

A Comparison of Current Elder Fitness Technologies to the Known Needs and Preferences of Elders: Scoping Review

Christopher Tacca, Arturo Vazquez Galvez, Izzy Thompson, Alex Bincalar, Christoph Tremmel, Richard Gomer, Martin Warner, Chris Freeman, mc schaefel

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Christopher Tacca¹; Arturo Vazquez Galvez²; Izzy Thompson³; Alex Bincalar¹; Christoph Tremmel¹; Richard Gomer¹; Martin Warner³; Chris Freeman¹; mc schaefer¹

¹School of Electronics and Computer Science Faculty of Engineering and Physical Science University of Southampton Southampton GB

²School of Electronics and Computer Science Faculty of Engineering and Physical Sciences University of Southampton Southampton GB

³School of Health Sciences University of Southampton Southampton GB

Corresponding Author:

Christopher Tacca
School of Electronics and Computer Science
Faculty of Engineering and Physical Science
University of Southampton
Building 32
University Rd
Southampton
GB

Abstract

Background: The population is ageing and research on maintaining and extending older adult independent living is growing in interest. An approach towards building and sustaining quality of life is to develop interactive technologies to support elder independent living through fitness. However, reviews of current fitness technologies for elders indicate that the success of these technologies is considerably limited.

Objective: This scoping review aims to investigate the reason for the limited outcomes from these technologies by comparing current fitness technology interventions to known needs and preferences of elders from elder specific technology acceptance research, barriers and enablers to elder physical activity, and qualitative research on elder fitness technologies. The scoping review questions investigated are: 1. How well do current elder fitness technologies align with known elder preferences? 2. How well do current research methodologies evaluate the known needs and preferences of elder adults?

Methods: Our review was conducted in compliance with the PRISMA guidelines for scoping reviews (PRISMA-ScR). Research articles from the last ten years were searched in the ACM Digital Library, IEEE Xplore, Medline, and PsycINFO databases using the key words related to older adults, technology, and exercise. Research articles were filtered only include articles that specifically evaluated technologies for fitness, focused specifically on elders, and mentioned a specific technology used in the intervention. Reviewed research articles were evaluated versus known needs and preferences of elders related to fitness technology. The assessment criteria was synthesis through literature on elder technology acceptance, barriers and enablers to elder physical activity, and qualitative research on elder fitness technologies. Interventions were scored by five reviewers using a dual-review approach.

Results: 43 research articles were selected in the scoping review. 16 of the reviewed articles were from medical journals, 15 from engineering journals, seven from HCI or computing journals, three from public health, and two from a combined computing and engineering journal. Only 16 of the 43 research articles cited elder specific design works. The Elder Fitness Technology Translation Assessment tool was synthesis from known preferences of elders with the following six factors: 1. Compatibility with Lifestyle, 2. Similarity with Past Experience, 3. Dignity and Independence, 4. Privacy Concerns, 5. Social Support, and 6. Emotion. The average scores for the 43 research articles across the six factors were 2 ± 0.85 on Compatibility with Lifestyle, 3.11 ± 0.80 on Similarity to Past Experience, 3.44 ± 0.76 on Dignity and Independence, 3.15 ± 0.92 on Privacy Concerns, 3.68 ± 0.91 on Short-Term Outcomes, 2.72 ± 1.15 on Long-Term Outcomes, 2.78 ± 0.88 on Social Support, and 3.13 ± 1.15 on Emotion. No research article scored a three or above on all of the six elder specific factors.

Conclusions: Overall, the results show a lack of consideration for the known preferences of elders related to technology and physical activity in the field. Three main opportunities for growth are identified: 1. Better alignment between the studied needs of

elders and current fitness technology interventions, 2. Better translation of findings from elder design work to designs in practice, and 3. More explicit usage of elder specific considerations in research methodologies. More explicit inclusion of elder specific factors in the design and assessment of elder fitness technologies is worth testing to evaluate how these established factors can support the development of more impactful interventions. We hypothesize that the proposed Elder Fitness Technology Translation Assessment tool can help bridge the gap between technological capability and real-world applicability, ultimately fostering greater adoption, respect for elders, and long term success.

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Review

A Comparison of Current Elder Fitness Technologies to the Known Needs and Preferences of Elders: Scoping Review

Abstract

Background: The population is ageing and research on maintaining and extending older adult independent living is growing in interest. An approach towards building and sustaining quality of life is to develop interactive technologies to support elder independent living through fitness. However, reviews of current fitness technologies for elders indicate that the success of these technologies is considerably limited.

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Social Support, and 3.13 ± 1.15 on Emotion. No research article scored a three or above on all of the six elder specific factors.

Conclusions: Overall, the results show a lack of consideration for the known preferences of elders related to technology and physical activity in the field. Three main opportunities for growth are identified: 1. Better alignment between the studied needs of elders and current fitness technology interventions, 2. Better translation of findings from elder design work to designs in practice, and 3. More explicit usage of elder specific considerations in research methodologies. More explicit inclusion of elder specific factors in the design and assessment of elder fitness technologies is worth testing to evaluate how these established factors can support the development of more impactful interventions. We hypothesize that the proposed Elder Fitness Technology Translation Assessment tool can help bridge the gap between technological capability and real-world applicability, ultimately fostering greater adoption, respect for elders, and long term success.

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Keywords: elder physical fitness; fitness technologies; digital health; physical activity promotion

Introduction

The global population is ageing. ^{1 2} Care needs for older adults, including maintaining and extending older adult independent living, has likewise grown as an area of research focus ^{1,2}. An approach towards building and sustaining quality of life is to develop interactive technologies to support such practices. The rationale for this technology-supporting-fitness approach notes that the benefit for elder independence in improving overall fitness in general ^{3,4} and strength building in particular ⁵ is well-established; and that, likewise, the scalability and affordability of interactive technologies relative to in-person specialist care ⁶ would enable such fitness support to be more accessible to more older adults.

Research adopting this rationale for the development and evaluation of innovative fitness tech for older adults has grown significantly over the past ten years. A search of journal articles including keywords related both to older adults, technological systems, and physical fitness returned 865 journal articles for 2024 alone, a 300% increase compared to the same search for 2014¹. Results also cross multiple fields, such as gerontology, medicine, public health, engineering, computing, and psychology. In the last seven years, there have been no less than eight related review articles around computational health interventions for older adults including: wearable devices for increasing physical activity ⁷, mHealth and eHealth solutions for increasing physical activity ⁸, smart technology interventions for increasing physical activity in comparison to face-to-face interventions ⁹, eHealth interventions for increasing balance and preventing falls ¹⁰, virtual reality (VR) based interventions for improving functional mobility in older adults ¹¹, adherence of technology based exercise interventions ¹², and elder experiences using wearable based interventions ^{13,14}. Crucially, the conclusions of these reviews, summarised in **Table 1** and discussed in the Related Work, indicate that successes in this area seem to be considerably limited. Findings from the review are characterised as very low to

moderate evidence of effectiveness^{8,9}, high risk of bias⁷, and low methodological quality¹⁰⁻¹².

Given both the increasing need for such work, and the growing interest across disciplines, it is concerning that these reviews, summarising work across a range of technologies from accelerometers to VR, do not evidence stronger successes and impact. The focus of this scoping review, therefore, has been to determine what the factors may be in common, across this research, that may be hindering better outcomes. To interrogate this problem, we took a dual approach to our review and its analysis:

1. First, rather than focus on a single technology or methodology as per current reviews, we brought together a broader range of work across disciplines. Our rationale has been to test that the existing reviews may have been too exclusive in their focus and may have missed capturing greater success or impact. The main criteria for inclusion have been that novel, digitally mediated or supported interventions are used to support or improve fitness for older adults. From this collection we then considered a range of shared quantitative features such as: technologies used, types of evaluations, whether co-design is part of the process, duration of evaluations. Each of the metrics is described in the **Methods** section below.
2. Second, of particular concern has been how to assess how well these technologies evidence their consideration of their participants - elders/older adults - in terms of both the technologies proposed and the associated physical practices. To this end we developed a novel assessment criteria based on an analysis and synthesis of extant research addressing three issues: needs and preferences for older adult technology use for strength building and other exercise¹⁵⁻¹⁸, elder specific factors that influence technology acceptance in general^{19,20}, and barriers and enablers for elders' physical activity^{16,21,22}. This lens, which we've called the Elder Fitness Technology Translation Assessment, (discussed in **Methods** Section) gives us a way to compare our heterogeneous collection of papers against a shared set of elder adoption criteria.

To our knowledge no review has compared the design and assessment of existing research on elder-oriented fitness technology interventions with the known needs and preferences of older adults in terms of technology acceptance and barriers and enablers to physical activity. In undertaking this scoping review, we hypothesised that reviewing these papers against both their mechanisms of study and these factors for elder engagement, we would get a clearer picture of the factors that may be leading to the kinds of results the reviews capture.

In the following sections, we first present Related Work to situate our work, and our main research questions motivating this study. We then present our methodology including process of paper selection and assessment criteria. Results, their analysis and discussion follow.

Related Work

In this section, we cover the related work that informs the survey methodology and approach. Overall topics discussed are as follows: current reviews in the field, the role of fitness, exercise, and health technology interventions in helping

older adults maintain their independence, and a background of older adult specific technology adoption factors, barriers and enablers towards physical activity and exercise, and qualitative research on elder technology preferences.

Current Reviews in the Field

As previously introduced, there are as many as eight reviews in the last seven years covering elder fitness and consumer health technologies. Cooper et al. examined the effectiveness of various health technology interventions including wearable devices for increasing physical activity and found a statistical significance of using accelerometers but not pedometers on physical activity levels. However, a high risk of bias was reported in most studies included in the review ⁷. McGarrigle and Todd, a review of reviews, found mixed evidence of effectiveness for mHealth and eHealth interventions for physical activity promotion, with three reviews citing low to moderate evidence and one review remaining inconclusive. Issues of bias were also reported ⁸. D'Amore et al. found no difference between smart technology based versus face-to-face physical activity interventions in community-dwelling older adults. The quality of evidence was also graded as very low based on the Grading of Recommendations Assessment, Development, and Evaluation criteria ⁹. Gaspar and Lapão found potential for eHealth to evaluate balance assessment and promote balance training for elders. However, differences in methodologies and variables included in the studies did not allow for proper comparison ¹⁰. Corregidor-Sánchez et al. found that VR was effective in improving functional mobility over no intervention and over conventional treatments. The quality of evidence was reported as moderate, and methodological quality of the studies was cited as low ¹¹. Valenzuela et al. found high adherence up to twelve weeks in technology-based exercise interventions. However, issues with study methodologies including small sample sizes, short follow-up, and the inclusion of healthy older people limit quality of evidence ¹². Moore et al. summarized qualitative studies on the user experience of wearable based health technology interventions. Major themes from this review include the importance of intrinsic and extrinsic motivation and ease of use of the technology ¹³. Vargemidis et al. focused on the interaction type and design processes of wearable physical activity technologies and found that most systems focus on supervising older adults, a top-down approach in a fairly rigid and restricted manner with predefined goals, versus supporting older adults, a more flexible interaction with opportunities for elders to engage with the technologies on their own volition. The types of activities tracked in the study were relatively limited, with a high focus on walking. In addition, the existence of co-design with elders was scarce ¹⁴. A summary of the reviews and their major findings is included in **Table 1**.

Table 1. Summary of the outcomes of relevant reviews in the field.

Review Authors	Subject	Outcomes
Cooper et al.	Effectiveness of Wearable based interventions for physical activity promotion	Accelerometers increased physical activity, pedometers did not. High risk of bias.
McGarrigle and Todd	Effectiveness of eHealth and mHealth for physical activity promotion	Low to moderate evidence to increase physical activity
D'Amore et al.	Comparison of smart technology versus face-to-	May improve daily step counts but very low evidence

	face interventions for physical activity promotion	
Gaspar and Lapão	Effectiveness of eHealth for increasing balance	Potential for balance improvements and fall risk reduction but with no clear comparison
Corregidor-Sánchez et al.	Effectiveness of virtual reality for functional mobility	VR effective compared to conventional treatment but with low methodological quality
Valenzuela et al.	Adherence to technology based exercise programs	High adherence through first 12 weeks of intervention, but with methodological problems including sample size, inclusion criteria, and follow-up times
Moore et al.	Elder experiences with wearable based interventions related to physical activity and fall prevention	Emergent themes of older adults' use of wearables include motivation, user characteristics, integration into daily life, and device features
Vargemidis et al.	Elder experiences with wearable physical activity interventions with a focus on the design and evaluation processes	Most interventions focus on supervising older adults versus supporting, older adults' involvement in design process is scarce

Importance of Fitness and the Role of Technology

Moderate and regular exercise is associated with decreased mortality and the prevention of health conditions such as coronary heart disease, stroke, and type 2 diabetes^{3,4,23-26}. In addition, exercise has been linked to reduced risk of developing dementia and Alzheimer's disease^{23,27} and linked to increased mental health and wellbeing^{26,28-30}. Strength building in particular has been shown to support healthy aging^{5,31} and decrease the likelihood of developing chronic diseases or disabilities later in life^{31,32}. As adults age, sarcopenia or the decrease of muscle mass can occur increasing the likelihood of bone loss (osteoporosis), fall and fractures, and difficulty performing regular daily functions such as walking upstairs or carrying groceries³³⁻³⁵. Lower muscle mass is also a risk factor for losing independence in older adults^{33,35}. As highlighted in the introduction, the use of technology to address these concerns is a rapidly growing area of research. Some of the most researched technologies over the past ten years include smartphones apps, smartwatches, computer-based interventions, and Microsoft Kinect (Microsoft Kinect Sensor, 2010), see **Table 3**.

Technology Adoption Research

Technology adoption research aims to better understand what motivates people to adopt certain technologies into their daily lives and predict which technologies will garner widespread use. Several models have been proposed in the field that outline the factors influencing the public's willingness to adopt a certain technology. One of the first widely used models for technology adoption, the technology acceptance model (TAM), proposes that adoption is influenced by the potential user's perceived usefulness and perceived ease of use of the technology³⁶. This model has been updated several times with frameworks including TAM 2, Unified Theory of Acceptance and Use of Technology (UTAUT), TAM 3, and UTAUT 2. Newer models such as the UTAUT 2 consider factors beyond perceived value and ease of use including social influence, habit, and price value and have a higher predictive power than previous models³⁷. Despite the existence of updated technology adoption frameworks, most proof of

concept and usability studies follow the TAM model by focusing solely on the ease of use (or usability) of a technology and the user's enjoyment or perceived value of the product. Examples of the following are commonly used digital usability questionnaires such as the Telehealth Usability Questionnaire (TUQ) ³⁸ and the Health Information Technology Usability Evaluation Scale (Health-ITUES) ³⁹. Furthermore, for studies on consumer technologies aimed at older adults, the specific needs of older adults and their technology acceptance preferences have been largely overlooked.

Elder Adult Technology Preferences and Elder Specific Technology Adoption Factors

Research aimed at adapting technology acceptance models specifically for older adults has shown different factors that influence whether an older adult will adopt a new technology. For example, in Lee et al. ¹⁹ and Lee and Coughlin ²⁰, ten factors are proposed for older adult technology adoption: value, usability, affordability, accessibility, technical support, social support, emotion, independence, experience, and confidence. An explanation of the ten factors included in Lee's model for older adult technology adoption can be found in **Table 2**. Further research by Lindberg and de Troyer has used Lee's model to outline guidelines for ICT design for older adults ⁴⁰. In addition to Lee's factors, older adults have been found to have different adoption preferences and concerns. Another elder specific technology adoption reference model by Lindberg and de Troyer identified value, technical support, social support, experience, confidence, usability, emotion, and independence as important UI design factors for technology acceptance ⁴⁰. From qualitative research on elder preferences related to technology, older adults tended to use traditional tools for personal health management, and had mixed reactions to wearables, tracking devices, and smartwatches ^{41,42}. Major concerns consistent across several studies include privacy concerns, difficulty with onboarding or setup, and cost concerns ^{40,41}. Privacy concerns were particularly present when discussing health related wearable devices with older adults unsure on ownership of their data, resistant to the constant monitoring and collection of health data, and with a preference for only collecting data necessary for their specific health concerns ⁴². Lastly, identity plays a role in older adults' willingness to adopt a new health related technology. For example, many older adults resist adopting assistive technologies, if they perceive the device as running contrary to their feeling of independence, self-reliance, and competence ^{40,41,43}. Thus, it is critical to both the design of the technologies themselves, and the verbiage used in the interactions with the user that older adults are met with dignity and not treated as weak or dependent.

Table 2. Lee's factors for elder specific technology adoption.

Factor	Description
Value	Perception of the usefulness and potential benefit
Usability	Perception of the user friendliness and ease of learning
Affordability	Perception of the potential cost savings
Accessibility	Knowledge of the existence and availability in the market
Technical Support	Availability and quality of assistance throughout use
Social Support	Support from family, peers, and community
Emotion	Perception of the emotional and psychological benefits

Independence	Social visibility, how it makes them look to others
Experience	Relevance with their prior experiences and interactions
Confidence	Empowerment without anxiety or intimidation

Barriers and Enablers to Physical Activity for Elders

Beyond research into elders' relationship with technology, elder fitness technology researchers and designers can look to qualitative research on elder needs and preferences as it relates to physical activity and exercise. These kinds of insights have been synthesized into several key barriers and enablers to elders' physical activity, factors limiting physical activity and factors encouraging physical activity, respectively. Some common barriers to physical activity for elders include health conditions^{16,21,22}, lack of social support²¹, inaccessibility^{16,21}, perceived level of difficulty²², and fear^{16,21,22}. Some common enablers to physical activity include motivation^{16,22}, enjoyment^{22,44}, accessibility^{16,22}, affordability¹⁶, social support^{16,21,44}, intentionality^{16,21,22}, and previous or short-term improved health^{16,22,44}.

Lens to View Elder Design

As elder fitness technology research has grown, researchers have begun to reflect on how elders have been framed with respect to technology, arguing against viewing elders as homogeneous and in terms of loss of ability or decline in faculty^{45,46}. Soro et al. noted the prevalence of research aimed to "assist" elders managing their independence built on negative assumptions and stereotypes of older adults' capability⁴⁶. Technologies with this approach are criticized for providing care without a human touch, and can result in disrupted routines, dependency, and isolation⁴⁶. From this work, Soro et al. identified two distinct perspectives in the literature: 1. A focus on the technical aspects and 2. A focus on the human perspective, noting very few works attempting to bridge that gap⁴⁶. Building on that work, Lazar et al. proposed the use of diffractive analysis to encourage researchers to include differing perspectives in designing for elders⁴⁵. Diffractive analysis can help illuminate incorrect assumptions made by researchers and the value from different methodological approaches and perspectives⁴⁵. Co-design or participatory design has also been found to help younger designers fill the knowledge gap and combat assumptions when designing for elders⁴⁷. Co-design works by establishing an equal relationship between users and designers, and encourages the active participation of users early and often in the design process⁴⁷.

Building on these papers, we review the literature by assessing health interventions across what is already known about older adult needs and concerns about health technologies and physical activity interventions.

Scoping Review Questions

In this scoping review, we specifically examine health technology interventions intended to help older adults build strength, improve physical fitness, and maintain independence. To assess how well these interventions align with the needs and preferences identified in elder-specific technology acceptance studies, we have structured a review to answer the following questions:

1. How well do current fitness related technology systems aimed to support elders align with known elder specific technology adoption factors, elder technology preferences, and barriers and enablers to physical activity?
2. How well do current research methodologies evaluate their interventions

across known needs and preferences of elder adults? And are the current research methodologies sufficient for understanding whether the technologies will have an impact beyond a research setting?

Methods

Our review was conducted in compliance with the PRISMA guidelines for scoping reviews (PRISMA-ScR), see **Appendix** for PRISMA-ScR checklist. The search methodology and selection process, synthesis of the Elder Fitness Technology Translation Assessment tool, and evaluation process are described in this section.

Research Article Selection Process

Work related to health technologies for elder adults is present in a variety of different fields including medicine, engineering, human-computer interaction (HCI), and psychology. Thus, the search strategy targeted the following databases to get a full interdisciplinary establishment of the evidence in this research topic: 1. ACM Digital Library, for health technology intervention in the field of HCI; IEEE Xplore, for interventions in the field of engineering and computer science; Medline, for interventions in the medical field, and PsycINFO, for interventions in the field of psychology and public health.

The specific search terms in the review were chosen to collect research that related to older adults, used any form of digital health related technologies, and aimed at building physical fitness or maintaining independence. The following terms were used to account for the different vocabulary used across fields in this type of work: 1. "Older Adults", "Elderly", or "Elder Adults", and 2. "Digital Health", "Technology", and "Interactive Systems" and 3. "Strength Building", "Balance Training", "Physical Activity", "Exercise", and "Exercise Programs". Searches were also filtered to only include results from the last ten years and research articles published in journals.

From the initial searches, an evaluation on the applicability of the articles was conducted by the research team against the following inclusion criteria:

Studies were included if they

- Specifically evaluated the impact of technology on physical activity, health, or independence among adults aged 60 and above, using either quantitative or qualitative methods (e.g., interviews or focus groups assessing user experiences).
- Focused specifically on older adults, defined as individuals aged 60 and above, and directly relate to promoting physical activity, building strength, or maintaining independence.
- Mentioned a specific computational technology used in the intervention, such as fitness trackers, mobile health applications, or assistive devices, with the technology being integral to the health intervention.

A detailed review of the full text of each article meeting the initial inclusion criteria was conducted, aspects such as study design, sample size, intervention methods, and outcomes were evaluated. Studies were excluded if they lacked a clear connection between the technology used and the health intervention outcomes, or if the sample did not include older adults as defined by our criteria. Following this detailed review, a final list of studies meeting all criteria was compiled. A flowchart of the full selection process is shown in **Figure 1**.

Figure 1

Synthesis of the Elder Fitness Technology Translation Assessment

Using existing research from different associated areas within the field, we synthesized six criteria to evaluate the current elder fitness technology interventions. As explored in the related works sections, an abundance of research has been conducted to better understand elders' needs and preferences when it comes to both technology and physical activity. Examples of these spaces that were used in the synthesis of the evaluation criteria include elder specific technology adoption factors, qualitative research of elders' health/technology preferences, and barriers and enablers to physical activity for elders. As elder fitness technology interventions require elders to both interact with technology and participate in some form of physical activity interventions, it is critical to consider elder preferences related to both of these areas, though as will be evidenced many of the important factors emerge across fields.

The six criteria are as follows:

Compatibility with Lifestyle. Lee et al.'s ¹⁹ work on elder specific technology acceptance coined the term "compatibility" to refer to the concept that "if a technology does not seamlessly fit into older adults' life patterns or mental models, they are less likely to adopt it." From this work, elders identified the need for technologies to fit into daily schedules and physical spaces as well as have conceptual compatibility with their culture and values. Similarly, from Naseri et al.'s ²¹ work on barriers and enablers for elder engagement in fall prevention activities, physical opportunity and environmental context was identified as a barrier for participation. Emergent themes from this barrier included lack of access to supervision support, suitable environments, and proper equipment. Naseri et al. include a specific example showing how lack of compatibility can act as a barrier from a participant's response referencing needing to go to the gym for exercise, "when I'm cold I just stay in bed and don't exercise". In Thøgersen-Ntoumani et al.'s ²² work on barriers and enablers to intermittent lifestyle physical activity, both "convenience" and "reframing physical activity" were identified as enablers. Elders were more likely to do physical activity if it could be incorporated into their daily lives or they could do it while doing other meaningful activities such as playing with children and cleaning the house. Elders identified that they disliked going to the gym and doing structure exercise which require planning, thus reframing everyday activities as exercise was an important enabler.

With this context, we chose the term "Compatibility with Lifestyle" to refer to how well a fitness technology intervention fits into the potential user's overall lifestyle including daily routines, habits, preferences, and values.

Similarity to Past Experience. Venkatesh et al.'s ⁴⁸ Unified Theory of Acceptance and Use of Technology extension (UTAUT2) identifies user's previous "experiences" as an important factor for influencing technology acceptance. For elder specific technology acceptance, Lee and Coughlin ²⁰ identified "experience" as an important technology acceptance for elders specifically, referring to how relevant the technology is with their prior experiences and interactions. Technologies that are perceived to be more familiar to elders or that build on prior knowledge are more easily

adopted. In addition to the technology design itself, the training methods and education are influenced by this factor as well. Building off Lee's elder specific technology acceptance work, in Lindberg and De Troyer's ⁴⁰ reference model for elder specific technology acceptance, identifies that technologies should ideally resemble the user's prior experience with other systems. While this is challenging in practice due to the diverse experiences of users, similarity with past experiences can be addressed through allowing users to personalize their interactions. In Pang et al.'s ⁴¹ work on elder specific technology acceptance and learning preferences, the importance of including flexible learning materials and instruction manuals was explored and noted a preference by elders for "augmenting current technologies" rather than general-purpose wearables.

With this context, we chose the term "Similarity with Past Experience" to refer to how similar the technologies elders interact with are to their previous experiences and how well training, education, and personalisation are incorporated into the intervention to prevent difficulties in uptake.

Dignity and Independence. In Lindberg and De Troyer's ⁴⁰ elder specific technology acceptance reference model, "independence" is identified as a key factor for technology acceptance. In their work, Lindberg and De Troyer warn that, "the language used in an application should avoid stigmatizing the user" and "older people who feel vulnerable or dependent on others may easily perceive an application as a threat to their independence or [feeling] patronized by the application". Astell et al.'s ⁴⁹ work on older adults' assistive technology preferences found that identity is a major factor for acceptance. Elders tend to resist the use of assistive technologies that constantly remind them of their old age and the negative connotations associated with that such as conflation of 'oldness' and 'disability' with 'helplessness', 'dependence', and 'incompetence'. For example, one participant in this work stated when referencing an assistive robot, "It must be for people who are very handicapped. It's not for me... It makes me think my life is terminated. I'd rather die than live with a robot." Furthermore, being stigmatised or discriminated against was a common fear for many participants and strongly impacted older adults' willingness to adopt assistive technologies. Devices that could stigmatise older adults as 'different', 'lonely', 'frail', 'dependent', or 'old' were not popular. Astell et al.'s also found that independence and control were key contributors towards acceptance.

With that context, we chose the term "Dignity and Independence" to refer to whether the health intervention, user interface and verbiage, and technology itself promotes a feeling of self-sufficiency and independence in its users, or does it promote stigmatization and a feeling of dependency on technology.

Privacy Concerns. Pang et al. ⁴¹ identify privacy as a major concern for accepting health technologies, finding that elders were reluctant to compromise privacy for general wellness tracking. Some elders expressed a preference for only tracking data directly relevant to their health condition, i.e., blood pressure measurements, over perceived frivolous

extras such as tracking distances and routes. In Zhang and Shahriar's ⁴² work on issues related to elder wearable healthcare technologies, data privacy was identified as a widespread concern. Many elders were unsure of the data storage and privacy policies of the wearables. Furthermore, Zhang and Shahriar urged for more data privacy education and prompt manufacturers to clearly state how data is used and allow users the ability to opt-out of providing it. Elders were also found to be resistant to the over collection and misuse of data, particularly related to wearables that require continuous use. Astell et al. ⁴⁹ raised the concern of privacy versus pragmatics with assistive technologies aimed at elders i.e. the perceived 'trade off' between personal privacy and the potential benefits of technologies. Technologies such as wireless sensor networks, bed occupancy sensors, and fall detection monitors were all met with privacy concerns. Elders were also reluctant to adopt monitoring or surveillance technologies fearing someone 'always watching' or 'spying' on them.

With this context, we chose the term "Privacy Concerns" to refer to how well the user's privacy concerns related to personal information and data is respected with a preference for technology systems that include clear data storage protocols and privacy policies, the ability to opt-out of certain data collection, and limit the amount of data collected to only directly relevant data necessary.

Social Support. Lee and Coughlin ²⁰, and Lee et al. ¹⁹ identify social connection and support as a key factor for elder specific technology adoption. Older adults were more willing to adopt a technology if peers in their social circle (family, friends, community members) also used the technology. The use of peer leaders, well-connected early adopters, and technology champions were critical. Furthermore, elders may view technology as a potential threat to decreased social connectivity and emotional contact, hindering adoption. Technologies that incorporate a way to easily connect with friends and family can become more attractive to elders. In Naseri et al.'s ²¹ work on barriers and enablers to elder physical activity, social support also played a key role. Access to social support, family assistance, partner participation, family, and trusted advisors were all identified as enablers. Furthermore, positive models of behaviour from peers can act as an enabler, i.e. if their friends, family, and neighbours are all exercising and having positive experiences doing it, elders are more likely to join. Thøgersen-Ntoumani et al. ²² found social engagement to be an important enabler towards elder physical activity through the normalisation of taking the active option. An example of this is if one participant took the stairs instead of the lift, it encouraged other people to take the stairs as well. In Pang's ⁴¹ work on learning preferences, after initial independent problem solving, elders tended to prefer to turn to family or peers for help with technologies. Incorporating a social network between could help elders learn from each other and foster independence.

With this context, we chose the term "Social Support" to refer to the ability for the health intervention/technology to encourage or support social connection.

Emotion. In Venkatesh et al.'s ⁴⁸ UTAUT2, "hedonic motivation" was

identified as an important factor towards technology acceptance, referring to the fun and pleasure derived from using a technology. Lee and Coughlin²⁰ identified “emotion” as a key factor to elder specific technology acceptance, referring to the perceived emotional and affective benefits. Naseri et al.²¹ identified several emotional aspects as key enablers to elder physical activity including motivation, confidence, and novelty. Additionally, Thøgersen-Ntoumani et al.²² found several emotional aspects to be enablers such as gamification, sense of achievement, and personally salient rewards.

With this context, we chose the term “Emotion” to refer to the ability for the intervention/technology to be motivating, fun, or emotionally stimulating.

In our evaluation, we also considered the short- and long-term outcomes from the research studies to examine both how well the health technology affected positive change for the participant and how well the outcome metrics in the research study aligned with the stated objectives. Outcomes were evaluated based on the results in the study and the stated use case of the intervention found in the respective research articles.

Short-Term Outcomes refers to the specific outcomes related to the main objective of the study immediately following the health intervention. In this case, outcomes can include behavioural changes (e.g. physical activity increase) or health markers (e.g. strength measures).

Long-Term Outcomes refer to the specific outcomes related to the main objective of the study in the long-term. This can be with continued use of the health intervention/technology or a specific period time after the intervention/technology is no longer in use. The implications of this difference will be discussed further in the discussion section of the paper.

Elder Fitness Technology Translation Assessment Process

To evaluate the 43 papers included in this review consistently, a structured rubric was developed, shown in the **Appendix**. For each category, the rubric identified the specific qualities of health intervention that would best address their respective concerns and specified what interventions would look. The rubric included a range from 1 to 5 with 1 being a technological intervention that is most in conflict with the given category and 5 being most in harmony with the given category. For example, using the Compatibility with Lifestyle category, an intervention that seamlessly integrates into a potential user’s current daily life patterns without much additional effort would be given a score of 5 and an intervention that requires a lot of extra time and effort to integrate to the potential user’s lifestyle would be given a score of 1.

The scoring process consisted of five reviewers, who individually assigned a score to each paper within every category based on how well the paper met the established criteria. To ensure that every paper was evaluated from at least two different perspectives, each paper was assigned to two independent reviewers using a dual-review approach. In occasions where the two reviewers disagreed with their assessment by a score of 2 or more, a third reviewer provided the tie breaker. Results from the evaluation were summarised by primary technologies, interaction types, and goals of the interventions to better understand how different types of interventions aligned with the known needs and preferences of elders and identify potential trends.

Beyond evaluation of the health interventions with the Elder Fitness Technology Translation Assessment tool, the health goal, research goal, study target, number of participants, study length, presence of a control group, presence of elder specific design methodologies, presence of co-design in the design process, number of interaction components, and major outcomes were summarised for each study/intervention. Results were summarised only using information available to reviewers in the research articles themselves.

Results

Included in this review are, 1. Overall themes and categories of research in this space, 2. Summary of the common technologies, interaction types, and goals 3. Overall takeaways from intervention types and research methodologies, and 4. A comparison of the health interventions with known preferences of elder adults from elder specific technology adoption work.

The 43 research studies were summarised by the journal they were published in, technological system, health goal, research goal, study target, number of participants, study duration, whether of there was a control condition, and finally the major outcomes presented in the work. Results from this process are shown in **Table 3**.

Table 3. Summary of Health Interventions for Older Adults. Overview of 43 interventions aimed at enhancing physical and cognitive health in older adults.

Article	Journal	System Summary	Health Goal	Research Goal	Study Target	# Prts.	Time	Control (Y/N)	Outcomes
Vaziri et al. (50)	Human-Computer Studies	MS Kinect Exergames	Balance training, fall prevention	Feasibility	65+, living in community, can walk 20 m without an aid, can watch TV from 3m without glasses, enough space for system	136	16-weeks	Yes, (C = 71, I = 63)	Analysis of system effect on subgroup: 1. Age (no difference), 2. Gender (female participants reduced fall risk at higher rate than male counterparts), and 3. IT literacy (main effect of literacy on fall risk reduction)) fall risk. Reduction of fall risk between all groups in comparison to control
Volders et al. (53)	Environmental Research and Public Health	eHealth system w/ wearables	Physical Activity Promotion	Longitudinal study of effects	65+, Dutch speaker, w/ chronic/ physical condition affecting mobility	438	12-months	Yes, (C = 264, I = 174)	No effects on objectively measured physical activity, 19.1% and 25.1% dropout at 6 and 12 months respectively, Intervention increased likelihood to perform self-reported cycling, gardening, and walking
Van Dyck et al. (56)	Journal of Medical Internet Research	eHealth w/ wearables (accelerometer)	Physical Activity Promotion	Longitudinal study of effects	65 -80, can walk 100m without an aid, Dutch speaker, access to email	65	5-weeks plus 3 month follow-up	Yes, (C = 31, I = 68)	Significant intervention effects on moderate-to-vigorous physical activity (MVPA)
X. Li et al. (59)	IEEE International Symposium on Mixed and Augmented Reality Adjunct (ISMAR-Adjunct)	Multisensory VR games	Maintaining visual function, cognitive ability, and physical function in older adults	Acceptability Study	½ Older/ ½ younger adults w/ no physical and mental impairments	28	40 minute acceptability sessions	Yes (younger adults)	Suggests that VR game could be well accepted by older adults
Uzor and Baillie (62)	ACM Transactions on Computer-Human Interaction (TOCHI)	eHealth system w/ wearables (2 IMU sensors - 9 DOFs)	Rehabilitation and fall prevention	Feasibility	65+, living in own home, fallen in last 12 months, can do home exercise using standard care booklet	38	8-weeks	Yes, (C = 22, I = 16)	Significant greater adherence vs. control group, more participants believed they achieved their rehabilitation goals vs. control group, Higher reduction in stride length variability vs. control group (measure of fall risk)

Nawaz et al. (65)	Pervasive Computing Technologies for Healthcare Conference	MS Kinect Exergames	Balance training, fall prevention, strength building	Usability	Not provided	12	1 hour sessions	No	Participant Feedback: Liked games that were related to real life (skiing and tennis) and physically challenging, wanted clear objectives, sense of progress, appropriate music, and a single activity at a time
Lin et al. (68)	Gerontology: Experimental, Clinical, Behavioural, and Technological Gerontology	Exergame, ergometer, smart fitness equipment	Physical Activity Promotion	Short Term Randomized Control Trial	50+, active in community	35	12 weeks	Yes	Significant improvements in muscle strength, flexibility, and aerobic endurance in comparison to control group
Petersen et al. (71)	JMIR Mhealth and Uhealth	mHealth (App), smart fitness equipment (exercise band)	Strength building and physical activity promotion	Usability	65+, English speaker, community dwelling	16	Not reported	No	Overall System Usability Scale (SUS) and Ease of Use (USE) scores were 66.4 and 41.3 respectively
Matz-Costa et al. (74)	Journal of Gerontological Social Work	Wearables (FitBit Zippedometer), mHealth (Tablet app), phone	Physical Activity Promotion, Cognitive activity, and social interaction	Feasibility	65+, relatively inactive (< 10 on HELP), city resident	25	8-weeks	Yes, (C = 13, I = 12)	83% retention rate, daily steps increased by 431 steps from baseline to week 4 and sustained at Week 8
Smaerup et al. (77)	Disability and Rehabilitation: Assistive Technology	eHealth system	Vestibular rehabilitation, physical activity promotion	Feasibility/ Long-term assessment of behaviour change	Diagnosed with peripheral, central and/or mixed vestibular dysfunction	7	16-weeks	No	Participants were basically self-efficient and accepted the technology, participants asked for greater variation in the exercises and closer contact with physiotherapist.

Ogonowski et al. (80)	ACM Transactions on Computer-Human Interaction (TOCHI)	MS Kinect, Exergame, Senior Mobility Monitor (SMM)	Balance training and fall prevention	Feasibility/ Long-term assessment	65+, without any chronic disease affecting physical fitness	12	6-months	No	Participants reported a greater awareness of their health and fall risk issues, and reported a feeling of lower fall risk, inactive and active older adults had the largest reduction in fall risk (PPA), 6 month adherence of the system was good but not all maintained the recommended training schedule of 120 minutes per week
Skjæret et al. (83)	Gerontology: Regenerative and Technological Section	Exergames, press and release step pad (DDR), virtual reality, MS Kinect	Physical activity promotion	Usability/ design guidelines	65+, able to walk safely without walking aid	14	Not reported	No	Playing The Mole on SilverFit (virtual reality based game) resulted in the best movement quality with the highest sum score, weight shift, speed variation, and variation in movement direction
Santini et al. (85)	Translational Behavioural Medicine	mHealth (App)	Wellness motivation, fall prevention, and physical activity promotion	Usability	60+, rural and urban communities	9 (4 full part.)	7 days max	No	Participants assessed the app as valid, usable, acceptable, and able to sense most reported free-living activities
McMahon et al. (87)	Environmental Research and Public Health	mHealth (App)	Physical activity promotion, mental well-being, and social interaction, transitioning to retirement	Longitudinal study of effects	55+, 3 years pre or post retirement, no care dependency, in good health status condition	62	10-weeks	No	The use of the digital coach improved participants' physical activity, mental well-being and self-efficacy during the first 5 weeks and only physical activity in the second 5 weeks
Sit et al. (89)	Frontiers in Public Health	Augmented reality,	Well-being	Usability	Not provided	1915	2-minutes	No	Reported overall satisfaction was high, participants showed enthusiasm using the

	Health	motion sensors, tablet app (iPad)	promotion, physical activity promotion						games
Muñoz et al. (91)	Sensors	MS Kinect	Physical activity promotion	Usability/feasibility	Not provided	57	15-days	No	Progressive acceptance of the system, improvement in measurement of physical achievements
Knight et al. (51)	The Physician and Sports medicine	mHealth (App), blood pressure monitor, glucometer, and pedometer	Physical activity promotion	Longitudinal study of effects	generally healthy, no diagnosis required	45	12-week	No	Significant changes from baseline for physical activity, body weight, and blood pressure
Baranyi et al. (54)	IEEE International Conference on Serious Games and Applications for Health	mHealth (App), serious game	Stroke Rehabilitation	Usability	Not provided	13	Not reported	No	Some initial difficulties with participant use of game, general positive feedback from participants and therapist involved in study
M. B. D. Rosario et al. (57)	IEEE Journal of Biomedical Health Informatics	mHealth (App), blood pressure monitor, and weight scale	Cardiac Rehabilitation	Pilot/feasibility	Referred to CRP for 1 st time hospital admission for a cardiac-related diagnosis/treatment, English speaker	51	6-week	Yes, (C = 22, I = 29)	88% completion rate in intervention group compared to 67% in control group, statistical correlation found between post six minute walking distance (6MWD) and average time walked each day
K. Al-Naime et al. (60)	Conference of Biomedical Engineering	Wearables, internet of things (IoT)	Preoperative Rehabilitation, rehabilitation	Feasibility	Not provided	17	4-6 weeks	No	System was able to accurately recognize physical activities at the gym and outdoors, able to facilitate mixed mode prehabilitation program
S. Mohieldin et al. (63)	IEEE International	mHealth (App), Smart	Strength building	Proof of concept/pilot	Not provided	7	Not reported	No	BandPass had 94% accuracy, recorded 147 exercises, demonstrated ability to facilitate remote monitoring of exercise

	Conference on Communications	fitness equipment (exercise band)							progress
S. Kanchanapaetnukul et al. (66)	International Technical Conference on Circuits/ Systems, Computers, and Communications (ITC-CSCC)	Video, MS Kinect	Physical Activity Promotion	Preliminary Evaluation, Usability Testing	Elderly (usability testing without elders)	26	Single session	No	System Results: Precision - 0.94, Recall - 0.98, F1 score - 0.96, Accuracy - 0.93, Ease of use of system statistically better compared to old system
T. El Salti et al. (69)	IEEE Computing and Communication Workshop and Conference	mHealth (App)	Physical Activity Promotion	Pilot Usability Study	Actively involved in providing remote and informal care to elderly	12	Single Interview	No	Participants mentioned that proposed system would strongly support their caregiving of older adults, broad acceptance from participants
Alizadeh et al. (72)	Extended Abstracts on Human Factors in Computing Systems	Wearables (Haptic Feedback)	Physical Activity Promotion	Preliminary Evaluation	Seniors (preliminary testing without seniors)	5	Single session testing	No	Simple haptic feedback can connect users with remote exercise, vibration useful for synchronization
Elder et al. (75)	Activities, Adaptation, and Aging	Computer , video	Physical Activity Promotion and Strength Building	Mixed Methods Short Term Pilot Study	50+	10	10 weeks	No	90% of participants showed improved sit-to-stand (STS) and timed up and go (TUG)
Ballesteros et al. (78)	Official Journal of the International Society for Gerontechnology	Computer , social network, wearables (smart watch), video	Physical Activity Promotion	Longitudinal Controlled Trial	65+	57	12 months	Yes (C = 27, I = 28)	User group showed improvement from pre-test to post test in wellbeing (SPF-IL)
Coley et al. (7566)	Journal of Medical Internet Research	eHealth	Healthy Ageing,	Multinational	65+, dementia free, community	2724	18 months, 6 month	Yes (C = 1335, I =	Compared to control group the adjusted mean difference of blood pressure, BMI,

(81)	Internet Research		healthy living	Randomized Controlled Trial	dwellers		follow up	1389)	and cholesterol, was −0.08 (−0.12 to −0.03), −0.04 (−0.08 to 0.00), and 0.00 (−0.08 to 0.08) in the high, moderate, and low engagement groups, respectively
Arkkukangas et al. (84)	Physiotherapy Theory and Practice	mHealth (App)	Fall Prevention	Qualitative Usability Study	65+, Swedish speaker	12 (7 F, 5 M)	Single day focus groups	No	Using the application helped all the participants perform the exercises, program was fun to use, monitoring helped participants follow and evaluate their progress regularly and adhere to the exercises
Gomes et al. (86)	Journal of Medical Internet Research	Interactive TV App	Healthy Living (Dietary) and Physical Activity Promotion	Feasibility and Acceptability Study	Older adults with food insecurity	31	12 weeks with 3-month follow up	No	Participants were significantly more interested in using eHealth for food insecurity following intervention, high levels of acceptability were found, reduction of food insecurity, decreased fatigue, and improved physical function
Hosteng et al. (88)	Journal of Physical Activity and Health	mHealth (App), Wearables (FitBit Zip)	Physical Activity Promotion and Social Interaction	Pilot Study	Older Adults living in Retirement Community	54 (42 F, 12 M)	8 weeks, 4 week follow up	No	Increased daily steps from 5438/day to 6201/day at week 8, but was not maintained at 4 week follow up following the intervention
Daly et al. (90)	JMIR mHealth and uHealth	Computer, Tablet (App)	Physical Activity Promotion and Strength Building	Short-term Pilot Study	65+, independent living	20	8 weeks	No	84% adherence, mean weekly walking time increased 78 minutes, MVPA increased 41 minutes, system usability was high
de Batlle et al. (92)	JMIR mHealth and uHealth	mHealth (App), Wearables (FitBit Flex, additional sensors)	Preventative Care for Complex Chronic Patients	Acceptability Study	55+, home dwelling, chronic conditions with history of pulmonary disease or heart failure, or hip/knee surgery	135	3 months	Yes (C = 58, I = 77)	Better continuity of care vs control, high scores for patient acceptability and usability, 77% usage of technology
Joosen et al. (52) https://preprints.jmir.org/preprint/75665	Frontiers in Digital Health	mHealth (App), Wearables (HR belt)	Physical Activity Promotion	Usability Study	60+, (1/2 self described balance issues)	24 (21 F, 3 M)	Single session focus group	No	Activity levels increased for first 5 weeks of intervention, slightly decreasing for next 5 weeks (no significant increase in % time active at week 10 vs baseline)

F. Delmastro et al. (55)	IEEE International Conference on Wireless and Mobile Computing, Networking And Communications (WiMob)	mHealth (App), Online/Web/Internet	Long-term care services	Usability Study	Older adults at Nursing home	57 for demo, 10	4 months	Yes	Primary Users: consider INTENSA services useful with a average/high level of acceptance to the proposed protocol. Secondary Users (Care Workers): System easy to use
A. K. Mishra et al. (58)	Conference of the IEEE Engineering in Medicine and Biology Society (EMBC)	MS Kinect	Remote Physical Therapy (Rehabilitation)	Feasibility/Validation Study	Not provided	4	Single day session	Yes (Vicon Motion Capture)	The therapist rated the technical quality of audio and video and the user satisfaction and PT interaction as high as 4.7 and 4.8 out of 5 respectively
J. Finkelstein and I. c. Jeong (61)	IEEE Point-of-Care Healthcare Technologies (PHT)	Smart exercise equipment (Stationary Bike), HR, BP, ECG, web-based	Geriatric rehabilitation	Design Study	Intended for geriatric rehabilitation (volunteers aged 23 to 55 participated)	8	Single day testing	No	Technology allows telemedicine interventions supporting safe and efficient exercise at senior patient homes.
H. G. Zadeh et al. (64)	Iberian Conference on Information Systems and Technologies (CISTI)	MS Kinect	Physical Activity Promotion, Mental Fitness, Disease Prevention	Feasibility Study	Older adults with Mild Cognitive Impairment (MCI) and Urinary Incontinence (UI)	21	Single day sessions	No	Participants found the game easy to play, master, and fun to replay the game
C. L. Petersen et al. (67)	IEEE/ACM conference on Connected Health: Application	mHealth (App), Smart fitness equipment	Strength Building	Feasibility Study	65+, who would like to lose weight and improve muscle strength	6 (6 F)	Single day sessions	No	Can be useful tool that will allow measurement of the number of repetitions per exercise

	s, Systems and Engineering Technologies (CHASE)	t (Resistance Band)							
J. Doyle et al. (70)	Conference on Pervasive Computing Technologies for Healthcare, PervasiveHealth	Computer (Flash App), wearables (Shimmer kinematic sensors, tracking markers)	Fall Prevention and Balance Training	Usability Study	Older adults	12	2 single day sessions	No	Participants felt confident could use system in their homes. Import themes: high fidelity animation for visual feedback, integration of multimodal feedback throughout the program, navigation prompts to facilitate moving through the program, allowing participant to control the pace and the importance of progression reports.
C. L. Petersen et al. (73)	IEEE/ACM conference on Connected Health: Applications, Systems and Engineering Technologies (CHASE)	mHealth (App), Smart fitness equipment (Resistance Band)	Strength Building	Field-Based Feasibility Study	65+	7 (3 M, 4 F)	1 month (once a week exercises)	No	Patients were positive about use: patient activation measure: 80.7±14; system usability scale: 6.9±2.9; and confidence in use: 7.7±2.7
H. B. Jimison et al. (76)	Conference of the IEEE Engineering in Medicine and Biology Society (EMBC)	MS Kinect, teleconferencing	Physical Activity Promotion	Usability, Engagement, and Adherence Study	Independent Living Elderly Enrolled in Health-coaching Program	6 (2 M, 4 F)	2-3 weeks	No	Able to maintain adherence to the exercise goals for most participants, Lessons learned: need to switch from computer monitor to digital TVs, difficulty finding room in participants homes, and challenges in using multiple remote control devices
F. Ofli et al. (79)	IEEE Journal of Biomedical Health Informatics	MS Kinect	Fall Prevention, Strength Building	Short-term Field Study	Independent Living Elderly Enrolled in Health-coaching Program	6 (2 M, 4 F)	~ 20 days (10 sessions every other day)	No	The system able to collect continuous exercise data for all sessions, participants expressed positive attitude toward using such a system

			Physical Activity Promoti on						
Uzor and Baillie (82)	Proceeds of the ACM on Interactive, Mobile, Wearable and Ubiquitous Technologie s	MS Kinect	Fall Rehabili tation	2-Part Qualitative Study on Design	65+, fallen at least once in prior 12 months	11 (6 F, 5 M), 16 (10 F, 6 M)	Workshop, 2 month study	No	High levels of acceptance, usefulness, and usability scores from 2 month user study

Summary of the Reviewed Research Articles

Overall, 16 of the review articles were submitted into medical journals, 15 were submitted into engineering journals, seven were submitted into HCI or computing journals, three were submitted into public health journals, and two were submitted into a cross publication between computing and engineering journals. The research focus of the articles was usability, feasibility, and acceptability for 27 of the articles, studies of effects for 14, and design for two of the articles. 13 of the 43 research articles were controlled studies. 22 of the research articles were of studies longer than four weeks, 4 lasted between one week and 4 weeks, 13 lasted only a single day, and four did not specify a study duration.

Summary of Fitness Technology Intervention Types

The primary user interaction technologies used in the selected health interventions include six different types:

1. Microsoft Kinect {12},
2. Wearables- Smart watches, heart rate monitors, etc. {15},
3. mHealth Apps (phone or computer based) {18},
4. Smart fitness equipment – resistance bands, exercise bikes, etc. {7},
5. Augmented or Virtual reality {3}, and
6. Website {2}.

Six common interaction types were found in the selected interventions:

1. Game {13},
2. Self-tracking {18},
3. Physician-tracking {2},
4. Personalized Health Advice {28},
5. Competition {1}, and
6. Planning {4}.

Despite disparate overall objectives including general well-being promotion, sarcopenia treatment, fall reduction, and rehabilitation, to achieve those objectives four common immediate health goals were observed in the selected interventions:

1. Build strength {10}
2. Increase Physical Activity {33}
3. Train Balance {9}
4. Train Mental Fitness {5}

A comprehensive list of the stated research and health goals of the selected interventions is included in **Table 3**. Reported outcomes included behavioural change outcomes (e.g. minutes of exercise), health outcomes (e.g. blood pressure), technological functioning (e.g. accuracy), and user feedback on usability and usefulness (both quantitative and qualitative).

Presence of Elder Specific Design Methodologies

Before assessing the research articles based on the elder design needs and

preferences synthesized in this work, research studies were reviewed for the presence of cited elder specific design research in their methodologies to get a basic understanding of how much of these works of being used to inform technology design in the field. Of the 43 papers reviewed, 16 explicitly reference research on elder design factors. Among these, eleven cite such factors in their background and related works section, ten cite them specifically as part of their design approach, and four incorporate them directly into their methodology. Of the 16 research articles that explicitly reference elder design works, reviewers scored six of the corresponding intervention designs as directly correlated with the stated requirements from the cited elder design works, one as mostly correlated, three as somewhat correlated, one as directly contradictory, and five as not having enough information to make an assessment. A summary of the cited elder design works can be found in **Table 4**.

Table 4. A summary of the cited elder design works in the reviewed articles and whether the outcomes from those cited works translated to the proposed technology interventions.

Article	Elder Design Works Cited	Where Work was Cited	Major Design Takeaways from Cited Works	Translation of Cited Works to the Design
Vaziri et al. (50)	1. Sherrington, C., Tiedemann, A., Fairhall, N., Close, J.C.T., Lord, S.R., 2011. Exercise to prevent falls in older adults: an updated meta-analysis and best practice recommendations. N. S. W. Public Health Bull. 22, 78. doi:10.1071/NB10056.	Design	Fall prevention exercises should have moderate or high challenge, be at least 2 hours per week, both group or home-based programs should be available, could incorporate strength training	Somewhat (180 minutes per week, at home exercise, strength training included, no option of group based training)
Volders et al. (53)	1. Boekhout, J.M.; Peels, D.A.; Berendsen, B.A.J.; Bolman, C.A.W.; Lechner, L. An eHealth intervention to promote physical activity and social network of single, chronically impaired older adults: Adaptation of an existing intervention using intervention mapping. JMIR Res. Protoc. 2017, 6, e230.	Background, Design, Methods	Include both At home and outdoor activities, stress long term health, stress social interaction, encourage advice from GP and physiotherapist, inform of exercise possibilities, give chose of delivery method between web and printed materials	Yes (Directly developed ActivePlus 65 system from these requirements)
Van Dyck et al. (56)	Did not Cite Elder Design Works	N/A	N/A	N/A

X. Li et al. (59)	Did not Cite Elder Design Works	N/A	N/A	N/A
Uzor and Baillie (62)	1. Gazihan Alankus, Amanda Lazar, Matt May, and Caitlin Kelleher. 2010. Towards customizable games for stroke rehabilitation. In Proceedings of the 28th International Conference on Human Factors in Computing Systems (CHI'10).ACM,New York, NY, 2113-2122. DOI:10.1145/1753326.1753649 2. Stephen Uzor, Lynne Baillie, and Dawn A. Skelton. 2012. Senior designers: Empowering seniors to design enjoyable falls rehabilitation tools. In Proceedings of the International Conference on Human Factors in Computing Systems (CHI'12). ACM, 1179-1188.	Background, Design	1. Assume no use of hands, simple games, less repetitive and more enjoyable exergames, 2. convey progress,	Yes (Exergames directly designed through the cited works)
Nawaz et al. (65)	1. Gerling, K. M., Schild, J., & Masuch, M. 2010. Exergame design for elderly users: The case study of SilverBalance, in Proceedings of the 7th International Conference on Advances in Computer Entertainment Technology. 2010, ACM: Taipei, Taiwan. p. 66-69.	Design	Exergames should be able to be played both standing up and sitting down, avoid too extensive and sudden movements, have adjustable difficulty level, simple interactions, constructive feedback	Mostly (simple, "limited information" exergames, constructive feedback, not enough information on the required interactions)
Lin et al. (68)	Did not Cite Elder Design Works	N/A	N/A	N/A

Petersen et al. (71)	1. Batsis JA, Naslund JA, Zagaria AB, Kotz D, Dokko R, Bartels SJ, et al. Technology for behavioral change in rural older adults with obesity. J Nutr Gerontol Geriatr 2019;38(2):130-148 [FREE Full text] [CrossRef] [Medline]	Design	Barriers include privacy concerns, access to tech, and complexity, Enablers: motivation, tracking, accountability	Yes (simple, includes progress tracking)
Matz-Costa et al. (74)	Did not Cite Elder Design Works	N/A	N/A	N/A
Smaerup et al. (77)	1. Phillips EM, Schneider JC, Mercer GR. Motivating elders to initiate and maintain exercise. Arch Phys Med Rehabil. 2004;85:S52-S57. 2. Hensel BK, Demiris G, Courtney KL. Defining obtrusiveness in home telehealth technologies: a conceptual framework. J Am Med Inform Assoc. 2006;13:428-431.	Background, Design	1. Adapt activity programs to enable less able-bodied people, facilitate empowerment, focus on accessibility and affordability, promote socialization, 2. Health technologies should minimize obtrusiveness to end users (physical, usability, privacy, function, interaction, self-concept, routine, and sustainability)	Somewhat (adaptable exercises, some issues with technology uptake, functionality, and motivation, also potential privacy concerns)
Ogonowski et al. (80)	1. Johanna Meurer and Rainer Wieching. 2012. Motivating elderly people to use fall preventive exercise training games at home: Are community based ict features always a good choice? In Proceedings of the 3rd International Workshop "Fostering Social Interactions in the Ageing Society." 28-31.	Background, Design, Methods	1. Design should focus on the necessary feature for training over nice to have community features, elders preferred personal contact over virtual social interactions, 2.	[No] (Complex technology design with many components, virtual social media platform)
Skjæret et al. (83)	Did not Cite Elder Design Works	N/A	N/A	N/A

Santini et al. (85)	1. Pak R. Designing displays for older adults. Boca Raton: CRC; 2010.	Design, Methods	Usability requirements for displays and user interfaces for older adult users	Yes (Directly informed design and approach)
McMahon et al. (87)	Did not Cite Elder Design Works	N/A	N/A	N/A
Sit et al. (89)	Did not Cite Elder Design Works	N/A	N/A	N/A
Muñoz et al. (91)	1. De Angeli, A.; Jovanović, M.; McNeill, A.; Coventry, L. Desires for active ageing technology. Int. J. Hum. Comput. Stud. 2020, 138, 102412. [Google Scholar] [CrossRef]	Background	1. Avoid portrays elders as in decline, ageing technologies should promote resilience, belonging, autonomy, feeling good, and doing good. 2.	Unknown (Not enough information on the promotion of resilience, belonging, and autonomy)
Knight et al. (51)	Did not Cite Elder Design Works	N/A	N/A	N/A
Baranyi et al. (54)	Did not Cite Elder Design Works	N/A	N/A	N/A
M. B. D. Rosario et al. (57)	Did not Cite Elder Design Works	N/A	N/A	N/A

K. Al-Naime et al. (60)	Did not Cite Elder Design Works	N/A	N/A	N/A
S. Mohieldin et al. (63)	Did not Cite Elder Design Works	N/A	N/A	N/A
S. Kanchanapae tnukul et al. (66)	Did not Cite Elder Design Works	N/A	N/A	N/A
T. El Salti et al. (69)	Did not Cite Elder Design Works	N/A	N/A	N/A
Alizadeh et al. (72)	Did not Cite Elder Design Works	N/A	N/A	N/A
Elder et al. (75)	Did not Cite Elder Design Works	N/A	N/A	N/A
Ballesteros et al. (78)	Did not Cite Elder Design Works	N/A	N/A	N/A
Gokey et al. (81)	Did not Cite Elder Design Works	N/A	N/A	N/A
Akenine U, Barbera M, Beishuizen CR,	Design, Methods	Engagement in self	Yes (Information presented	

(81)	Fallah Pour M, Guillemont J, Rosenberg A, HATICE study group. Attitudes of at-risk older adults about prevention of cardiovascular disease and dementia using eHealth: a qualitative study in a European context. BMJ Open 2020 Aug 06;10(8):e037050		management prevention programmes is influenced by access to reliable information, trust in healthcare providers, and burden of dementia and stigma --> eHealth interventions should be reliable, accessible, and safe	was reliable and accessible)
Arkkukangas et al. (84)	Did not Cite Elder Design Works	N/A	N/A	N/A
Gomes et al. (86)	Did not Cite Elder Design Works	N/A	N/A	N/A
Hosteng et al. (88)	1. Chen YM. Perceived barriers to physical activity among older adults residing in long-term care institutions. J Clin Nurs. 2010;19(3-4): 432-439. doi:10.1111/j.1365-2702.2009.02990.x [PubMed: 20500283]	Background	Barriers to physical activity include physical health problems, fear, past sedentary lifestyle, and lack of understanding, effective interventions should reduce these barriers and provide a supportive environment	Unknown (Not enough information on how the intervention reduced the outlined barriers)
Daly et al. (90)	1. Ziebart C, McArthur C, Lee L, Papaioannou A, Laprade J, Cheung AM, et al. "Left to my own devices, I don't know": using theory and patient-reported barriers to move from physical activity recommendations to practice. Osteoporos Int 2018 May;29(5):1081-1091. [doi:	Background	1. Barriers to physical activity include lack of knowledge on exercises, fear of fracturing, and trust in providers. Interventions should be tailored to gender, age, or	Yes (At home strength and balance training with exercise program)

	10.1007/s00198-018-4390-3] [Medline: 29441402] 2. Yardley L, Kirby S, Ben-Shlomo Y, Gilbert R, Whitehead S, Todd C. How likely are older people to take up different falls prevention activities? Prev Med 2008 Nov;47(5):554-558. [doi: 10.1016/j.ypmed.2008.09.001] [Medline: 18817810]		presence of comorbid conditions. 2. Elders preferred to carry out strength and balance training at home	
de Batlle et al. (92)	Did not Cite Elder Design Works	NA	N/A	N/A
Joosen et al. (52)	1. Kim HS, Lee KH, Kim H, et al. Using mobile phones in healthcare management for the elderly. Maturitas 2014; 79: 381-388.	Background	Difficulties encountered by elders using IT: physical and cognitive changes, difficulty learning new tasks on mobile phones	Unknown (Not enough information to determine whether the technology addresses the elder specific difficulties cited)
F. Delmastro et al. (55)	Did not Cite Elder Design Works	N/A	N/A	N/A
A. K. Mishra et al. (58)	Did not Cite Elder Design Works	N/A	N/A	N/A
J. Finkelstein and I. c. Jeong (61)	Did not Cite Elder Design Works	N/A	N/A	N/A

H. G. Zadeh et al. (64)	1. R. Pak and A. McLaughlin, Designing Displays for Older Adults. London: CRC Press, 2010. 2. A. Fiske, J. L. Wetherell, and M. Gatz, "Designing for older adults: Principles and creative human factors approaches," Annu. Rev. Clin. Psychol., vol. 5, no. 1, pp. 363-389, 2004.	Background	1. Display and user interface guidelines for elders, 2. Vision, hearing, and haptics affect user interaction, design of interfaces, 3.	Unknown (Not enough information)
C. L. Petersen et al. (67)	Did not Cite Elder Design Works	N/A	N/A	N/A
J. Doyle et al. (70)	Did not Cite Elder Design Works	N/A	N/A	N/A
C. L. Petersen et al. (73)	Did not Cite Elder Design Works	N/A	N/A	N/A
H. B. Jimison et al. (76)	Did not Cite Elder Design Works	N/A	N/A	N/A
F. Ofli et al. (75)	W. Ijsselstein, H. H. Nap, Y. de Kort, and	Background,	1. Interface design for	Somewhat (Supports range

(79)	K. Poels, "Digital game design for elderly users," in Proc. Conf. Future Play, 2007, pp. 17-22. J. Kelly, and B. Caulfield, "Design considerations in therapeutic exergaming," in Proc. 5th Int. Conf. Pervasive Comput. Technol. Healthcare, 2011, pp. 389-393.	Design	elders should minimize burden on spatial memory, working memory, visual functions, and motor ability. Interfaces should be adaptable. 2. Therapeutic exergames should be support a wide range of exercises, hands free, minimal number of sensors, adaptable feedback, customizable	of exercises, but includes fixed in exercise feedback)
Uzor and Baillie (82)	1. Gazihan Alankus, Amanda Lazar, Matt May and Caitlin Kelleher. 2010. Towards Customizable Games for Stroke Rehabilitation. In Proceedings of the 28th International Conference on Human Factors in Computing Systems (CHI '10). ACM, New York, NY, 2113-22. DOI: 10.1145/1753326.1753649 2. Bert Bongers, Stuart T. Smith, Victor Donker, Michelle Pickrell, Rebecca Hall and Stefan Lie. 2014. Interactive Infrastructures Physical Rehabilitation Modules for Pervasive Healthcare Technology. In: Pervasive Health – state of the art and beyond. Andreas Holzinger, Martina Ziefle, Carsten Röcker. (eds.) Springer, London, UK, 229-54	Background	1. Assume no use of hands, simple games, less repetitive and more enjoyable exergames, 2. Three main issues affecting rehabilitation: motivation, customisation, independence	Unknown (Not enough information on the user experience)

Overview of Findings for the Assessment of Elder's Needs and Preferences

On average, the interventions scored 2.97 ± 0.85 on Compatibility with Lifestyle, 3.11 ± 0.80 on Similarity to Past Experience, 3.44 ± 0.76 on Dignity and Independence, 3.15 ± 0.92 on Privacy Concerns, 3.68 ± 0.91 on Short-Term Outcomes, 2.72 ± 1.15 on Long-Term Outcomes, 2.78 ± 0.88 on Social Support, and 3.13 ± 1.15 on Emotion. Distribution of elder specific technology adoptions scores for the 43 selected interventions are shown in **Figures 2-7**. The average scores for the most common intervention goals, building strength, increasing physical activity, and training balance were 3.35, 3.13, and 3.31 respectively.

Figures 2-7

Beyond overall scores, an assessment of the scores across primary interaction technologies, interaction types, and common goals was conducted.

Results by Primary Interaction Technologies

The average scores for the most common technologies used, apps, wearables, and MS Kinect based systems were 3.25, 3.05, and 3.33 respectively. Between the three most common technology types, wearables scored highest in compatibility with lifestyle (3.40) and similarity with past experience (3.50), apps scored highest in dignity and independence (3.56), privacy concerns (3.28), short-term outcomes (3.91), and social support (2.97), and MS Kinect scored highest in long-term outcomes (4.50) and emotion (4.00). Full results are included in **Table 5**.

Table 5. The average scores of the six elder adult specific technology adoption factors across the six common critical technologies found in the survey: 1. mHealth (Apps), 2. Wearables, 3. MS Kinect, 4. Smart Fitness Equipment, 5. Virtual and Augmented Reality (AR/VR), and 6. Website.

Critical Technology	#	Compatibility	Similarity	D and I	Privacy	Social	Emotion
mHealth (Apps)	18	2.46	2.63	3.46	3.17	2.54	4.00
Wearables	15	3.40	3.50	3.47	2.70	2.80	2.63
MS Kinect	12	3.25	3.33	3.56	3.28	2.97	2.72
Smart Fitness Equipment	7	2.86	3.07	3.71	3.29	3.07	3.07
AR/VR	3	2.33	2.50	3.50	3.50	3.00	4.67
Website	2	3.75	4.75	2.75	3.00	2.00	1.75
Total	43	2.97 ± 0.85	3.11 ± 0.80	3.44 ± 0.76	3.15 ± 0.92	2.78 ± 0.88	3.13 ± 1.15

Results by Interaction Types

The average scores for the most common interaction approaches, personalised health advice, self-tracking, and exergames were 3.13, 3.20, and 3.23 respectively. Between the three most common interaction approaches, personalised health advice scored highest in compatibility with lifestyle (3.18) and long-term outcomes (3.00), self-tracking scored highest in similarity with past experience (3.31) and privacy concerns (3.25), and exergames scored highest in short term outcomes (4.11), social support (2.88), and emotion (4.38). For dignity and independence, both self-tracking and exergames tied with a score of 3.58. Full results are included in **Table 6**.

Table 6. The average scores of the six elder adult specific technology adoption factors across the six common critical interactions found in the survey: 1. Games, 2. Self-Tracking, 3. Physician-Tracking, 4. Personalised Health Advice, 5. Competition, and 6. Planning.

Critical Interaction	#	Compatibility	Similarity	D and I	Privacy	Social	Emotion
Personalised Health Advice	28	3.18	3.30	3.45	3.18	2.71	2.66
Self-Tracking	18	3.08	3.31	3.58	3.25	2.69	2.97
Game	13	2.38	2.73	3.58	3.00	2.88	4.38
Planning	4	4.00	4.25	3.63	3.00	2.75	2.25
Physician-Tracking	2	3.25	3.50	4.00	2.75	2.75	4.00
Competition	1	4.00	4.00	4.50	2.00	3.50	3.50
Total	43	2.97±0.85	3.11±0.80	3.44±0.76	3.15±0.92	2.78±0.88	3.13±1.15

Results by Common Goals

The average scores for the most common health goals, increase physical activity, train balance, and build strength were 3.13, 3.31, and 3.35 respectively. Between the three most common health goals, interventions aimed at increasing physical activity scored highest in compatibility with lifestyle (3.08), similarity to past experience (3.18), and privacy concerns (3.18), training balance scored highest in short term-outcomes (4.30) and emotion (3.83), and building strength scored highest in dignity and independence (3.55). For long-term outcomes, both interventions aimed at building strength and training balance tied with a score of 4.5. Full results are included in **Table 7**.

Table 7. The average scores of the six elder adult specific technology adoption factors across the four common intervention goals found in the survey: 1. Strength Building, 2. Physical Activity Promotion, 3. Balance Training, and 4. Mental Fitness Training.

Intervention Goal	#	Compatibility	Similarity	D and I	Privacy	Social	Emotion
Physical Activity	33	3.08	3.18	3.42	3.18	2.80	3.03
Strength	10	2.55	2.9	3.55	3.1	2.75	3.6
Balance	9	2.33	2.78	3.50	2.72	2.50	3.83
Mental Fitness	5	3.20	3.40	3.20	3.10	2.40	3.40
Total	43	2.97±0.85	3.11±0.80	3.44±0.76	3.15±0.92	2.78±0.88	3.13±1.15

How Long-Term Outcomes are Assessed

Long-term outcomes are essential for understanding the sustained effectiveness of interventions, especially those designed to improve physical activity or independence in older adults over time. Reviewers were asked to only consider either behavioural change outcomes (e.g. minutes spent exercising) or health outcomes (e.g. blood pressure) as other outcomes such as usability and usefulness would be assessed in other technology adoption categories. Only seven of the 43 research articles reported any long-term outcomes of the interventions despite many of the interventions being intended for long-term use in practice. Reviewers categorized the reasons for the missing long-term outcomes in three categories: 1. The intended use of

the health intervention is short-term (e.g. rehabilitation interventions), 2. The research was not yet at the stage where long-term studies were feasible, and 3. The reviewers suggested that long-term outcomes should have been considered. Reviewers exempted research studies that recorded short-term health or behavioural change outcomes from category two though they are aware that in many cases the time and resources needed to conduct a long-term study is prohibitive. Scores are only meant to show the potential areas for further study in the field. Of the 36 research articles that did not include long-term outcomes, eight were meant for short-term applications, 16 were not yet at the stage of development, and 15 could have benefited from recording long-term outcomes. These scores not only reflect the current effectiveness of various technologies, interaction methods, and health goals but also highlight areas that need further research and refinement to better support older adults' health outcomes. For example, while MS Kinect shows strong long-term outcomes, its impact on privacy concerns and lifestyle compatibility could be explored in future studies.

Figures 8 and 9

Complexity

Interventions were also assessed for the number of technological components necessary for elders to interact with the fitness interventions, an approximate measure of complexity and a portion of similarity and compatibility factors. Roughly half, 21 of 43, of the interventions required elders to interact with one or two technological components and 38 of the 43 interventions required elders to interact with four or less technological components as assessed by reviewers shown in **Figure 10**. One health intervention required elders with ten different identified technologies and another with twelve^{55,70}.

Figure 10

Co-Design

An additional investigation into the presence of co-design, a design methodology shown to reduce assumptions and better align design choices with the preferences of potential users⁴⁷ found that only 13 of the 43 papers mentioned any use of co-design. The types of co-design found include focus groups, user experience interviews, and specified user-centric design processes.

Discussion

Overall, the results of this scoping review illuminate three main opportunities for growth in the field:

1. Better alignment between the studied needs of elders around interactive technology interventions and the current technology interventions for research around tech for elder fitness support.
2. Better translation of the findings of elder design work to the designs in practice.
3. More explicit usage of elder specific considerations in the research methodologies for this growing area of research.

We unpack of each of these points, below:

Alignment Between Expressed Elder Needs and Current Technology Interventions

From the Elder Fitness Technology Translation Assessment, none of the interventions scored a 3 or above on all eight factors as assessed by our reviewers suggesting that there was a least one easily identified elder specific translation problem for *every single one of the included interventions* as compared to understood needs and preferences of elders. The overall middling averages across all the papers considered, and the lack of a consistent pattern across technologies, interactions, and goals between interventions point to differing strengths and widespread weaknesses. The results from our assessment, also point to a need to learn from other intervention designs and interdisciplinary works to better incorporate elder specific needs into the designs of elder fitness technology interventions. The alignment of new designs with the identified factors around elder preferences has the potential to afford better effect and increase potential for uptake with minimal changes to designs. For example, concerns around compatibility, similarity, and privacy include the space and cost requirements of technologies such as MS Kinect, the potential daily life disruption of strictly regimented exercise plans, the uptake concerns around complex and unapproachable technology systems, and the unease with systems that require 24/7 monitoring. Drawing on awareness of elder technology concerns, each of those factors could have been identified and adjusted early in the design process to avoid translation problems in the future of even the most promising of interventions.

Translation from Cited Elder Specific Design Works to Design in Practice

To better understand the reason for the middling results, reviewers looked to the presence of referenced elder specific design work in the reviewed research articles. If very few of the research articles referenced elder specific design work, then it could point to a lack of awareness in the field as the reason for the mixed results. Of the 43 research articles, only 16 explicitly cited elder specific design works and only eleven directly referenced those works as part of the fitness technology design. Furthermore, in all of the referenced elder specific design works, none of them encompassed all of the considerations outlined in the Elder Specific Technology Translation Assessment with five of the research only citing works relating to the physical limitations of elders. This points to a general lack of awareness to the full scope of elders' needs and preferences related to fitness technologies.

However, for the research articles that did cite elder specific design works, reviewers also found a lack of translation of the outcomes from the cited works and the design choices of the reviewed articles. Only six of the reviewed fitness technology interventions fully aligned with the stated outcomes in the elder design works. An example of this disconnect between the use of elder specific design research and the proposed interventions is illustrated in the work of Ogonowski et al.⁸⁰, chosen as an exemplar because it follows the design approach mostly closely related to what is being

proposed as effective in this review. That is, it cited elder specific design considerations in the background, design, and methodology, and utilized participatory research or co-design with elders. In this example, viewing only the elder design work cited as forming the system requirements for their fitness technology intervention, a disconnect was found. The cited elder specific design work by Meurer and Wieching found a preference against the online social networks and menus with “lots of other accessories and other extras”, and a preference for enabling in person social connections and simple, easy to use technology interactions⁹³. Despite those identified preferences, the resulting technology included a social media platform for participants in which participants could meet other users virtually and post training results, news, questions, and suggestions⁸⁰. When comparing it to the known research surrounding the needs and preferences of elders using the Elder Fitness Technology Translation Assessment tool, compatibility concerns were raised over the space requirements of the technology and privacy concerns were raised over the continuous monitoring of elders through the senior mobility monitor.

Ethical Need for More Elder Specific Considerations in Research Methodologies

In conducting the scoping review, many of the questions from the Elder Fitness Technology Translation Assessment remained unanswered from the published outcomes of the reviewed studies such as how well the technologies fit into elders’ routines, how effective were the interventions over the long term, and how effective were the interventions outside of a research setting. The immediate implication of this is that it was hard to predict how well the technology interventions would translate to elder use in practice. For technology interventions aimed to be used in elders’ homes, in community centres, as part of public health initiatives, and in medical interventions, ethically, the implications of use in practice should be considered, including elder specific needs and preferences to avoid wasting funding and increase the likelihood of success beyond research environments. The reported outcomes from the reviewed studies include strength gains, balance improvements, increased minutes of physical activity/daily steps, perceived usefulness and utility, usability, functionality, and general qualitative feedback from elders. However practical considerations for elders remain unanswered, such as how well does the proposed technology intervention fit into elders’ daily lives, routines, and space at home, do elders have any privacy concerns when using the intervention, how similar is the interaction to something they have done before, and does the intervention promote a feeling of dignity and independence for elders.

Asking these questions can help progress the field by building insights for how elders feel about different fitness technologies and intervention types and supporting the overall elder specific fitness technology factors with direct outcomes from the field. For example, which types of social engagement systems work best, which intervention types are more likely to fit into routines, and which technologies are elders more willing to engage

with. Implementing explicit inclusion of elder specific factors into the assessment methodologies of interventions in the field could help to address this gap and avoid potential pitfalls that may otherwise only be found once used in practice.

Summary: Potential Value to Explicitly Considering Elder Specific Factors

This scoping review has considered papers across a range of fields that all have in common presenting novel designs of or novel use of interactive technologies to support building or sustaining fitness for older adults. To quantify factors across these papers that may be affecting the efficacy of this research as modelled across the other cited reviews in this domain, we have organised the included papers against a number of features such as types of technology used, types of evaluation carried out. We also developed a novel assessment criteria based in the research literature that affect elder technology acceptance and elder physical activity uptake. We used the resulting six factors as a further way to assess design efficacy.

Overall, as highlighted in the analysis of the results above, while there is some awareness of design-specific guidance for older adult technology uptake, it is more noticeable in the breach rather than in the adoption. Particularly striking is, across this wide range of research domains focused on this same space of interactive tech for elder fitness support, at least two thirds point to some literature referencing elder-specific design considerations for technology adoption in general and for fitness technologies in particular. What the analysis further shows, however, is that no matter the domain of the research, from medicine to engineering, engagement with that elder design research guidance – even when present – even in cases where it is cited, that guidance is effectively ignored within the application or assessment itself.

As we underscore in point three in this section, lack of attention to these known qualities for older adult technology adoption has implications for the development and delivery of ethical research. It means that participants' time may be wasted – not least among potentially more vulnerable participant populations of elders. Taking into account needs or preferences of a particular demographic is standard practice to inform design. That there is both a rich literature to draw on around older adult technology adoption and around barriers to fitness uptake, and that this work is largely absent from work around elder technology adoption for fitness has implications for appropriate use of research funding, when known affordances and constraints are ignored.

A straight-forward take-away from this review is that more explicit inclusion of elder specific factors in design and assessment is worth testing to evaluate how these established factors' integration can support the development of more inclusive and impactful elder fitness technologies. By integrating the elder specific factors summarised in the Elder Fitness Technology Translation Assessment into design and assessment methodologies, we hypothesise we will be much better able to assess the efficacy of the interventions in practice. Furthermore, we hypothesize that it

can help bridge the gap between technological capability and real-world applicability, ultimately fostering greater adoption, respect for participants and long-term success in supporting older adults' health and well-being.

Conclusion

Overall, this review contributes the following:

1. An analysis of how work on the common strategies of elder fitness technology interventions and what the strengths and weaknesses are in the field.
2. A synthesis of the needs and preferences of elders from elder specific technology acceptance research, barriers and enablers to elder physical activity, and qualitative data from elder fitness technology called the Elder Fitness Technology Assessment Tool.
3. An evaluation of the state of current research in comparison to the known needs and preferences of elders using the Elder Fitness Tech Assessment tool.

This scoping review aimed to interrogate the lack of compelling results across a range of reviews looking at the efficacy of innovative technologies designed to improve factors affecting older adult fitness, like strength and balance. Our approach has been to consider factors we can characterize across these papers: methods for design of an intervention; evaluation approach; use of design literature specifically related to development of interactive technology for older adults.

We also proposed a novel rubric to assess across the six elder specific criteria how well the design of the presented elder fitness technology systems align with the known needs and preferences of elders in engaging with fitness and interactive technologies. Our goal has been to create a mechanism that enables very different technologies and approaches to still be compared against critical, meaningful criteria. This analysis does show an overall low consideration of any of our six elder-sensitive criteria. This finding suggests if not causation, then a likely strong correlation between the types of middling effects captured in the existing review articles and a systemic lack of attention to elder-sensitive design and evaluation criteria. Considering the topic area is to support elder adoption - via technology - of sustainable fitness practices, this lack of attention to well established elder tech dynamics is surprising. In general, the results of this review suggest that there is significant opportunity for improving and re-visiting how to best utilize the potential of these technologies to impact elders' daily lives and wellbeing in a positive way by starting the design process with the known preferences and constraints of elders and adjusting our assessment processes to explicitly consider elder specific factors beyond usefulness and usability.

A limitation for our analysis is the lack of detailed information on the elder interaction with the technologies and the lack of outcome metrics that directly related to the factors included in the Elder Fitness Technology Assessment tool. Thus, reviewers needed to use their best judgement from

the information provided in the published research articles. Future work is needed to validate the Elder Fitness Technology Assessment tool for new fitness technology designs. It is our hypothesis that more explicit consideration of the work done on elder technology adoption, technology preferences, and physical activity intervention preferences could help the field increase the daily life impact of research in the field.

We hypothesize that the use of the Elder Fitness Technology Assessment tool would significantly help address the issues that motivated this review. Future work is necessary to inform the best practices for incorporating elder specific criteria into our designs and evaluations in the field.

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Abbreviations

ACM: Association for Computing Machinery

EPSRC: Engineering and Physical Sciences Research Council

HCI: Human Computer Interaction

ICT: Information and Communication Technology

IEEE: Institute of Electrical and Electronics Engineers

JMIR: Journal of Medical Internet Research

MS: Microsoft

PRISMA-ScR: Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for Scoping Reviews

UKRI: United Kingdom Research and Innovation

UTAUT2: Unified Theory of Acceptance and Use of Technology extension

Appendix

Figures 11 and 12

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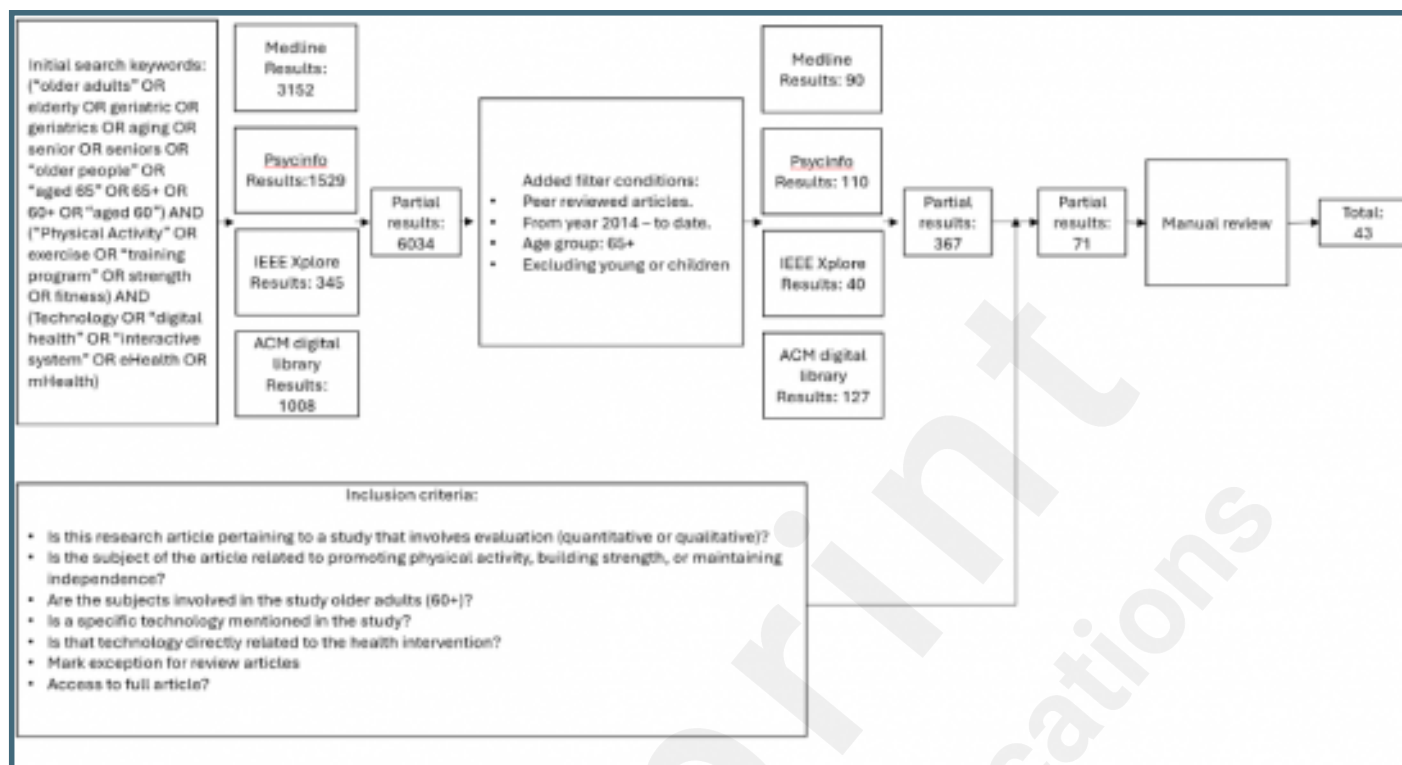
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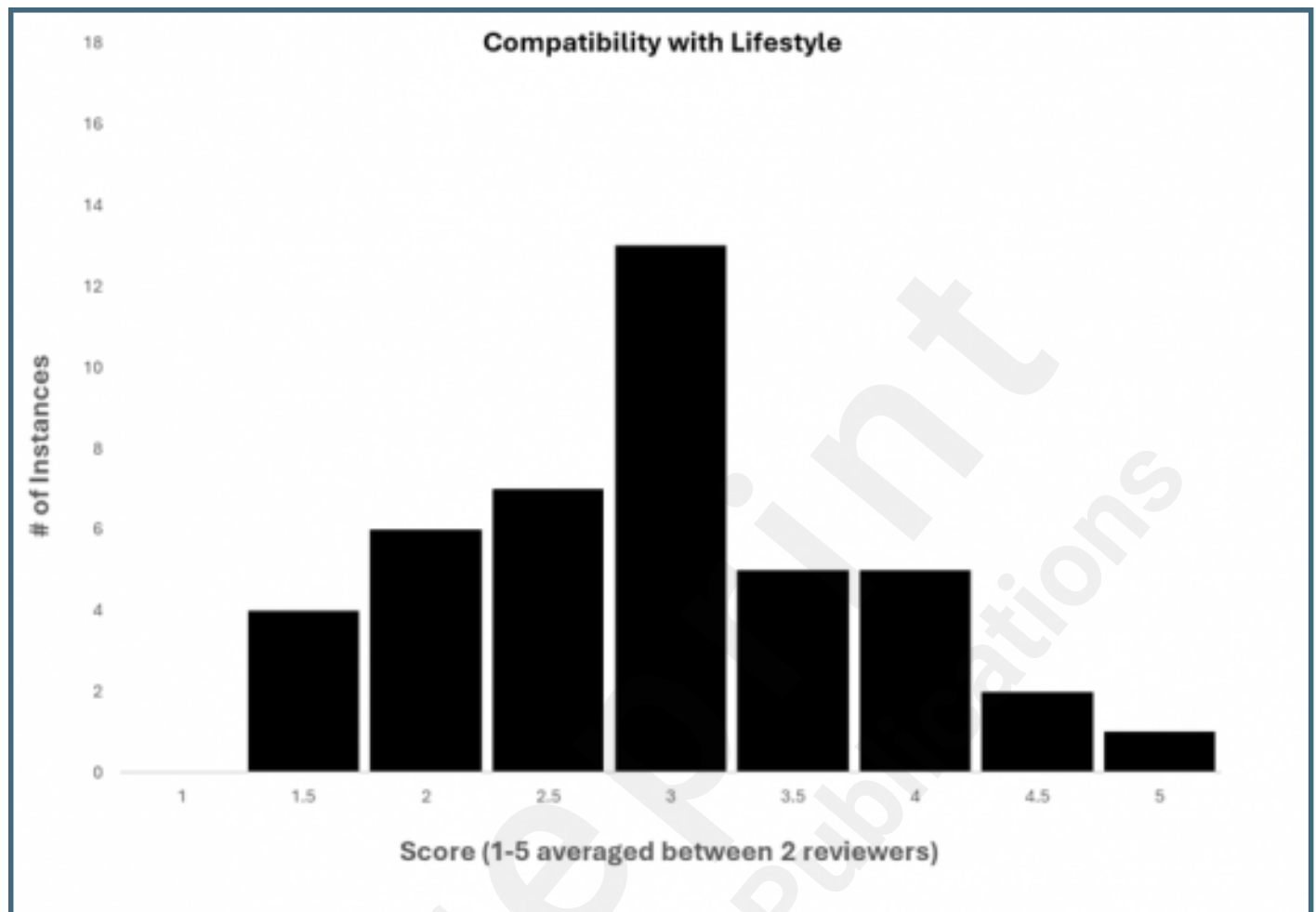
Supplementary Files

Figures

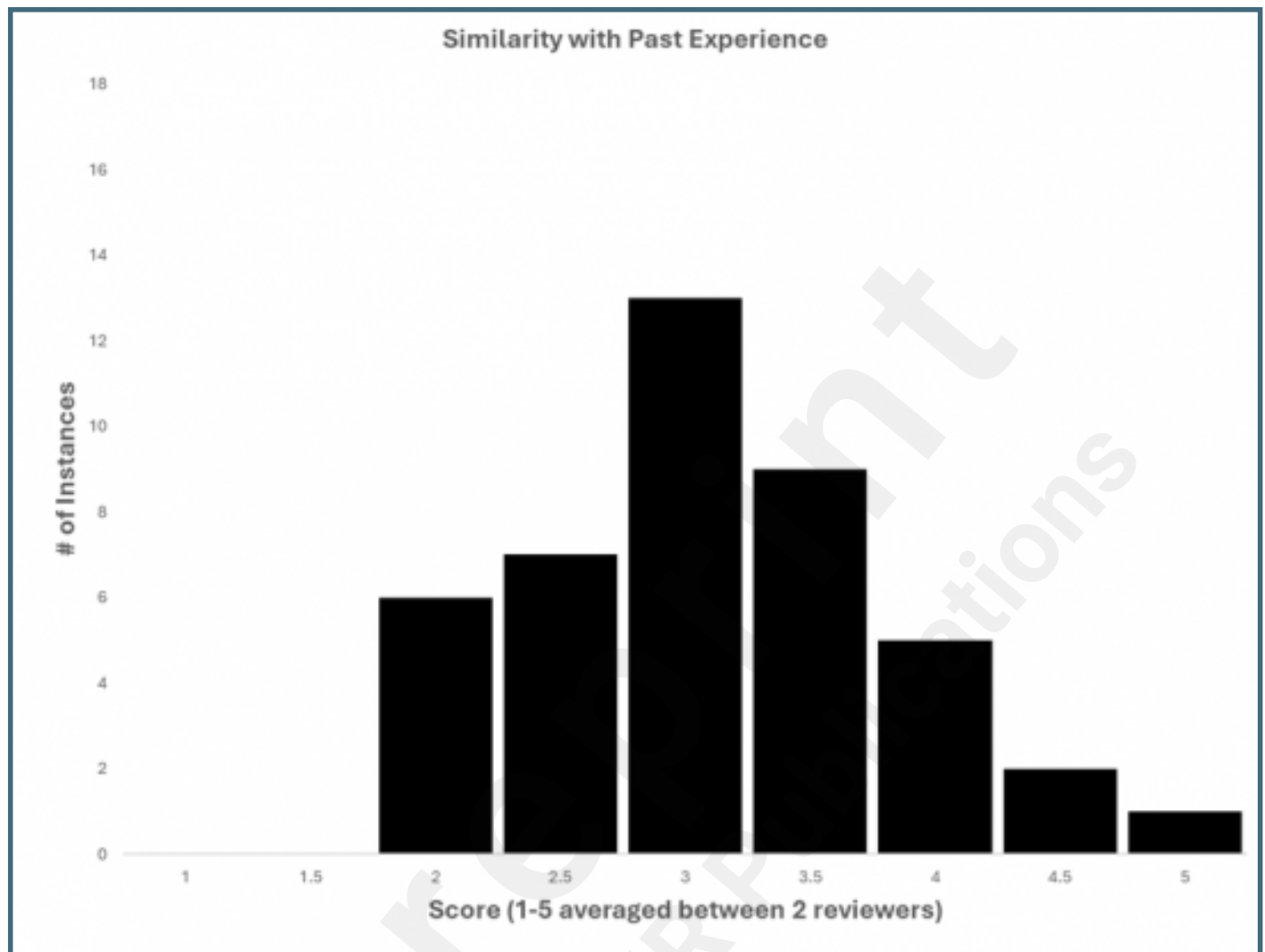
Flowchart of the article selection process in the review.



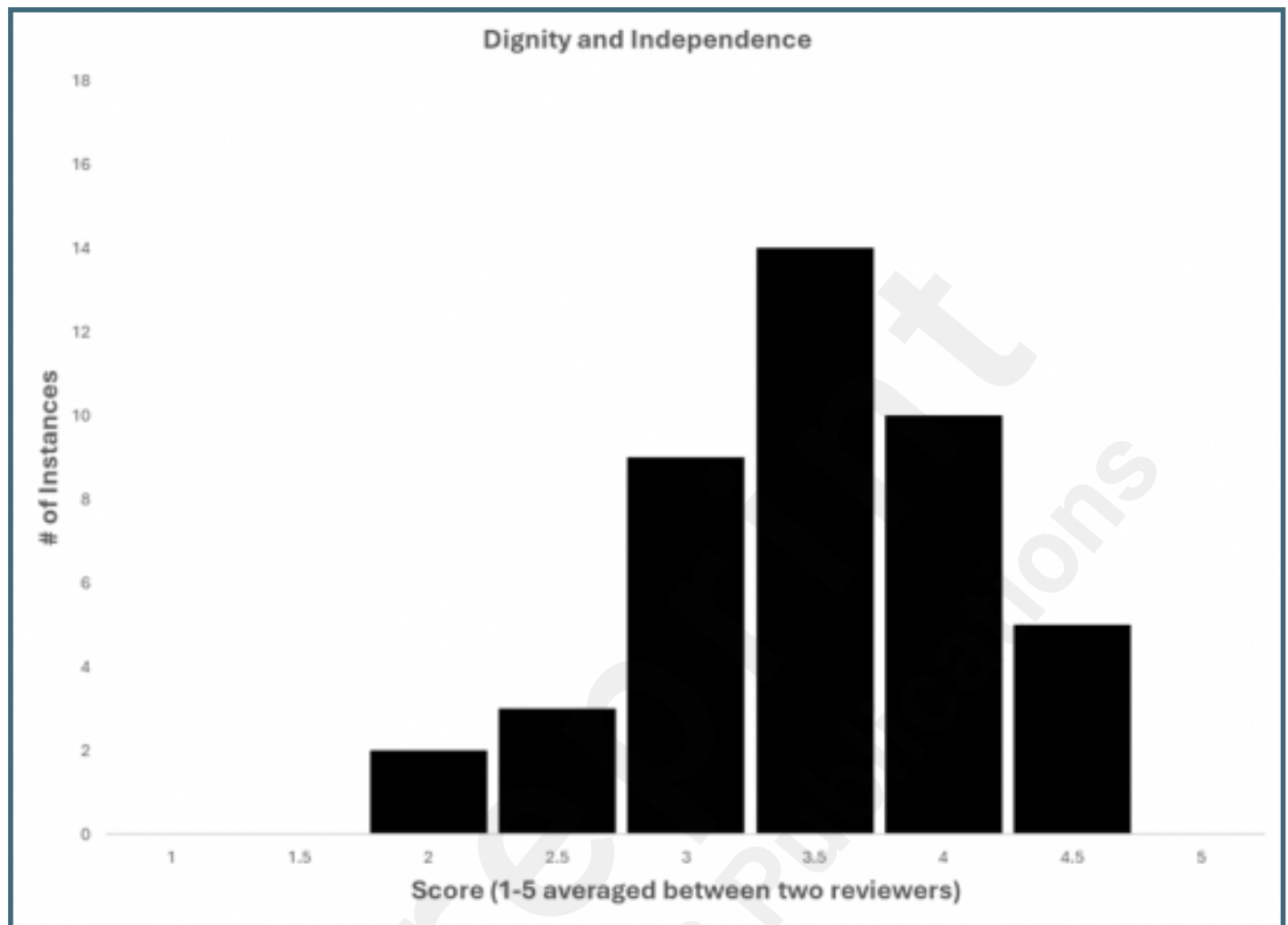
The distribution of compatibility with lifestyle scores for the 43 reviewed health interventions.



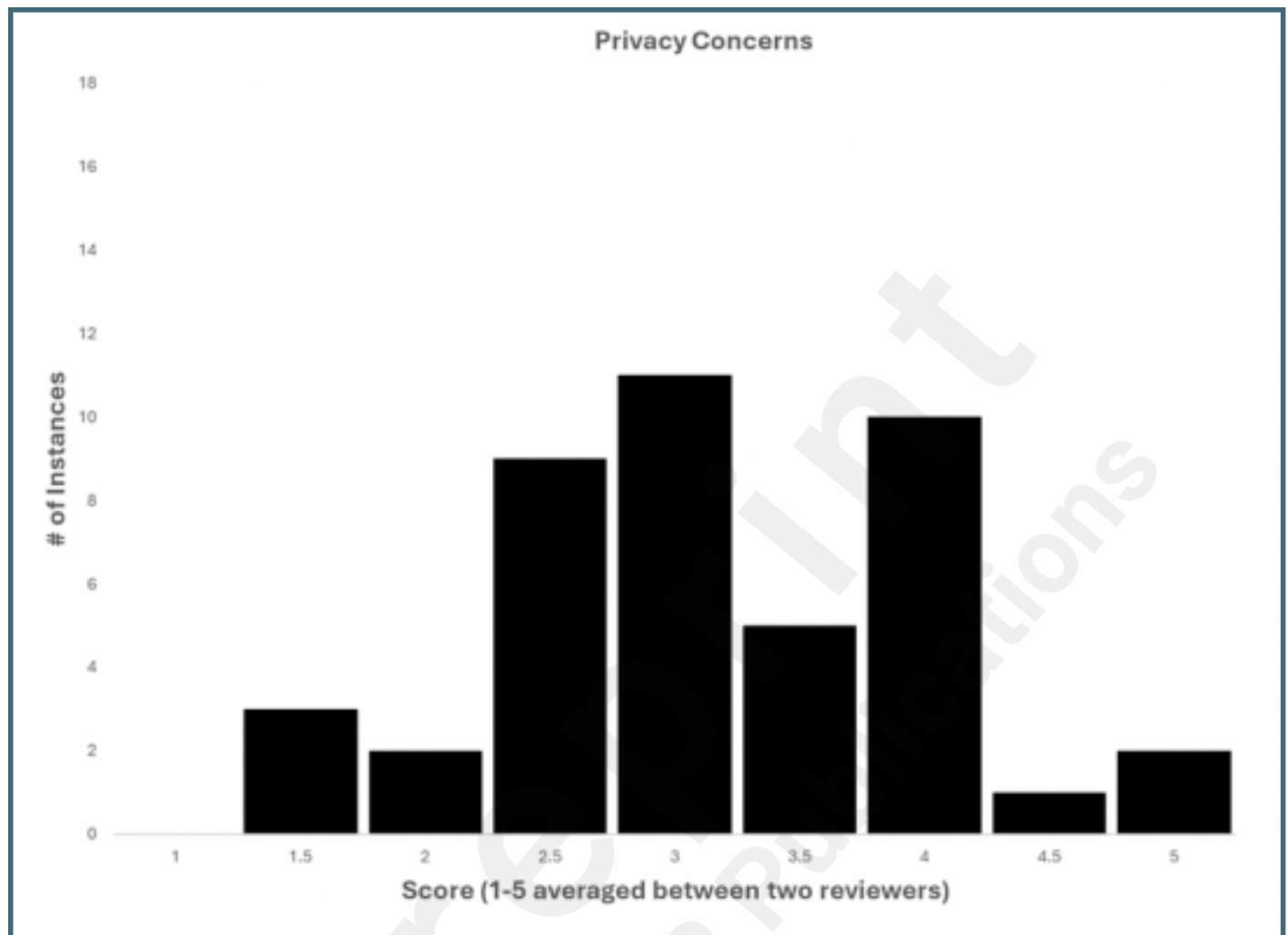
The distribution of similarity with past experience scores for the 43 reviewed health interventions.



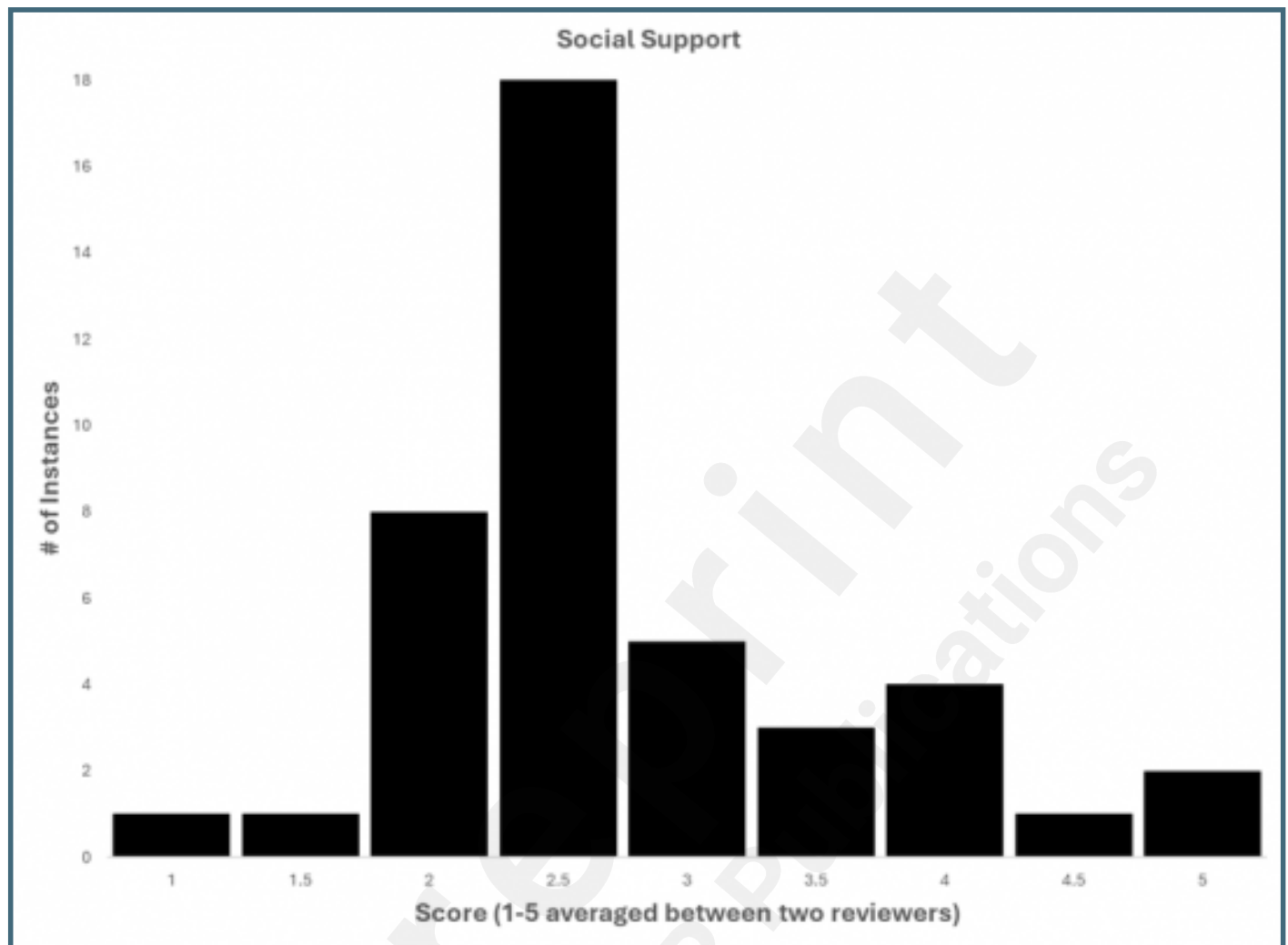
The distribution of dignity and independence scores for the 43 reviewed health interventions.



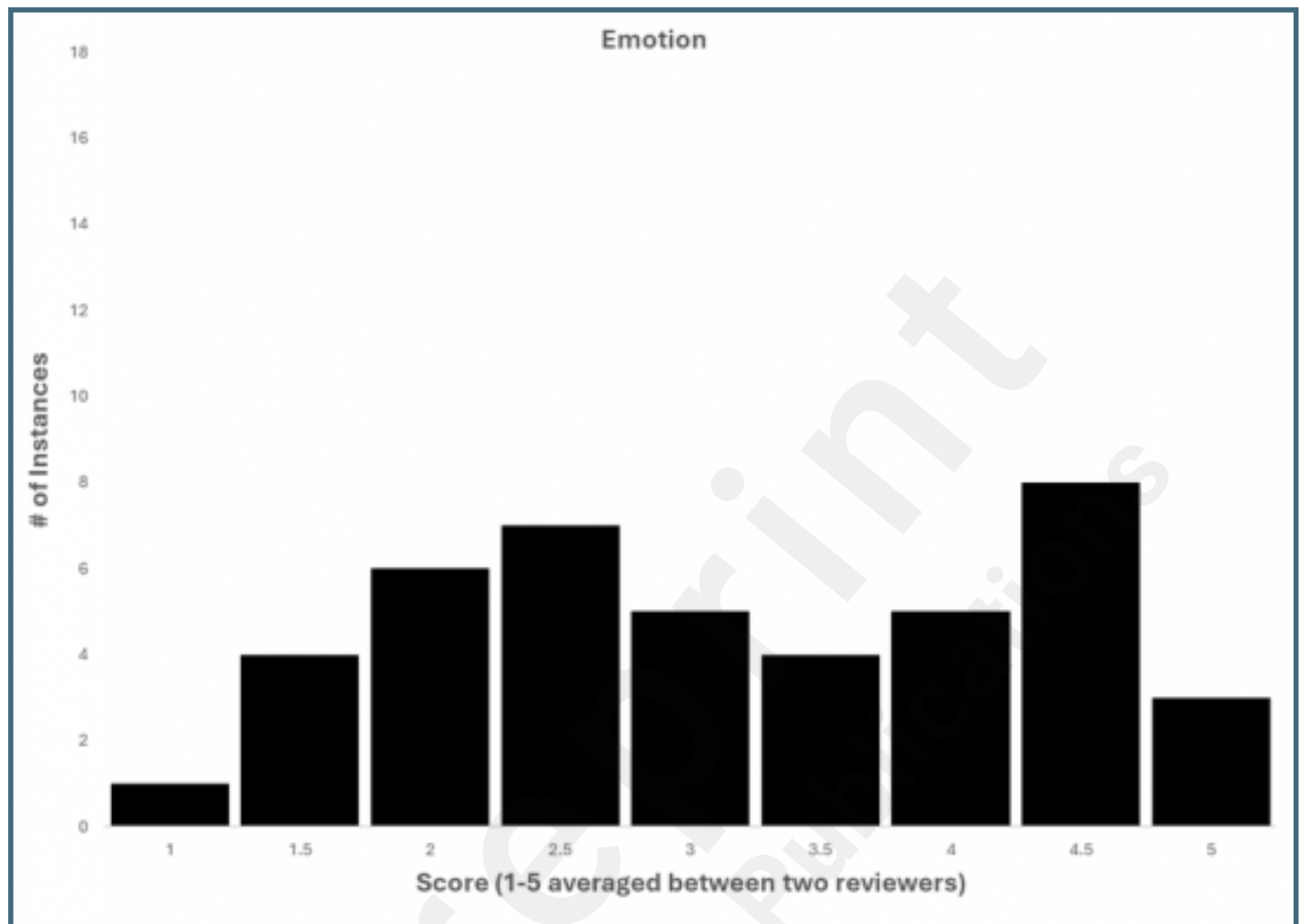
The distribution of privacy concerns scores for the 43 reviewed health interventions.



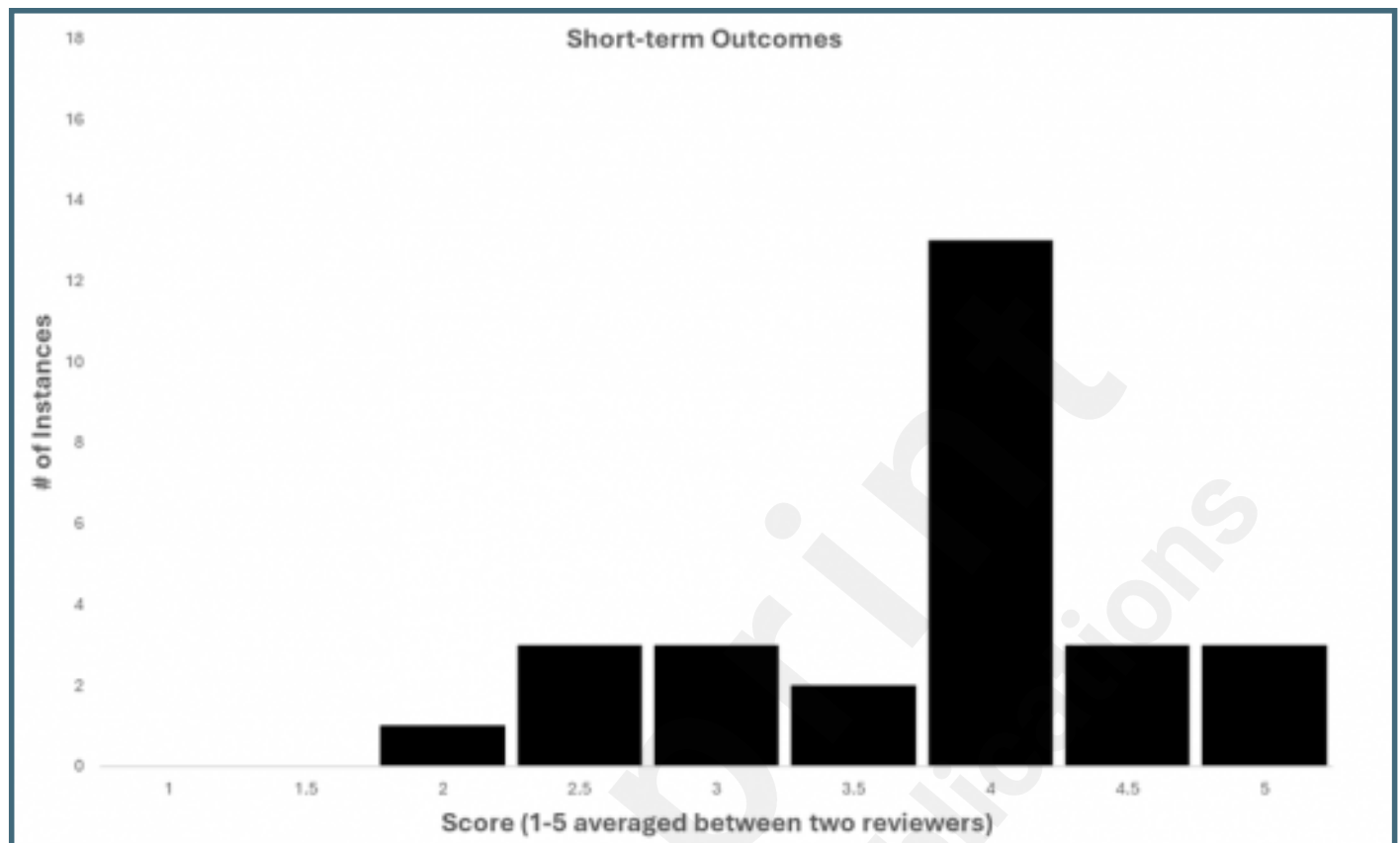
The distribution of social support scores for the 43 reviewed health interventions.



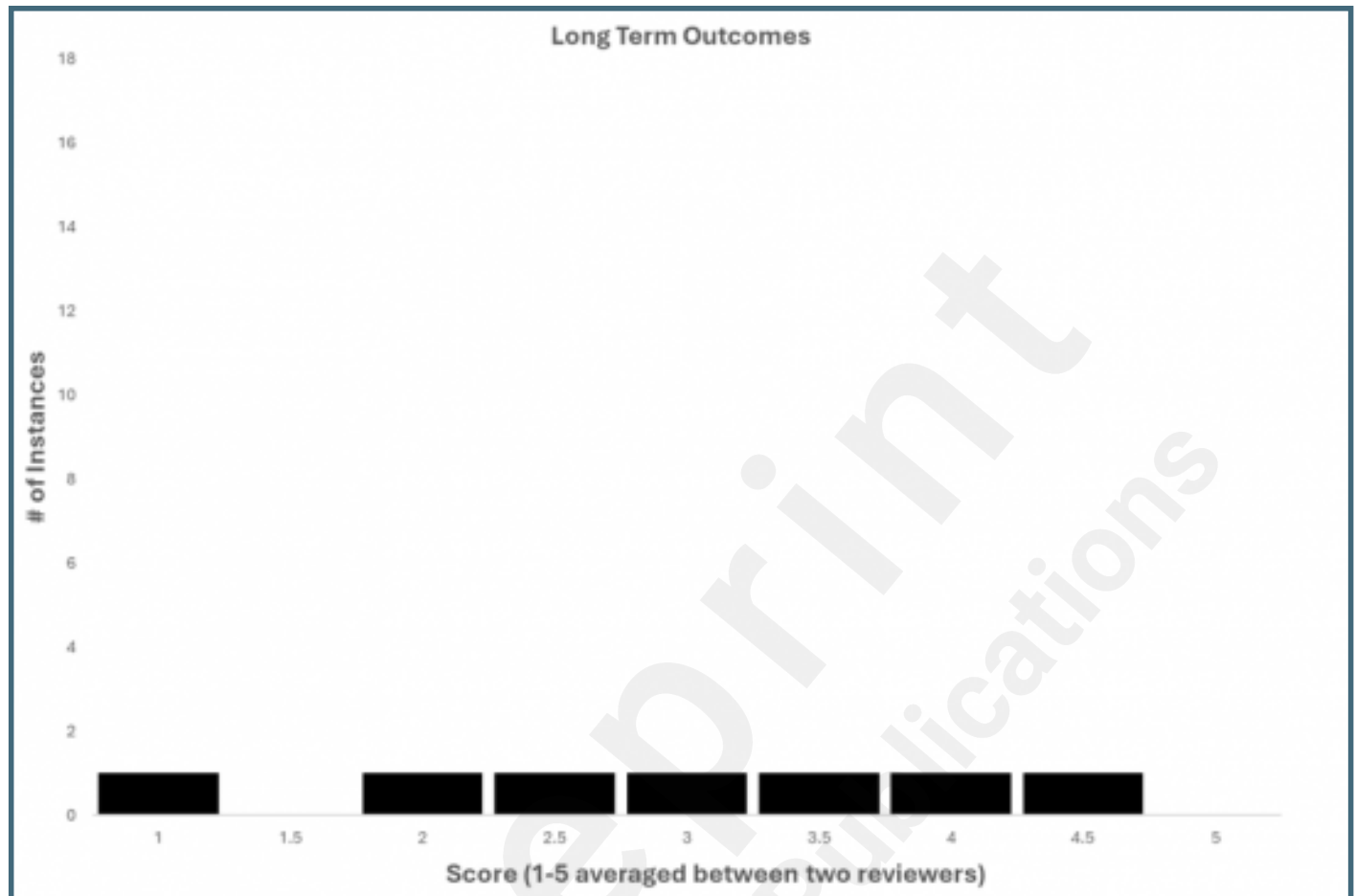
The distribution of emotion scores for the 43 reviewed health interventions.



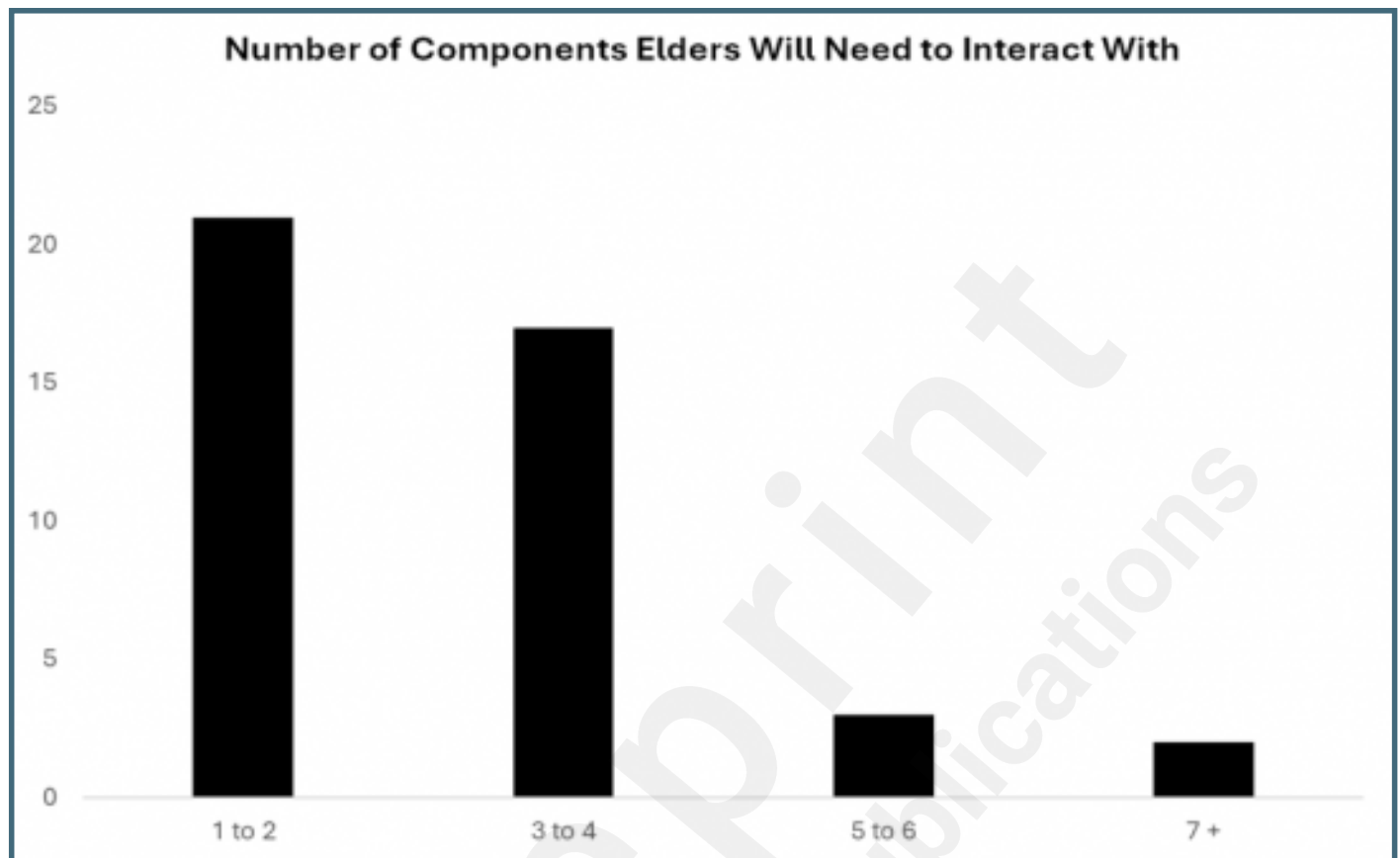
The distribution of short term outcome scores for the 43 selected interventions.



The distribution of long term outcome scores for the 43 selected interventions. Only 7 interventions collected any long term outcomes.



The number of components required for elders to interact with to utilise the fitness technology intervention.



The detailed rubric used by reviewers to assess the 43 papers included in this review across the following eight factors: 1. Compatibility with Lifestyle, 2. Similarity with Past Experience, 3. Dignity and Independence, 4. Privacy Concerns, 5. Short Term Outcomes, 6. Long Term Outcomes, 7. Social Support, and 8. Emotion.

	5	4	3	2	1
Compatibility with Lifestyle	Health technology fits seamlessly with lifestyle patterns and values, integrates well with daily life, and does not require deliberate actions or actions incongruous with their values for its effective use.	Health technology fits well with lifestyle patterns and values, takes into consideration how it would integrate into user's daily life, and requires only low barrier to entry deliberate actions and no actions incongruous with values for its effective use.	Health technology fits moderately with lifestyle patterns and values, integrates with daily life to some extent, and requires some deliberate actions but minimal actions that might be incongruous with values for its effective use.	Health technology fits poorly with lifestyle patterns and values, integrates with daily life in a limited way, and requires frequent deliberate actions or some actions that might be incongruous with values for its effective use.	Health technology does not fit with lifestyle patterns and values, does not integrate well with user's daily life, and requires high barrier to entry deliberate actions or actions that are incongruous with user values for its effective use.
Similarity to Past Experience	Health technology is aligned with users' past experiences with technology. The interaction is intuitive or requires actions that are both directly similar and easily recognizable to something else commonly experienced by the target population.	Health technology is mostly aligned with past experiences of the user, requiring only a small learning curve. The interaction is somewhat intuitive and involves actions that are somewhat similar and recognizable to the target population.	Health technology is moderately aligned with past experiences of the user. The interaction has a moderate learning curve and requires actions that may not be immediately familiar but are not entirely foreign to the target population.	Health technology is poorly aligned with past experiences of the user. The interaction has a steep learning curve and requires actions that are not very similar or recognizable to the target population.	Health technology is not aligned with past experiences of the user. The interaction is not intuitive, requiring actions that are unfamiliar and not easily recognizable to the target population.
Dignity and Independence	The health technology promotes autonomy and independence for its users, allows them to customize their experience for their own specific goals, and avoids features, functions, and verbiage that stigmatize its users.	The health technology promotes autonomy and independence for its users, provides customization options for specific goals, and mostly avoids features, functions, and verbiage that stigmatize its users.	The health technology may promote autonomy and independence for its users, offer some customization options for specific goals, but may also include some features, functions, or verbiage that could potentially stigmatize its users.	The health technology promotes limited autonomy and independence for its users, offers few customization options for specific goals, and includes features, functions, or verbiage that might stigmatize its users.	The health technology does not promote autonomy and independence for its users, lacks customization options for specific goals, and contains features, functions, or verbiage that stigmatize its users.
Privacy Concerns (when weighing between amount of data, control is more important)	The health technology only collects data necessary for users to achieve their specific goals, allows them control over what data is collected and how, and has systems in place to ensure collected data is secure.	The health technology primarily collects data necessary for users to achieve their specific goals, provides the user control over what data is collected and how, and has systems in place to ensure collected data is secure.	The health technology collects data that is relevant to users' specific goals but does collect some data that users may find extraneous, offers some control over what data is collected and how, and has systems in place to ensure collected data is secure.	The health technology collects data that is not necessary for users to achieve their specific goals, does give users control over their data, but does have systems in place to ensure collected data is secure.	The health technology collects excessive or irrelevant data for users' specific goals, does not give users control over their data, and lacks adequate systems to ensure collected data is secure.
Short Term Outcomes (Please only Consider health outcomes (HR, BP, etc.) or Behaviour Change outcomes (steps, mins exercised, etc.))	Outcomes at the conclusion of the intervention are significantly positive. A significant change in either a clinical health outcome or positive health behaviour change is observed.	Outcomes at the conclusion of the intervention are mostly positive. Not all outcomes are positive but a significant change in either a clinical health outcome or positive health behaviour change is observed.	Outcomes at the conclusion of the intervention are mixed. For some outcomes a significant change (behavioural or clinical) is observed but for others no significant change is found.	Outcomes at the conclusion of the intervention are mostly insignificant. Only minor improvements or significant changes are observed.	Outcomes at the conclusion of the intervention are either insignificant or negative. No significant changes are observed.
Long Term Outcomes (Please only Consider health outcomes (HR, BP, etc.) or Behaviour Change outcomes (steps, mins exercised, etc.))	Most users achieve and maintain their health goals, positive behaviour change is observed even after the intervention is over, and technology is no longer required for positive change to continue. For rehabilitation applications, users fully recover from health condition.	Most users achieve and maintain their health goals, some positive behaviour change is observed even after the intervention is over, technology may be required for positive change to continue, but is not always necessary. For rehabilitation applications, most users fully recover from health condition.	Some users achieve and maintain their health goals, for some positive behaviour change is observed even after the intervention is over, and technology is typically required in some capacity for positive change to continue. For rehabilitation applications, some users fully recover from health condition.	Only a few users are able to achieve and maintain their health goals, most positive behaviour change is no longer observed once the intervention is over, and technology is required for positive change to continue. For rehabilitation applications, only a few users fully recover from health condition.	Users are unable to achieve and maintain their health goals, positive behaviour change is not observed once intervention is over, and technology is required for the change to continue. For rehabilitation applications, no users fully recover from health condition.
Social Support	The user interaction promotes social connection at the user's discretion and either enhances or does not interfere with users' existing social structures.	The user interaction promotes some social connection at the user's discretion and does not interfere with users' existing social structures.	The user interaction may include some promotion of social connections or at least allows users to use system socially if they prefer.	The user interaction does not promote social connection, but does not interfere with users' existing social structures and plans.	The user interaction does not promote social connection and in fact participating in this intervention actively conflicts with users' existing social structures and plans.
Emotion	Most users enjoy using the technology or report having a positive experience while using it. Care is taken in the design to make the experience fun, meaningful, or emotionally stimulating for users.	Most users enjoy using the technology or report having a positive experience while using it than not. Many parts of the design are aimed at making the experience fun, meaningful, or emotionally stimulating for users.	Users report having a mixed experience while using it. At least some part of the design is aimed at making the experience fun, meaningful, or emotionally stimulating for users.	Most users do not enjoy using the technology or report having a negative experience while using it than do. Little care is taken in the design to make the experience fun, meaningful, or emotionally stimulating for users.	Users do not enjoy using the technology and report having a negative experience while using it. No care is taken in the design to make the experience fun, meaningful, or emotionally stimulating for users.

Preferred reporting items for Systematic reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR) checklist.

Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR) Checklist

SECTION	ITEM	PRISMA-ScR CHECKLIST ITEM	REPORTED ON PAGE #
TITLE	1	Identify the report as a scoping review.	1
ABSTRACT			
Structured summary	2	Provide a structured summary that includes (as applicable) background, objectives, eligibility criteria, sources of evidence, searching methods, results, and conclusions that relate to the review questions and objectives.	10-10
INTRODUCTION			
Rationale	3	Describe the rationale for the review in the context of what is already known. Explain why the review questions/objectives lend themselves to a scoping review approach.	1-3
Objectives	4	Provide an explicit statement of the questions and objectives being addressed with reference to their key elements (e.g., population or participants, concepts, and context) or other relevant key elements used to conceptualize the review questions and/or objectives.	9-10
METHODS			
Protocol and registration	5	Indicate whether a review protocol exists, state if and where it can be accessed (e.g., a Web address), and if available, provide registration information, including the registration number.	10
Eligibility criteria	6	Specify characteristics of the sources of evidence used as eligibility criteria (e.g., years considered, language, and publication status), and provide a rationale.	10
Information sources*	7	Describe all information sources in the search (e.g., databases with dates of coverage and contact with authors to identify additional sources); as well as the date the most recent search was executed.	10
Search	8	Present the full electronic search strategy for at least 1 database, including any limits used, such that it could be repeated.	10
Selection of sources of evidence†	9	State the process for selecting sources of evidence (i.e., screening and eligibility) included in the scoping review.	11
Data charting process‡	10	Describe the methods of charting data from the included sources of evidence (e.g., calibrated forms or forms that have been tested by the team before their use, and whether data charting was done independently or in duplicate) and any processes for obtaining and confirming data from investigators.	17-18
Data items	11	List and define all variables for which data were sought and any assumptions and simplifications made.	17-18
Critical appraisal of individual sources of evidence§	12	If done, provide a rationale for conducting a critical appraisal of included sources of evidence; describe the methods used and how this information was used in any data synthesis (if appropriate).	N/A
Synthesis of results	13	Describe the methods of handling and summarizing the data that were charted.	17-18
RESULTS			
Selection of sources of evidence	14	Give numbers of sources of evidence screened, assessed for eligibility, and included in the review, with reasons for exclusions at each stage, ideally using a flow diagram.	11
Characteristics of sources of evidence	15	For each source of evidence, present characteristics for which data were charted and provide the citations.	19
Critical appraisal within sources of evidence	16	If done, present data on critical appraisal of included sources of evidence (see item 12).	N/A
Results of individual sources of evidence	17	For each included source of evidence, present the relevant data that were charted that relate to the review questions and objectives.	20-21
Synthesis of results	18	Summarize and/or present the charting results as they relate to the review questions and objectives.	20-24
DISCUSSION			
Summary of evidence	19	Summarize the main results (including an overview of concepts, themes, and types of evidence available); link to the review questions and objectives, and consider the relevance to key groups.	20
Limitations	20	Discuss the limitations of the scoping review process.	37-38
Conclusions	21	Provide a general interpretation of the results with respect to the review questions and objectives, as well as potential implications and/or next steps.	37-38
FUNDING			
Funding	22	Describe sources of funding for the included sources of evidence, as well as sources of funding for the scoping review. Describe the role of the funders of the scoping review.	39

JBI = Joanna Briggs Institute; PRISMA-ScR = Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for Scoping Reviews.
 * Other sources of evidence (see second footnote) are compiled from, such as bibliographic databases, social media platforms, and Web sites.
 † A more inclusive/heterogeneous term used to account for the different types of evidence or data sources (e.g., quantitative and/or qualitative research, expert opinion, and policy documents) that may be eligible in a scoping review as opposed to only studies. This is not to be confused with information sources (see first footnote).
 ‡ The frameworks by Arksey and O'Malley (6) and Levac and colleagues (7) and the JBI guidance (8, 9) refer to the process of data extraction in a scoping review as data charting.
 § The process of systematically examining research evidence to assess its validity, results, and relevance before using it to inform a decision. This term is used for items 12 and 16 instead of "risk of bias" (which is more appropriate to systematic reviews of interventions) to include and acknowledge the various sources of evidence that may be used in a scoping review (e.g., quantitative and/or qualitative research, expert opinion, and policy document).

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