%	19% had less than high school education	Not reported.	95	United States	A tablet-based conversational agent (embodied in the form of an animated avatar) designed to provide psychosocial and health care support for hospitalized patients	Social inclusion; delirium prevention; fall prevention
Stal et al[97]	Quantitative research (Within-subject experiment)	65+, M = 72.2	35%	50%	Not reported.	20	The Netherlands	A conversational agent, which is embedded in a frailty assessment app and provides training in healthy nutrition, physical health, cognitive health for older adults	Healthy dieting; physical and cognitive function improvement
Steinert et al[98]	Quantitative research (Usability study)	61–76, M = 68	Not reported.	Not reported.	None of the participants had smartphone experience.	30	Germany	MyTherapy, a mobile app that helps older adults achieve health-related goals	Diverse health-related goals

Motor coordination problems

Gestural interactions. Gestural interactions represent how elderly users interact with applications via a set of touchscreen gestures. One design guideline is to *use simple gestures* (eg, tapping) and *avoid complex ones* (eg, scrolling, zooming).[26,37,39,47,63,80,84] In one study, elderly users perceived tapping to be easier than swiping and hence preferred to use a tap-only interface than an interface that supported both tapping and swiping.[84] Another guideline is to *use large and structured buttons* to facilitate user interactions with applications.[38–40,43,61,63,67,83,86,87,90] However, no study has specified appropriate button sizes. Prior human-computer interaction (HCI) studies have suggested using rectangle buttons larger than 15.9×9.0 mm and square buttons between 16.51 mm and 19.05 mm square to facilitate user interactions.[100,101]

Minimize text input. Text input can be challenging for motor-impaired elderly users. Specific strategies to reduce text input include *supporting voice control*,[80,81,96] and *using a button-only interface*.[27,47] For example, Goumopoulos et al[81] supported voice commands to facilitate elderly users with motor skill problems to interact with the mHealth application.

Cognitive and memory deterioration

Simple and consistent layout. Layout refers to the location of data elements on the application interface. It is crucial to *provide a simple and consistent layout* so that elderly users could easily process and comprehend the application content.[36,38,52,65,81,90] Specific layout design suggestions include *ensuring adequate white space*,[26,40,81] *adapting layout based on the screen size* ,[89] *avoiding large blocks of texts*,[81] *avoiding texts over images*,[81] and *using a culturally appropriate layout*.[25]

Easy navigation. Navigation design describes how to guide users through an application via a set of predefined steps. Overall, designers suggested keeping the navigation structure simple and straightforward, such as *using a flat navigation structure*,[29,40,50,55,89] *placing main functions in the home screen*,[86] *reducing menu options*,[61] and *providing a clear return button and a static menu on every page*.[38]

Multimedia presentation. Multimedia presentation describes an application interface that presents information in the form of texts, images, and videos. This practice is strongly recommended by several studies because multiple sensory cues could effectively ease the information processing for older adults by providing sensory awareness.[35,46,50,55,58,66,70,85,87]

Easy-to-understand content. Finally, it is important to ensure that the application content is easy to understand for elderly users. For example, designers suggested *using labeled buttons* so that users could easily comprehend the functionality of each button.[25,40,63] Other suggestions include *organizing related topics into groups*,[81] and *using age-appropriate and common languages*.[25,51,70,81]

Recommendations for persuasive feature designs

We have also identified 5 categories of persuasive features that provided motivational affordance for older adults to adhere to mobile-based interventions: reminders, social features, game elements, personalized interventions, and health education (see Figure 2 and Supplementary Appendix D).

Reminders

Twenty articles included reminders as part of their mobile interventions to remind elderly users to complete important daily tasks such as appointment and event scheduling, physical activities, nutrition and water intake, and medication intake.[27,29,34–36,38,41,45,46,48,52,57,69,78,80,81,88,91,98,102] Among these studies, 2 studies found that older adults appreciated reminders and reported that reminders provided a sense of modernity, independence, and control in task completion.[29,46] Another study examining a HIV prevention and self-care application found that medication reminder was one of the most frequently used features among elderly users.[48] In contrast, Farsjø and Moen[88] found that meal notifications of a nutrition application did not work as expected, and only one user paid attention to this feature. Also, Loh et al[41] revealed that reminders of a mobile-based geriatric assessment-driven intervention were not useful for 3 elderly patients who already had an appointment and medication tracking system. On the other hand, 4 studies examined the impacts of reminders, and the results were mixed.[36,41,45,98] Specifically, Mertens et al[45] found that reminders of the Medication Plan app significantly improved medication recording adherence. Hackett et al[36] showed that a reminder application improved the the completion of the Remember to Drink tasks for older adults with dementia and mild cognitive impairment.[36] In contrast, the other 2 studies suggested that reminders alone may be inadequate to promote behavioral changes. Loh et al[41] found that reminders were effective at improving medication adherence but not physical activities. Likewise, reminders increased medication adherence and fish and water intake, but not physical activities and social communication with friends and relatives.[98]

Social features

The fulfillment of psychological and social needs is essential when designing mHealth applications. The most commonly used social feature is coaching or professional care services ($N = 16$).[34,38,41,42,54,57,58,61,62,69,72,78,81–84] Six out of the 16 studies reported positive end-user perceptions of this feature.[38,42,54,61,78,86] For example, Jongstra et al[38] found that elderly participants enjoyed discussing their lifestyle goals with coaches and appreciated their support. Moreover, Van Het Reve et al[78] examined the messages sent and received on a strength–balance training app and found that most interactions occurred between caregivers and participants rather than between participants.

Second, 8 studies incorporated peer support by enabling users to communicate, interact and network with peer users.[35,38,75,78,81–84] In particular, 1 study examining Senior App Suite showed that elderly users were satisfied with the social networking service and used it 3 times per week on average.[81] Further, 2 studies evaluated the effectiveness of InTouch, a mobile application that supports multi-modality messages (ie, audio, wave, picture, and video messages) to increase social connectedness. They found that messages brought positive communication and relationship changes among elderly users.[83,84] They further noted that audio messages were the easiest to use and were used most frequently, whereas wave messages were perceived as useless and were used the least.

Third, 6 studies introduced collaborative activities such as group-based online exercises,[54,75,78] collaborative digital games,[62,75,78] offline group discussions ,[34] and offline social activities.[82] Only 1 study examined the effect of collaborative activities, and the results were not encouraging.[34] It designed mobile-based interventions for cognitive training that involved offline group dis-

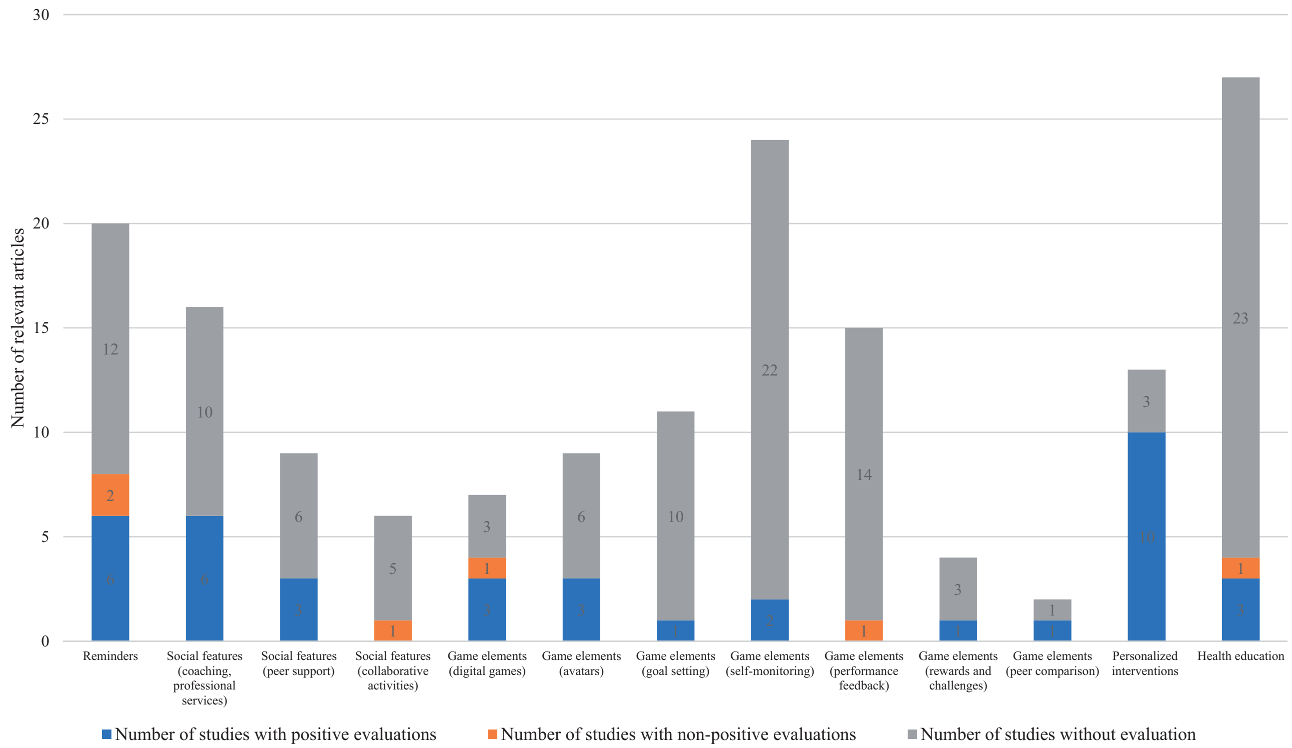

Figure 2. Summary of persuasive features.

cussions and social interactions. It showed that although elderly participants created social ties throughout the training intervention, they did not experience an improvement in cognitive and psychosocial outcomes.

Finally, 3 studies evaluated the impact of social features as a whole.[54,75,78] Specifically, Baez et al[54] examined the effects of tablet-based online group exercises and found that there were no significant differences in social well-being outcomes between the group training group and the individual training group. The other 2 studies compared two exercise training interventions delivered by ActiveLifestyle application (ie, an individual version and an social version) against a control group using training plans on paper sheets.[75,78] Van Het Reve et al[78] found that both individual and social groups had improved gait and physical performance compared with the control group. Silveira et al[75] found that social features were more effective at stimulating training compliance and healthy behavior changes. They further noted that 83% of participants felt motivated by external monitoring, followed by emotional support (75%) and collaborative games (58%).

Game elements

Seven studies employed digital games to promote healthy aging.[26,31,43,51,70,74,76] The evaluation results were mixed.[43,51,70,74] For example, Shake et al[74] evaluated Bingocize, a serious game for exercising and health education, and found that it improved quality of life in older adults by improving physical and cognitive performance. In contrast, Li et al[70] designed and assessed 5 exergames among community-dwelling older adults. They found that although the exergames brought exercise enjoyment, they failed to improve self-efficacy, reduce loneliness, and improve life satisfaction.

We also analyzed specific game elements from the included articles, such as avatars ($N=9$),[28,38,44,51,54,74,80,96,97] goal-setting ($N=11$),[38,59,64,69,72,75–78,86,97] self-monitoring and tracking ($N=25$),[27,30,32,38,40,41,46,48–50,52,54,56,57,69,70,75,76,79,86–88,91,95,97] performance feedback ($N=16$),[40,43,53,54,61,62,65,66,69–71,86,87,92–94] reward and challenges ($N=6$),[27,36,65,66,74,75] and peer competition ($N=2$).[69,75] Regarding avatars, Chi et al[80] examined a human-operated conversational agent embodied in a dog or cat avatar. Overall, elderly participants felt comfortable with the agent, even though they felt worried that their social interactions might be adversely affected if their emotional attachment to the avatar became too strong. Bott et al[96] investigated the impact of a relational conversational agent in the form of an animated avatar and found that hospitalized patients who received the avatar had lower incidences of delirium, loneliness, depression, and falls than control patients. Finally, Stal et al[97] compared user preferences of two embodied conversational agent appearances for health assessments (ie, an older male agent and a young female agent) and found that elderly users did not perceive an added value of the agent. Regarding other game elements, Aure et al[86] found that the most regularly used feature of the Appetitus application was the self-monitoring dietary function. Silveira et al[75] reported that 67% of elderly participants of ActiveLifestyle application felt motivated by the goal-setting and self-monitoring features, followed by positive and negative reinforcement via rewards and praises (50%), and the peer performance comparison feature (42%). Two studies examining an attention training application revealed that elderly users appreciated working through challenges and perceived negative feedback as distracting and frustrating.[65,66]

Personalized interventions

Thirteen studies provided personalized interventions to motivate elderly users to participate in health-promoting programs, such as physical and cognitive training, nutrition advice, therapy, and rehabilitation.[34,35,41,54,57–59,64,68,71,73,77,89] Of these, 10 studies investigated the effectiveness of the personalized interventions as a whole with promising results.[34,35,41,54,57–59,68,71,77] For example, Loh et al[41] provided a tailored mobile intervention to support elderly cancer patients and found that the intervention was effective at decreasing symptom severity and health care utilization. The remaining 3 studies did not examine the intervention's effectiveness.[64,73,89]

Health education

27 studies provided education on various health topics to older adults.[25–27,32,35,37,38,41,42,48,52,59,67–69,72–75,82,87,91–94,96,97] Shake et al[74] examined the efficacy of a health education program that covered fall risks and osteoarthritis and found that elderly users' health knowledge of the two topics increased over time. Hsieh et al[67] reported that elderly participants perceived a fall risk mHealth application to be useful in learning their risk of falling. Sun et al[52] assessed a diabetes self-management app and found that elderly users had improved self-management skills and knowledge of diabetes. In contrast, Algilani et al[91] investigated the feasibility of a mHealth application for early assessment and management of patient-reported concerns. The results revealed that some users provided positive opinions regarding the self-care advice, whereas others failed to appreciate its usefulness and availability. The remaining studies did not report the benefits of their education feature.

DISCUSSION

Our review provided specific and actionable mHealth application design recommendations to develop elderly-oriented interface and persuasive features. We classified the included studies into 3 categories based on the design aspects. Category I includes 43 studies that proposed interface design recommendations to cater to the perceptual, motor, and cognitive deterioration of older adults. Category II contains 66 studies that incorporated persuasive features to provide motivational affordance toward healthy behavior changes. In contrast, Category III includes 37 studies that discussed both elderly-friendly interface and persuasive feature designs. Category III studies are particularly important because appropriate interface designs could reduce users' confusion and frustration and thus improve application acceptability and usability, while persuasive features could motivate elderly users to adherence to mobile interventions and improve health outcomes. Future work in this field should consider both application design aspects based on our derived recommendations to assist older adults in achieving healthy aging.

We found that 6 studies focused on psychosocial well-being,[80–85] and 10 studies focused on mental disease prevention and self-prevention.[26,29,31,33–36,43,44,51] However, it is important to note that older adults are vulnerable to social isolation and psychological distress. They may suffer from declined functional abilities, age-related diseases, and decreased socioeconomic status after retirement.[103–106] Worse still, a recent WHO report indicates that approximately 15% of older adults were suffering from mental health problems,[107] and most of them were reluctant to seek professional healthcare services.[108] Considering the potential of mobile-based interventions to improve the accessibility and efficacy of mental healthcare services,[109] we suggest future studies should devote more effort to the design and evaluation of mHealth applications for the mental well-being of the elderly.

Our analysis also revealed that only 5 studies (6.8%) based their design elements on theories, which included social cognitive theory,[38] behavior change wheel,[28] technology acceptance model,[25] theory of planned behavior,[64] and unified theory of acceptance and use of technology.[60] We recommend future research to propose theory-based application designs to provide a clearer understanding of the mechanism underlying each single design feature and, consequently, inform the theories of aging.[13] For example, using the complexity literature as a theoretical basis, researchers have found that although older adults perceived a *high comprehensiveness recommendation agent* (that elicited detailed product attribute preferences and provided more product recommendations) to be more complex, they also perceived it as more beneficial than its counterpart.[110] This contradicts the prevalent view that older adults should use simpler digital technologies.

Another important observation is that many studies proposed more than one design element and assessed the application as a whole. Consequently, our knowledge of end-user perceptions and the effectiveness of each single persuasive feature is relatively limited, particularly for peer support, collaborative activities, digital games, goal-setting, self-monitoring, performance feedback, rewards and challenges, peer comparison, and health education features (Figure 2). Moreover, elderly users who provided positive ratings on application usability may perceive specific features as difficult to use or useless.[28,30,39,41,47,55,64,65,79,80,85,87,89,91,92] We thus recommend future research to investigate each design element in detail.

Finally, although 41 studies assessed the effects of mHealth applications on health-related outcomes, the strength of the evidence was limited due to poor research design. Specifically, approximately half of these studies ($N = 22$, 53.7%) did not have a comparison or control group. Moreover, 9 out of the 12 RCTs suffered from significant biases in study design.[34,38,46,48,52,58,59,71,90] Therefore, stronger research designs are needed to rigorously quantify the effectiveness of application designs.

Limitations

We acknowledge that this review has several limitations. First, we restricted our scope to English-written, peer-reviewed journal articles. Our review could benefit from the inclusion of relevant conference publications and articles published in other languages. Second, we only included mHealth applications from the existing literature. Future research may consider conducting a more comprehensive evaluation of mHealth applications available for elderly users in the market.

CONCLUSION

This review identifies, synthesizes, and reports elderly-friendly interface and persuasive feature designs for mHealth applications from the existing literature. We derived 9 interface design recommendations that addresses the perceptual, motor, and cognitive deterioration of older adults. We also compiled 5 categories of persuasive features that may motivate older adults to achieve healthy aging. Overall, we provide specific and actionable suggestions for elderly-friendly mHealth application design and provide directions for future research in this field.

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AUTHOR CONTRIBUTIONS

NL and HHT designed the systematic review. JY, NL, and SST screened the title and abstracts of the included articles. JY, NL, NKY, and HHT extracted and synthesized the article information. All authors were involved in the data analysis, drafting, editing, and proofreading of the manuscript.

SUPPLEMENTARY MATERIAL

Supplementary material is available at *Journal of the American Medical Informatics Association* online.

DATA AVAILABILITY STATEMENT

The data underlying this article are available in the article and in its online supplementary material.

CONFLICT OF INTEREST STATEMENT

None declared.

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