Understanding The Experiences Of Older Adults While Using Interactive Surfaces To Encourage Activity Participation

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UNDERSTANDING THE EXPERIENCES OF OLDER ADULTS WHILE USING INTERACTIVE SURFACES TO ENCOURAGE ACTIVITY PARTICIPATION

A dissertation submitted in fulfilment of the requirements for the degree of Doctor of Philosophy

by

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The playing adult steps sideward into another reality.

- *Erik Erikson*

Play is not a luxury. Play is a necessity.

- *Kay Redfield Jamison*

Declaration

This thesis contains no material that has been extracted in whole or in part from a thesis that I have submitted towards the award of any other degree or diploma in any other tertiary institution. No other person's work has been used without due acknowledgment in the main text of the thesis. All research procedures reported in the thesis received the approval of the relevant Ethics/Safety Committees (where required).

Joyce Lim Kianying 10 March 2025

Acknowledgements and Dedication

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Abstract

With mixed reality (MR) technologies becoming a popular tool in the promotion of healthy ageing, there is a need to know more about the facilitators and barriers to using these technologies in older participants. Participation is an important component of healthy ageing, where staying physically and cognitively active through meaningful activities offers benefits like reducing obesity, lowering risk of cardiovascular disease, maintaining cognitive health and enhancing emotional well-being, ultimately leading to a better quality of life. Despite the importance of staying active, many older adults fail to meet recommended activity levels, raising concerns about the long-term implications on their independence and quality of life. Most of the current research on MR technology use among older adults has concentrated on its application in clinical settings and has mainly investigated the effectiveness of MR-based applications on health outcomes instead of focusing on user experience. There remains a need for more research that aim to understand the perspective of older adult users to ascertain the feasibility and user experience with MR-based applications for these individuals. To fill this research gap, a systematic review was conducted to understand the UX aspect of older adults' use of MR applications. Two studies were then conducted to understand the different aspects of UX of older adults using MR applications, using a MR-based digital interactive experience known as the EDNA Playboards.

To explore the factors influencing older adults' participation in activities, this thesis first utilised the Family of Participation-Related Constructs (fPRC) model, discussed in Chapter 1,

which highlighted that participation in an activity is not just about being present (i.e., attendance), but also requires the attendee's involvement. This leads to the importance of assessing internal and external factors that may be barriers and facilitators to engaging in activities during older adulthood. In relation to MR applications, understanding the older adults' user experience (UX) helps address any barriers that may impede older adults' participation, attendance and involvement in engaging in such technology facilitated activities, while also supporting facilitators in running these activities effectively. The Components of User Experience (CUE), detailed in Chapter 2, offers a structured method for assessing the usability (instrumental qualities), emotion reactions, and aesthetics (non-instrumental qualities) of MR applications, components that form a comprehensive view of UX that goes beyond usability.

The systematic review (Chapter 4), which aimed to comprehend the existing research results regarding the user experience (UX) of MR applications for older adults, analysed recent experimental research on the instrumental, emotional, and non-instrumental facets of user experience among healthy older adults concerning MR applications. The review analysed studies from January 2010 to July 2021 and identified 15 eligible studies, all of which were found to assess instrumental quality, with most also examining emotional responses of the older adult participants. However, only six explored the aesthetic qualities of the MR applications. All studies aimed to improve health domains, such as cognitive or physical training. Overall, the systematic review highlighted that the instrumental quality of MR applications was the focus within user experience research, with substantially fewer studies addressing the non-instrumental aspects.

To address some of the gaps identified in the systematic review, two empirical studies were conducted to investigate the experiences of older adults using a surface computing based digital interactive system. The first of these studies was carried out with a group of older adults living in a retirement village (Chapter 6), while the second involved people living in an aged care facility (Chapter 7). The EDNA Playboards system was designed to foster physical and social engagement as well as cognitive stimulation. The studies focused on the participants' engagement and UX with the digital interactive system, and utilised a mixed-methods research design where participants completed a questionnaire after their involvement in a semi-structured interview.

Empirical Study 1 (Chapter 6) involved eleven residents (mean age ± standard deviation: 78 ± 7.94 years; six males and five females) from a retirement village in Australia. Both quantitative and qualitative results indicated an overall positive experience with the EDNA Playboards system. Participants noted social and cognitive benefits from their interaction with the system. They emphasised their preference for clear objectives, suitable levels of challenge, additional time for familiarisation, and recognisable audiovisual effects instead of digital ones. These findings offer important insights for game designers creating interactive systems that cater to older adults.

Empirical Study 2 (Chapter 7), involved ten residents (mean age ± standard deviation: 86.6 ± 4.7 years; four males and six females) from an aged care facility in Australia. Participants engaged with EDNA Playboards in one-hour sessions, playing in groups of three or four. While also designed as a mixed method research, this study did not include quantitative analysis as the participants did not return the questionnaires post-game session. Nevertheless, the qualitative analysis suggested an overall favourable UX, with participants appreciating the cognitive challenge and the opportunity for social interaction. They indicated a desire for straightforward instructions, a slow introduction process to prevent any feelings of being overwhelmed, and clearly defined gameplay goals. Although they found the visual components to be a unique and welcomed part of the interactive experience, the audio elements were perceived as confusing. These insights were valuable for creating MR interactive experiences specifically designed for older adults.

As exploratory studies into the use of EDNA Playboards, the findings of this thesis were limited by the small sample size, single-site recruitment, and a single MR session, restricting generalisability. However, the results and discussion offer valuable preliminary insights into the feasibility of MR systems like EDNA Playboards in retirement villages and aged care settings and identify potential modifications to enhance older adults' experiences prior to larger scale studies and broader implementation.

Chapter 1 Activity and participation in older adults

Healthy ageing, as it relates to the latter years, is characterised by staying physically and mentally active through activities that older adults find meaningful (Guell et al., 2016). These activities include exercising, completing daily tasks, volunteering, and socialising with friends and the wider community. Staying active is an essential part of healthy ageing and offers numerous benefits, such as reducing obesity and lowering the risk of cardiovascular disease and premature death. Physical activity also helps with the maintenance of functional ability and cognitive health, improved mood, and fewer days spent feeling physically or mentally unwell. Collectively, these benefits lead to a better quality of life (Kell & Rula, 2019; Penedo & Dahn, 2005). Despite the benefits of staying active, nearly a third of the global adult population are insufficiently active to maintain good health (approximately 1.8 billion adults), with those classified as being physically inactive failing to meet the current World Health Organization (WHO) recommendation of participating in 150 minutes of moderate-intensity physical activity per week (Strain et al., 2024). This situation appears to be worsening with an increasing trend of physical inactivity globally (Strain et al., 2024). In the span of ten years, the age-standardised proportion of the global population who were classified as being insufficiently physically active increased from 26.4% in 2010 to 31.3% in 2022 (Strain et al., 2024). In older adult populations specifically, regardless of geographical region and gender, the proportion of people who were considered physically inactive was shown to increase after the age of 60 (Strain et al., 2024).

1.1 Physical inactivity in Australian older adults

Specifically looking at recent Australian statistics, both physical activity levels and participation in muscle-strengthening activities were tracked by the Australian Institute of Health and Welfare (AIHW), with the following data taken from the 2022 National Health Survey (Australian Institute of Health and Welfare, 2024c). The AIHW's definition of insufficient physical activity refers to not engaging in at least 30 minutes of physical activity on five or more days a week; similar to the guidelines provided by the WHO but with more specificity on the number of days. The AIHW also recommends at least two days of muscle-strengthening activity per week as part of physical activity, with no specific recommendation offered for the time spent on these muscle-strengthening exercises per session. Muscle strengthening activities include yoga, Pilates, resistance-band training, high intensity activities (e.g., cycling, jogging), climbing stairs or hills, squats, push-ups, sit-ups, and weight training. Their data indicated that many adults aged 65 and older were insufficiently active and missing the benefits of staying active in the later years. Specifically:

i) 89% of older adults did not meet the recommended amount of physical activity (5+ days of 30-minute physical activity per week), nor the muscle-strengthening activity guidelines (2+ days of muscle-strengthening exercise per week).

ii) Focusing on the guideline for physical activity (i.e. 5+ days of 30-minute physical activity per week), 57% of older adults did not meet the guidelines, of whom two-fifths (39%) were entirely inactive, having engaged in no physical activity in the previous week.

iii) Focusing on muscle-strengthening activities, 84% did not meet the guidelines, of whom 95% engaged in zero days of muscle-strengthening activity in the previous week.

Inactivity in older adults is not limited to the Australian population, as globally, physical activity guidelines for older adults are rarely met (Izquierdo et al., 2021). These findings indicate that more steps need to be taken to support older adults in meeting physical activity targets during the latter years of life. Designing healthy ageing strategies that target inactivity will require a better understanding of the factors that influence and potentially limit participation in activities within older adult cohorts.

1.2 The fPRC as a theoretical model for factors influencing activity and participation

Participation is briefly defined by the WHO's International Classification of Functioning, Disability, and Health (ICF) as "involvement in a life situation" (World Health Organization, 2007). These activities can be inside or outside the home environment, or in the wider community (Coussens et al., 2021), and are across different domains of life, such as learning, general tasks, communication, mobility, self-care, interpersonal interactions and relationships, and community, social and day-to-day life (World Health Organization, 2007). The Family of Participation-Related Constructs (fPRC), proposed by Imms et al. (2017), expands on this definition and provides a structured and comprehensive framework to understand the processes underlying participation. By viewing participation through the fPRC framework, it is possible to increase conceptual clarity and aid in the measurement of participation in research and practice (Imms et al., 2016; Imms et al., 2017).

Specifically, the fPRC considers participation to consist of two elements: i) attendance; and ii) involvement. Both elements can influence and be influenced by person-focused intrinsic processes and environmentally-focused extrinsic factors. *Attendance* refers to the objective aspect of being physically present in the activities in which an individual engages (Imms et al., 2017). It can be measured by how often activities are attended and the variety of activities that are participated in (Imms et al., 2017). *Involvement* refers to the subjective experience of engaging in activities, including emotions, motivation, engagement, persistence and social interactions (Imms et al., 2017).

Both attendance and involvement are shaped by individual and environmental elements. Individual factors consist of: i) *activity competence,* which is the ability to perform an activity to an expected level of proficiency; ii) *sense of self*, which is a concept that includes intrapersonal factors, such as an individual's confidence, satisfaction, and self-esteem; and iii) *preferences*, which are the personal interests of the individual (Adair et al., 2018; Imms et al., 2017). Environmental factors refer to the context and setting in terms of: i) *availability*, which is the provision of activities or services; ii) *accessibility*, the ability to access the activity; iii) *affordability*, the financial, time, energy, and other resource limitations that can affect attendance; iv) *accommodability*, which is the extent to which an activity can be adapted or modified to fit the needs of the individual; and e) *acceptability*, reflecting the person's acceptance of the situation, as well as others' perceptions of the individual within that context.

To gain a comprehensive understanding of the various factors that influence an individual's participation in activities, it should be recognised that simply attending an event does not equate to full engagement or involvement in the experience itself. That is, an individual may be physically present in the environment or within an activity but, without active engagement or an attempt to derive meaningful benefit from it, the individual is not truly participating according to the fPRC framework. Given the importance of involvement in the concept of participation, research seeking to develop an improved understanding of the barriers that limit or prevent activity involvement in older adults is clearly needed.

While the term 'participation' often conjures thoughts that are centred around physical activity, the relationship between participation and involvement extends beyond purely physical actions to include other domains ranging from social activities to technology-facilitated activities, like virtual and mixed reality applications. An individual's ability to be involved in the activity will be impacted by the usability and accessibility of the activity, as their experience influences their capacity and willingness to be involved in the activity. For example, in the context of a digital application, the level of immersion and the nature of the emotional reactions that are triggered by using the application are determinants of the overall user experience. With respect to intrinsic factors, activity competence and sense of self can be impacted by the usability of the application, as a well-designed application would enable an individual to effectively use it and to feel confident using it. Similarly, individual preferences may influence an application designer's consideration of the aesthetic elements of the application to engage different users in different ways. In contrast, environmental factors may include the consideration of features that ensure an application can be customised to meet the needs of the user and that its use is accepted by the target user population. Collectively, these characteristics are all factors that can influence the user's experience and therefore may be potential enablers or barriers to an individual's involvement in activities that utilise mixed reality technologies. As such, exploration of the factors influencing user experience may facilitate the identification of barriers that hinder participation and inform the development of strategies to enhance user engagement and involvement. In turn, this would stand to encourage greater participation in activities across different settings and have important implications for the physical and psychological well-being of ageing individuals.

The fPRC was initially developed to inform research and practice in the area of childhood disability, and has been applied to research on children with developmental disabilities (Coussens et al., 2021), children and adolescents with neuromuscular disorders (Stroobach et al., 2023), and children with complex communication needs (Prinsloo et al., 2024), showing its applicability across many different types of health needs. Beyond childhood cohorts, it has recently been applied to research on young adults with cerebral palsy (McKenzie et al., 2023; Quartermaine et al., 2024), and other complex disabilities that are characterised by a combination of physical, intellectual, and sensory impairments, communication difficulties, and associated medical conditions (Cassidy et al., 2024). While its effectiveness for evaluating participation in older adults has not been established, the developers of the framework suggest that it can be applied to children and adults living with long-term impairments or health conditions (Imms et al., 2017). It can be further argued that the framework can be relevant to any activity or environment and can involve individuals with varying levels of competence as the fPRC did not operationally define participation based on the life situations in which participation takes place nor the abilities used during the activity (Adair et al., 2018). Thus far, research on participation in activities have focused heavily on physiological health factors (Imms et al., 2017), but this narrow focus overlooks biopsychosocial factors, and the interactions between these factors, that are just as important when designing effective interventions. The use of the framework in this thesis is critical to ensuring factors beyond an individual's physical health function are considered and to gain a robust and comprehensive appreciation of an older adult's participation needs. Furthermore, the studies in this thesis broaden the use of the fPRC framework beyond childhood disability by exploring its relevance and adaptability within the older adult population. This framework is used to explore how internal and external factors interact and influence participation in activities among older adults.

1.3 Internal factors affecting activity participation in older adults

Older adults' participation in activities is influenced by their actual and perceived functional capability and psychological capacity to perform the requisite skills and tasks. Functional capability, one's ability to perform a physical task, is influenced by physical health characteristics (e.g. strength, frailty, mobility, sensory abilities), cognitive ability (e.g. mental status, memory) and social aspects (e.g. social support, social relationships, social status) that collectively interact with environmental factors (e.g. access to transportation, economic status, living environment) (Zhang & Wang, 2023). Ill health can be a barrier to exercise, with those who have existing health difficulties or joint damage (Melillo et al., 2001; Simmonds et al., 2016) reported to be less likely to participate in physical activities when advised to refrain from physical activity (Simmonds et al., 2016). Concerns about safety are another important factor in determining one's willingness to participate in physical activities. For example, fear of falling and injury are known to lower confidence and reduce a person's motivation to participate in activities which, in turn, leads to a restriction in the types of activities engaged in by older adults (Li et al., 2003; Melillo et al., 2001; Meredith et al., 2023). These findings are supported by a systematic review (Spiteri et al., 2019) that compared factors that influence physical activity in middle-aged adults (those aged 50-64 years) and older adults (aged above 65 years). This study found that concerns about safety were a significant barrier to physical activity among older adults, but less so for those who were middle-aged (Spiteri et al., 2019). Despite the age-related link between physical activity and safety concerns, research shows that improving a person's level of functional ability is associated with a reduced fear of falling (Li et al., 2003).

In factors relating to sense of self, people who view themselves as an exerciser and incorporate exercise into their self-concept are more motivated to engage in physical activity (Meredith et al., 2023). The results of a systematic review on barriers and motivators of physical activity participation in older adults found that having past experiences of being physically active was a motivator, while the lack of such experiences was a barrier (Spiteri et al., 2019). Mastering physical activity gave older adults a sense of competence that helped maintain their enthusiasm for continued exercise (Franco et al., 2015). Staying active was also important in building their self-esteem. A randomised controlled trial (RCT) examining the relationships between physical activity, self-esteem, and self-efficacy in 174 older adults over a year (6 months of exercise intervention and 6 months follow-up) found a significant increase in self-esteem levels upon completion of either a muscle toning or aerobic intervention (McAuley et al., 2000). This positive effect decreased 6 months post-intervention when participants indicated that they had decreased their level of exercise, suggesting that consistent physical activity is required to sustain a positive impact on self-concept. A longitudinal follow-up with the same sample indicated a consistent relationship between the effects of physical activity and self-efficacy on self-worth and global self-esteem (McAuley et al., 2005). In addition, perceptions of having (or not having) an attractive body and/or physical conditioning were significantly related to older adults' level of physical self-worth in the original study (McAuley et al., 2000). This result was supported by other studies that found a relationship between body image, sense of self-worth and self-esteem in older adults (Baker & Gringart, 2009) and across the life span (Adams et al., 2017; Steinsbekk et al., 2021).

1.4 Environmental factors affecting activity participation in older adults

Environmental factors also influence older adults' willingness to participate in physical activity. Despite the positive impact of physical activity on self-esteem, older adults may feel a lack of confidence while engaging in physical activities outside of the home. This is especially the case when engaging in group activities with varying ages, genders, and abilities where they may worry about keeping up with others (Franco et al., 2015). However, by providing adequate professional instructions and facilitation during physical activities, it may be possible to help older adults feel supported and motivated, as indicated by the results of several systematic reviews (Franco et al., 2015; Meredith et al., 2023; Spiteri et al., 2019). A safe and effective physical activity programme requires facilitators to have knowledge of the underlying health concerns of the older adults and an understanding of how to promote the desired physiological adaptations despite these health limitations. For example, facilitators would need to recognise that prescribing a lower number of sets and repetitions for each exercise (relative to what might be prescribed to a younger cohort) can effectively increase muscle strength in older adults (Fragala et al., 2019). However, the need for professional instruction brings up another crucial factor, which is affordability, and the cost of professional instruction can be a substantial obstacle for many older adults.

Research indicates that affordability matters in encouraging older adults to continue participating in activities. Considering that slightly more than half (57%) of older Australians relied on government pension as their main source of income, and that households headed by older adults were more likely to be in the lowest 40% of the household income distribution (Australian Institute of Health and Welfare, 2024a), older adults' limited income meant that the high cost of attending exercise classes presents as a barrier to engaging in physical exercise (Boulton et al., 2018). Older adults have also reported an unwillingness to pay to engage in physical activities as they are not viewed as essential, preferring to go for free or low-cost exercise classes (Franco et al., 2015). However, financial affordability may not be the main barrier to staying active, as attendance rate was not high even when there was free access provided for exercise programmes and exercise equipment, with older adults citing concerns about their health, inadequate professional guidance and lack of access to programmes tailored for older adults as barriers to engaging in these programmes (Bethancourt et al., 2014). A lack of accessibility to physical activity further diminishes the ability of older adults to engage in activities, as they are impeded by barriers such as poor transportation access, neighbourhood safety and a lack of proximity to activities (Boulton et al., 2018; Franco et al., 2015). Transportation challenges can lead to long travel times that are not well accepted by older adults, while unsafe neighbourhoods can leave older adults feeling vulnerable about leaving their house. Older adults may also no longer be able to drive due to age-related health declines and losing their license (Chihuri et al., 2016), leading to a lack of autonomy in being able to leave their house and engage in activities. For older individuals, the importance of being able to drive themselves to social engagements cannot be overstated, with a 13-yearlong study indicating that the cessation of driving in older adults was associated with a 51% decrease in their social network size (Mezuk & Rebok, 2008). Importantly, this decline in social network size was not mediated by access to other forms of transportation, emphasising the perceived importance of holding a car license to one's sense of independence (Mezuk & Rebok, 2008).

1.5 Conclusion

While the sections above focused on engagement in physical activities due to its clear and significant impact on healthy ageing, encouraging older adults to participate in social activities is similarly important. Staying socially engaged has been associated with better health (Yen et al., 2022), slower cognitive decline (Haslam et al., 2014), less psychological distress (Mackenzie & Abdulrazaq, 2021) and overall improvements in quality of life and life satisfaction (Yen et al., 2022). Based on systematic reviews (Lee et al., 2022; Townsend et al., 2021; Vaughan et al., 2016), many of the intrinsic and environmental barriers and facilitators that impacted physical activities similarly influenced social participation. This included health conditions, physical and social accessibility to social activities (again including access to transportation and neighbourhood cohesion), social support, and socioeconomic status. One of the systematic reviews also suggested that older adults would be motivated to participate in community-based social activities due to altruistic and prosocial goals, leading to increased level of participation and higher perceived quality of social engagement (Townsend et al., 2021). Overall, interventions addressing these common set of factors may simultaneously enhance engagement in both physical activity and social activity participation.

In summary, older adults are not meeting recommended levels of physical activity, which is a concern given the established connection between physical activity, independence, and quality of life. To better understand the complex factors impacting participation in older adults, the fPRC model was introduced and used as a guide to search for empirical evidence. This ensured that essential internal and external factors influencing activity participation are taken into consideration. Participation is not only about physical activities, but also includes social participation and other life domains (World Health Organization, 2007), and the barriers and facilitators for physical and social activities appear to be overlapping. Older adults' engagement in activities is shaped by their perceived and actual abilities, self-concept, and environmental factors such as affordability and accessibility of the activities. Addressing both internal and external factors will be crucial for encouraging and sustaining physical activity and social engagement in older adults. In the context of Mixed Reality (MR) technology, ensuring that it meets the needs of older adults requires a comprehensive understanding of their user experience (UX) while using MR applications. By applying the theoretical framework of the fPRC to UX research, older adults' experience while participating in MR-based activities can be assessed.

The Components of User Experience (CUE) framework, introduced in the next chapter (Chapter 2) further provides a structured approach to evaluating user experience, offering insights into usability, accessibility, and overall satisfaction. By integrating fPRC theory with UX research guided by CUE, this thesis seeks to generate insights that supports the design of MR technology to be more inclusive, intuitive, and supportive of older adults' participation in activities.

Chapter 2 Use of mixed reality interactive experiences to promote activity and participation for healthy ageing: Theory, benefits and limitations

As the world's population ages, there is a growing need for innovative solutions that promote healthy ageing. Mixed reality (MR) is one such solution that holds significant promise in this regard. MR is an umbrella term that encompasses technologies such as augmented reality (AR), virtual reality (VR) and others that create an interactive and immersive experience for users. This chapter explores the theory, strength and limitations associated with the use of MR to promote healthy ageing.

2.1 Definition of key terms: Mixed Reality (MR) and User Experience (UX)

In accordance with the fPRC, this thesis considers both attendance and involvement as critical elements of participation, with one's experiences serving as potential motivators or inhibitors to their current and future involvement. In the context of this thesis, which considers the suitability of a MR-based system for use by older adults, the user's experience (UX) can be assessed using the Component of User Experience (CUE) model developed by Thüring and Mahlke (2007). According to Thüring and Mahlke (2007) there are three key factors that contribute to a user's experience: i) the perceived instrumental quality of the application; ii) the emotional responses evoked by the application; and iii) the perception of its non-instrumental aspects. A comprehensive assessment of user experience encompasses factors such as user-friendliness, affective responses, engagement, sensory perceptions, visual appeal, and subjective evaluation of the application (Hassenzahl & Tractinsky, 2006; Saariluoma & Jokinen, 2014; Thüring & Mahlke, 2007).

Based on the CUE model (Thüring & Mahlke, 2007), the primary emphasis of the application's instrumental aspect is on how users perceive its ease of use, as well as the scheduling and execution of the intervention protocol. It also evaluates how participant limitations are addressed, including issues related to physical abilities, mobility, and safety. The emotional aspect of user experience is dependent on factors such as immersion, sensory stimulation, perceived control, competence, level of challenge, empathy, positive and negative emotions, and engagement with the application before and after use. Lastly, the non-instrumental aspect of user experience encompasses the aesthetic elements and subjective appraisal of the application's appeal.

The multi-faceted approach of UX emerged from the need to go beyond the early literature's focus on usability. When it comes to usability and UX, there are two main differences. Usability focuses on reaching behavioural objectives during application use, while UX considers the application's attributes before, during, and after use (Hassenzahl & Tractinsky, 2006; Saariluoma & Jokinen, 2014; Thüring & Mahlke, 2007). Secondly, the evaluation of usability alone neglects to incorporate the emotional aspect of the user's experience, which is a crucial element of UX (Luther et al., 2020). Together, UX goes beyond just usability and includes the user's subjective feelings and perceptions throughout the entire process of using the application (Luther et al., 2020).

Another key term in this thesis is mixed reality. Mixed reality refers to a range of technologies that combine the physical and digital environment. The definition of mixed reality can be challenging to resolve, but it can be considered a spectrum that ranges from complete immersion in a virtual environment (VR) to the integration of digitally augmented environments (AR) into the real-world setting. The reality-virtuality continuum was proposed by Milgram and

Kishino (1994) and is commonly used to define digitally enhanced environments. Based on the original framework, any environment that includes a mix of real (i.e., from the physical environment) and virtual (i.e., artificial) objects that are *visually* perceived at the same time within a single display is termed MR (Milgram & Kishino, 1994). MR includes both AR and VR, but their level of immersion in a virtual environment varies.

With the progression of technology, the definition of MR has become unclear, with researchers using various definitions of the technology (Skarbez et al., 2021). A paper by Speicher et al. (2019) suggested that there are six widely used working definitions of MR. Some use the term interchangeably with AR, while others define it as a combination of AR and VR. The use of different terms stems from the fact that the original framework was solely centred on visual displays and disregarded other sensory inputs. This made it difficult to categorise new technological advances that combine other sensory inputs, such as sounds or tastes, with digital environments. This key limitation of the MR definition presented by Milgram and Kishino (1994) has prompted suggestions for change from researchers. Skarbez et al. (2021) proposed a revised version of the reality-virtuality continuum to tackle this problem, indicating that MR technologies encompass more than just visual digital displays and can incorporate various technologies that allow users to experience both virtual and real content through different senses. The revised continuum reaffirms the classification of current VR technology as MR, existing within the category of an "External Virtual Environment" (Figure 1). Specifically, in virtual reality, the display devices are tangible objects that are present in the real world, allowing users to interact with virtual elements while remaining in their physical surroundings. Should technology continue to advance and surpass this physical limitation, it would extend beyond MR and into a "Matrix-like" Virtual Environment (Skarbez et al., 2021), with “Matrix” referring to the popular science-fiction movie.

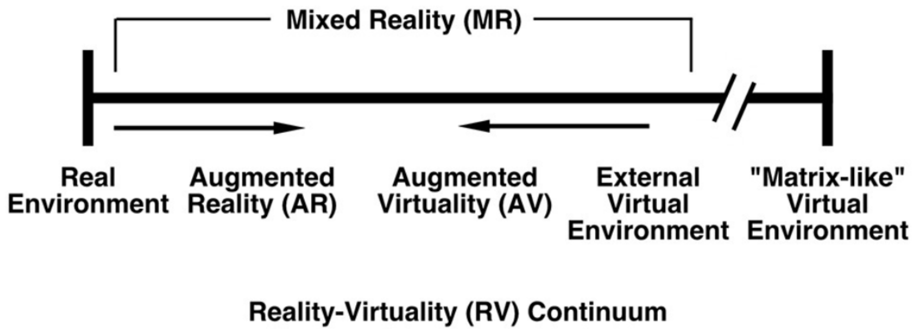

Figure 1 Revised reality-virtuality continuum framework by Skarbez et al. (2021)

The expanded definition of MR, as proposed by Skarbez et al. (2021), will serve as the framework for this thesis to reflect the current state of technology. It incorporates the diverse display and user interface mediums of AR and VR technologies. Restricting MR solely to visual displays would neglect numerous potentially beneficial applications for promoting healthy ageing, which have emerged through technological progress that was not encompassed in Milgram and Kishino's (1994) original definition. For instance, many applications designed to support healthy ageing go above and beyond traditional visual components and include motion, such as Nintendo Wii games that utilise motion capture technology (Liukkonen et al., 2015; Pyae et al., 2016), and haptics, like the tangible user interfaces found in various applications (Boletsis & McCallum, 2016; Meza-Kubo et al., 2014).

The term *digital interactive experiences* may also be used to describe the wide variety of applications under the umbrella of MR, which incorporates experience, art and game aspects of the digital applications (Candy & Ferguson, 2014). This term emphasises application designs where users *actively participate in* and influence their interaction with digital environments, such as through immersive elements of multisensory auditory and visual interactions. Due to the complexity of digital interactive experiences and interventions, these applications are by their nature often cross-disciplinary, drawing upon and adapting from Human-Computer-Interaction (HCI), Human Movement, UX, game design and practice-based research (Candy & Ferguson, 2014; Ciemer et al., 2025). In the context of this thesis, the user engagement emphasis that is inherent in digital interactive experiences is in line with the fPRC's (Chapter 1) suggestion that participation goes beyond merely attending an activity, illustrating how digital intervention designs can benefit from a collaboration between the disciplines of HCI/UX and health.

A user's experience in a MR system is also affected by several aspects, including immersion, presence, involvement, interest and emotional response (Slater, 2003). Again, the definition of these key terms, especially that of immersion and presence, has been inconsistent in the literature within the HCI space (IJsselsteijn et al., 2001; Slater, 2003). This thesis follows the definition that immersion is first and foremost an objectively measurable property of a technology's design that makes a user feels they are really inside that virtual world by engaging their sensory modalities (e.g. the tracking technology of motions or the use of high-definition, realistic graphics) (Slater, 2003). At the same time, a review of existing definitions on immersion suggested that immersion also has two subjective dimensions; i) immersion as a response to the narrative and world of the virtual environment (narrative immersion); and ii) immersion as a response to the cognitive and sensorimotor challenges provided by the virtual environment (challenge-based immersion) (Nilsson et al., 2016). The latter two is characterized by the user's "experience of intense and focused attention on events in the virtual world" (Nilsson et al., 2016). Presence, on the other hand, is a subjective user's response to their immersion within a

MR system (Slater, 2003) and a sense of being in the virtual environment (Nilsson et al., 2016). Since presence and the sense of being in the virtual environment requires the user's attention to be actively engaged, there are similarities between the concept of immersion and presence and they concepts are strongly related. The following analogies were suggested by Nilsson et al. (2016) and Slater (2003). Even if two people use the exact same virtual reality system (i.e., they experience the same degree of immersion within the system by wearing the same VR headset), they might not feel equally present in the virtual environment. One person might feel completely within the virtual world, while the other may have difficulty progressing beyond feeling only partially within the environment. Also, people can react to virtual stimuli with indifference or with excitement, just as they do in real life. A virtual stimulus may be perceived as uninteresting, engaging, cognitively demanding, or insignificant, but this reaction is not what determines whether they feel like they are really in the virtual environment. The sense of being there (immersion) can occur regardless of how they personally feel about what's happening (presence). Different systems (e.g. a fully immersive VR headset vs an augmented reality device) may also make different people feel the same level of presence, as what feels very real to one person might not feel real to someone else and vice versa. In some ways, immersion and presence are akin to fPRC's suggestion that one can be physically engaging in an activity, perhaps through the way an activity is designed (immersion within the activity), yet may not be actively participating in it, emotionally, cognitively and socially (presence).

2.2 Potential benefits of the use of MR technology in healthy ageing

Promoting healthy ageing extends beyond merely tackling age-related diseases. It involves sustaining optimal functional ability, aligning with overall well-being, quality of life and fostering ongoing independence in older individuals, as highlighted by Aronson (2020) and

Fleury et al. (2022). This is crucial for the well-being of older adults as doing so leads to a reduction in the need for healthcare and long-term care, whether at home or in aged-care facilities. In the context of MR and its potential application in promoting healthy ageing, current research has focused on gamified forms of MR. For this reason, the present thesis focused on examples of MR technology that included elements of gamification or were explicitly based on games.

2.2.1 Cognitive benefits

MR can be used to promote cognitive health in older adults through memory, attention and reasoning skills training (Li et al., 2020). Studies have shown that actively participating in cognitive stimulation activities can help slow cognitive decline in older adults, such as instances of dementia and Alzheimer's disease (Ball et al., 2002; Wilson et al., 2002), showing the importance of designing cognitive training applications that are effective and engaging to older participants. Meza-Kubo et al. (2014) designed a tangible user interface for illiterate older adults living in Mexico. A tangible user interface is a type of MR application that transforms digital information into a physical form, using physical objects as both representations and controllers for computational media (Ullmer & Ishii, 2000). In Meza-Kubo et al.'s (2014) study, participants placed physical Tangram pieces over puzzle tasks projected on a multi-touch tabletop surface. The researchers considered the limited digital knowledge of older adults, and their relatives were included as collaborators in designing the MR application. Furthermore, the device notified the relatives if the older players required assistance with the gamified task, which reduced barriers to play. The game design encouraged social interaction between the older adult participants and their family, and social engagement was an additional protective element against cognitive decline. All participants perceived the application as useful and easy to use and described the game as highly enjoyable. It was also found that the overall level of anxiety was low for all participants, which was important as MR games were new to the participants. Nevertheless, older adults did experience slightly higher levels of anxiety than the younger relatives who accompanied them on the trials. These findings serve as an example of how MR applications can be an innovative and pleasant way for older adults to engage in cognitive training.

2.2.2 Physical skills benefits

MR can be used to promote physical health in older adults by providing interactive and engaging activities that challenge the body's sensory and motor systems. For example, MR technology can be used to create personalised exercise programs that are tailored to an individual's needs and abilities, making it easier for older adults to improve balance, flexibility and strength. Lee et al. (2021) trialled an immersive cycling training system for healthy older adults aged over 65 years of age who had no prior experience with using VR applications. Participants engaged in a 360-degree VR video scene shown on a large, curved screen while biking for 20 minutes during a single training session to test the system. Results of the trial found that scores for system usability were high, indicating a high level of acceptability and ease of use. The participants also showed low levels of cybersickness, with only minor symptoms of nausea and/or disorientation reported. The researchers noted that, to create cycling content that caters to the needs of older adults, it was essential to consider the physical, psychological, and cognitive abilities of the intended users. Feedback from the participants indicated that the game content had a practical and realistic background setting and user-friendly controls to ensure an immersive visual experience for the older adult participants.

2.2.3 Social connectedness

One of the biggest challenges faced by older adults is social isolation, and with social isolation comes association of loneliness, depression and low self-rating of health in older adults (Czaja et al., 2021). In theory, MR technology can be used to create multi-player games where older adults can connect with others, be it in games where participants are co-located, or connecting digitally with other older adult gamers from the comfort of their own homes. However, existing research on MR applications for older adults seem to have a focus on improving health domains such as cognitive and physical functioning. This may be a missed opportunity, as previous research has shown that social interaction holds great importance for older adult gamers (De Schutter & Vanden Abeele, 2010; Duplàa et al., 2017). It should be noted that not all games aid in social participation, but those that do typically include group play and online multiplayer elements for social benefit (Duplàa et al., 2017; Kaufman et al., 2016). For instance, a study focusing on older individuals who live independently found that taking part in an eight-week Wii Bowling competition with multiple players had a notable impact on reducing their loneliness and increasing their social connectedness (Schell et al., 2016). In addition to fostering connections within the game setting, Schell et al. (2016) discovered that participating in the tournament expanded participants' social networks beyond the usual sessions. This included engaging in conversations, dining out, and playing other games with new acquaintances from the tournament.

2.3 Use of MR in older adult population

Past literature on the use of MR in healthy ageing provides insights into the research focus of recent studies. A key aspect of utilising games instead of other health interventions is that gaming brings playfulness and enjoyment in addition to its health benefits. An example of health intervention games would be exergames, games that require physical movement and activity (Li et al., 2017), combining elements of exercise and play. In a comparison evaluation between exergames designed specifically for older adults, traditional exercise, and a control group, Li et al. (2017) found a higher enjoyment level for the exergame group of community-based older adults, which was considered to potentially lead to a higher exercise adherence rate. Older adults often face challenges in adhering to exercise routines, with lower adherence compared to other age groups due to age-related barriers related to health concerns, fear of falling, and/or the lack of company while exercising (Lees et al., 2005; Moschny et al., 2011). Enhancing the enjoyment of physical activities is crucial for older adults as a high level of enjoyment and activity satisfaction is linked to increased exercise adherence (Fachko et al., 2013; Wollersheim et al., 2010). For example, Bird et al. (2015) found that a sample of healthy older Australians showed high participation rates in a five-week period of exergaming, after recording a high level of perceived health benefits and enjoyment.

Despite the importance of enjoyment, research on technology that is intended for use to foster healthy ageing has focused almost exclusively on the effectiveness of the applications (Dermody et al., 2020). This focus on the usability and associated health benefits for older adults raises concerns about a possible reductionist perspective on ageing. Rather than acknowledging old age as a life stage with potential for activities like gaming for play, enjoyment, and socialisation, there is a tendency to accept it is a stage that is characterised by declines in cognitive and physical abilities (De Schutter & Vanden Abeele, 2015).

2.3.1 Research methods utilised

Highlighting the multi-factorial nature of UX, a mix of quantitative and qualitative approaches have been used to investigate the experience of older adults. The choice of research method may be influenced by the specific aspect of UX that the study is targeting. Instrumental UX is often assessed via the use of questionnaires. In an evaluation of mini cognitive training games for older adults, Boletsis and McCallum (2016) assessed instrumental UX by administering the System Usability Scale. The researchers found that there was average usability, with participants experiencing loss of depth perception when required to use the device and interact in the real world simultaneously as part of the game. In another example, Chan et al. (2020) utilised the Stimulator Sickness Questionnaire (SSQ) to find that there were few reported incidents of adverse events relating to the use of VR games for older adults.

Both quantitative and qualitative measures have been used to assess emotional UX. For instance, the Game Experience Questionnaire (GEQ) was used by Liukkonen et al. (2015) to assess the level of positive and negative affect, competence, immersion, and flow experienced by older adults playing two exergames, with these results supplemented by a game observation record and participant interviews. The mixed-method design highlighted that there was more positive emotional experience in one of the games, as suggested by the GEQ results, and that it may be due to the calmer pace and easier mechanics of the game. Similarly, Pyae et al. (2017) utilised the GEQ, System Usability Scale (SUS), and post-game interviews to explore the UX of older adults trailing an exergame in Japan and Finland, with both quantitative and qualitative results indicating that both groups of participants had a positive UX, the exergame was found to be user-friendly, and the older adults were interested in using exergames as an alternative way of exercising.

While there is a growing body of literature concerning the assessment of instrumental UX and emotional reactions elicited during the use of MR applications, it is currently less clear how non-instrumental UX has been assessed in the past. A search of recent literature showed fewer examples of studies incorporating non-instrumented UX into their assessment of MR applications. Participant interviews were used by Rebsamen et al. (2019) and Pyae et al. (2016)

in their studies on the use of exergames in older adult populations. When non-instrumental UX was assessed, participants provided a range of feedback that was important for game designers and researchers. Specifically, participants indicated that: i) both music and visual aspects of games were important to older adults as they help with game engagement; ii) choice of virtual environment matters, with participants preferring games set in real-life environments; and iii) they enjoyed controller-free games (Pyae et al., 2017; Rebsamen et al., 2019).

2.3.2 Empirical studies

Extensive research has focused on utilising MR for health intervention in older adults within clinical populations, particularly in motor rehabilitation (Cavalcanti et al., 2018). However, there has been comparatively less emphasis on incorporating MR technologies with healthy older adults in community and residential aged care settings. While understanding the needs and concerns of healthy older adults is crucial in designing MR applications for maximum benefits, systematic reviews focusing on technology use in these settings are scarce. Existing reviews predominantly centre on the effectiveness of MR applications, primarily assessing physical well-being, health outcomes, quality of life, motivation, and social functioning (Buyl et al., 2020; Dermody et al., 2020; Miller et al., 2014). Despite showing promising benefits for physical health, studies included in these reviews are of low-to-moderate quality, attributed to factors such as small sample sizes, short trial durations, the absence of longitudinal studies, and the utilisation of low-quality (non-RCT) research designs. Moreover, these reviews highlight a predominant focus on improving physical outcomes, neglecting the potential impact of MR on non-physical outcomes. Consequently, there is a notable gap in understanding the acceptance and usability of MR applications among older adults, warranting further research.

2.4 Limitations and challenges of using MR in healthy ageing

In the context of healthy ageing, MR offers novel approaches to enhance cognitive and physical well-being. Despite its potential, as with any emerging technology, the application of MR in the study of healthy ageing is not without its limitations and challenges. This includes technological barriers, acceptance by older adults, usability issues unique to older adults and the lack of research on older adults in general.

2.4.1 Technological barriers

Some of the biggest challenges associated with using MR in promoting healthy ageing are technological barriers. There may be a common over-generalisation, held also by this author prior to starting this thesis, that older adults lack digital literacy. And while Wilson et al. (2019) found that in an Australian cohort of older adults were rated the least digitally included, it is noteworthy that McCosker et al. (2023) found that there was a wide disparity of digital literacy among Australian older adults. The degree of access to digital technologies was heavily influenced by workplace experiences of the older adults, leading to differences in opportunities for use, learning and adaptability. McCosker et al. (2023) suggested that to effectively bridge the digital divide and literacy gaps across the country, it was imperative to disaggregate older adults as a cohort and acknowledge the differences in their life circumstances and demographics. In the context of MR application design, it is important to consider the target group, and older adults who were not familiar with MR technology would require different levels of training, support, and game challenge than their age-matched counterparts who have a higher level of digital skill. There may also be issues with hardware and software compatibility that need to be addressed, as well as the high cost associated with some immersive VR devices (McCosker et al., 2023).

2.4.2 Acceptance by older adults

Another limitation of using MR to promote healthy ageing is its acceptance by older adults and their perceived or actual usability issues. Many older adults are not familiar with technology and may be hesitant to use MR. They may require reassurance and support from family members, such as in the cognitive training game designed by Meza-Kubo et al. (2014). MR experiences need to be designed with older adults in mind. Jeremic et al. (2019) found that older adults were less likely to continue playing exergames if they were too fast and complex, and if they had to focus on both mental and physical activities at the same time, particularly within a limited period.

2.5 Conclusion

This chapter highlights the relative lack of research on MR applications for older adults and that the studies that have been conducted in this area have often adopted technologies originally designed for younger cohorts. Activities that draw upon MR hold significant promise in promoting healthy ageing. The assessment of UX involves considering each component individually as well as collectively to obtain a thorough understanding. By doing so, software designers and developers can create applications that not only achieve their functional goals but also provide a positive and engaging user experience. MR technologies have the potential to provide a range of benefits for older adults, including promoting cognitive and physical health as well as reducing social isolation. Examples of MR applications for older adults included immersive VR cycling, Wii exergames and tangible user interfaces for puzzle games. With the continued development of MR, there is an opportunity to create more innovative solutions that can improve the quality of life for older adults. At the same time, the challenges of designing MR applications for older adults need to be addressed, such as technological barriers, usability issues and acceptance by older adults. Research and testing focused on older adults will be critical to realising the full potential of MR in promoting healthy ageing.

Chapter 3 Aims and Objectives

Globally, there is an increase in both the number and proportion of older individuals within our population (World Health Organization, 2024). The World Health Organization (WHO) estimates that the proportion of the world's population over 60 years of age will nearly double from 12% to 22% between 2015 and 2050, while the number of individuals aged 80 years and older is expected to triple, reaching 426 million (World Health Organization, 2024). In Australia, one in six individuals is currently aged 65 or older (Australian Institute of Health and Welfare, 2023, 2024a). By 2066, it is anticipated that older adults aged 65 and older will account for approximately 22% of the total Australian population (Australian Institute of Health and Welfare, 2024a). The percentage of older adults aged 85 and above is also anticipated to double from 2.1% in 2020 to 4.4% by 2066 (Australian Institute of Health and Welfare, 2024a).

3.1 Impact of an ageing population

An ageing population impacts the world in many ways, including socio-culturally and in public health and policy (Sander et al., 2015). Ageing affects older adults emotionally and physically, as outlined in Chapter 1 of this thesis. The current section focuses on two important matters related to the ageing population – global economics and healthcare.

An ageing population is likely to impact economic growth in Organisation for Economic Co-operation and Development (OECD) countries, where growth in gross domestic product (GDP) is expected to slow down due to slower employment growth and labour productivity growth, which will lead to a decline in labour compensation and wages (Bloom et al., 2010;

Maestas et al., 2023). One recent estimate suggested that each 10% increase in the proportion of the population aged 60 and older was associated with a 5.5% decrease in per capita GDP (Maestas et al., 2023), a signal of the broader economic challenges that would affect all of society. In Australia and many other countries, the old age dependency ratio (OADR), a demographic indicator that measures the financial burden on the workforce, is increasing, leading to changes in public policies such as the Australian Government's move to increase the pension age from 65 to 67 in 2023, and possibly increase further to 70 by 2035 (Chen et al., 2025).

The healthcare system would also be impacted by the change in demographics, such as an increased demand for healthcare services due to an increase in age-related diseases, multimorbidity and complex health needs (Choi et al., 2024). With the increase in life expectancy, there has also been an increase in number of 'unhealthy years of life', with Australia ranking second amongst the countries, behind the USA who ranked first, and above Canada who were ranked third (Choi et al., 2024). This information provides important insight into other factors that are adding to the pressure experienced by our already strained and under-resourced healthcare system (Jones & Dolsten, 2024). This issue is compounded when there is a shortage of professionals trained in geriatric care, with 27% of medical schools globally not offering training in geriatric medicine, including 19% of schools in high-income countries, and even more in developing countries, leading to inadequate number of specialists in geriatrics to meet the needs of the population (World Health Organization, 2016). There is also inequity in the access, quality and affordability of healthcare, and the impact of an overburdened public health system is likely to be felt even more by individuals on lower-income and minority segments of the society (Jones & Dolsten, 2024). To address the needs of an ageing population, emphasising preventative care would make a significant impact, as enabling healthy behaviour and reducing risk factors could prevent or delay the onset of diseases (Beard & Bloom, 2015). Consequently, the concept of 'healthy ageing' has emerged as a significant area of focus in public health and gerontology research (Fleury et al., 2022). Healthy ageing would extend beyond merely addressing age-related diseases. It would also involve promoting and maintaining high functional capability, physical health, independence, and overall well-being among older adults (Aronson, 2020; Fleury et al., 2022). To this end, there is also growing support and advocacy for investment into the use of technological interventions not just for healthcare solutions, but to support individuals with ageing in place (Jones & Dolsten, 2024).

3.2 Providing support to older adults through technology

One type of technology-enabled intervention for healthy ageing is gamified Mixed Reality (MR) applications and interactive experiences tailored for older adults. In the context of human-computer interaction, "gamified" refers to the incorporation of game elements or mechanisms into mixed reality experiences, leveraging the inherent motivational qualities of games to foster user engagement, learning and enjoyment (Condino et al., 2022; Seaborn & Fels, 2015). This would then encourage older adult users to continue participating actively in activities.

It is important to understand the acceptability of such interventions through exploring the experiences of older adults when engaging with gamified MR applications. EDNA Playboards is a surface computing system that has been adapted from a prior intervention (Resonance) for clinical adult populations (Duckworth et al., 2015). This system has demonstrated efficacy in improving functional performance and social engagement in adults with traumatic brain injuries. With its user-friendly design and appealing aesthetic, the EDNA Playboards system may effectively promote cognitive stimulation, physical activity, and social interaction among older adults living in residential communities and aged care facilities.

3.3 Rationale

Most of the current research on the use of technology with older adults has focused on its clinical use (Bertolazzi et al., 2024). Existing research has primarily examined the effectiveness of mixed reality on health outcomes rather than the user experience and has predominantly used quantitative research approaches (Buyl et al., 2020; Dermody et al., 2020; Miller et al., 2014). Furthermore, there remains a need for more research to understand the perspectives of the users of the technology – in this case, the older adults (Bertolazzi et al., 2024), to establish the feasibility and user experience for these individuals.

In accordance with the fPRC (Chapter 1), it is understood that participation involves both attendance and involvement, and people can attend activities without being fully engaged in the experience; that is, they are not truly participating. To better understand the barriers and facilitators that influence involvement in these activities, it is essential to explore their overall experience. This thesis proposes that, based on the fPRC, attendance and involvement are the two core elements of participation in activities and that these elements are influenced by both intrinsic and extrinsic factors. In the context of the fPRC, it is important to recognize that older adults may attend activities but not be truly involved in them. To understand these factors and their impact on participation, it is crucial to examine the experiences of the participants. In the context of MR activities, the CUE framework (Chapter 2) provides a comprehensive approach for understanding user experience with MR technologies. The CUE consists of three subcomponents, usability, emotional reactions and aesthetics, which can also be understood as intrinsic and extrinsic factors affecting user engagement and participation. The interplay between participation, as defined by the fPRC, and user experience, as assessed by the CUE, is visually depicted in Figure 2. This integration of two frameworks may provide a practical approach for researchers seeking to enhance user participation in activities, particularly for older adults engaging in the use of MR applications.

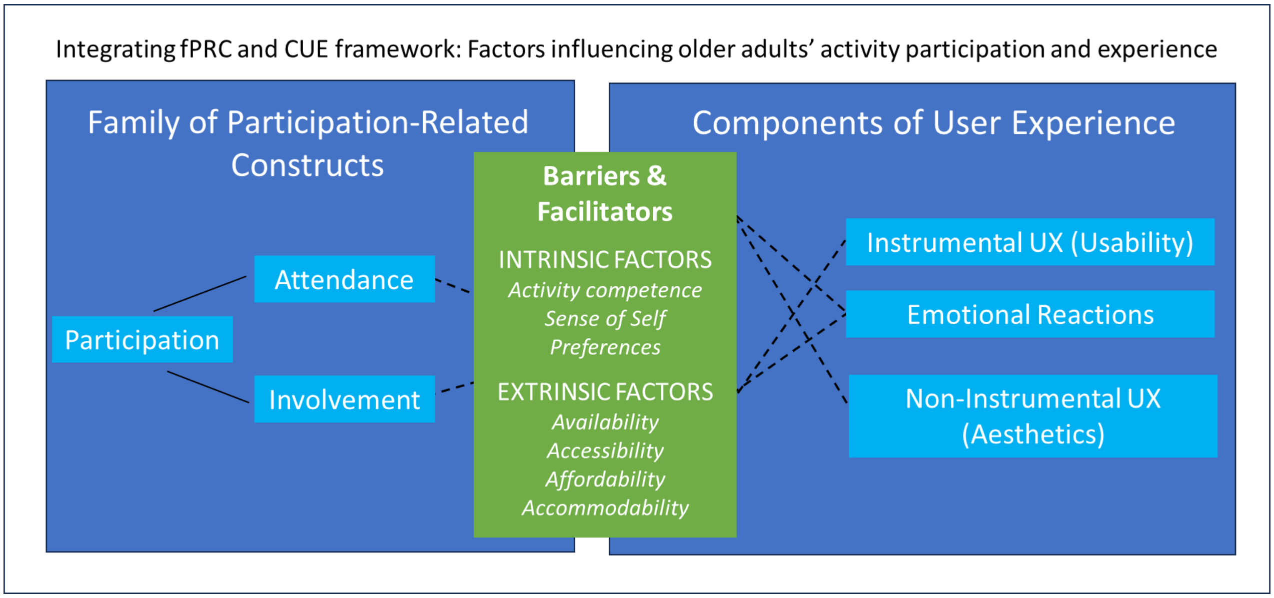

Figure 2: Integrating the fPRC and CUE frameworks: Factors influencing older adults' activity participation and experience

As discussed earlier in Chapter 2, there is an increasing interest in using MR technologies with older adults, but previous research has primarily focused on effectiveness of MR devices rather than their usability and user experience. Existing reviews have highlighted low-quality studies and a concentration on traditional VR applications. Consequently, there is a need for greater emphasis on the user experience of MR applications aimed at healthy ageing, and a systematic review was planned to explore this for healthy older adults who enlist any MR-based technology for physical, cognitive and social activity, utilizing a three-factor model that includes instrumental quality, emotional response, and non-instrumental quality (i.e. the CUE model).

In this thesis, the use of MR devices, particularly the EDNA Playboards, was chosen to explore the UX of older adults when participating in group activities. The use of EDNA

Playboards was selected for this thesis as it allows users to engage in competitive and cooperative games that encourage active involvement (participation) and increase social presence through having shared goals. Based on the CUE dimensions of usability, emotional reaction and aesthetics, the EDNA Playboards had also been previously used with individuals with brain trauma, a sample of individuals with high accessibility needs, and hence was considered less likely to pose usability barriers to the intended sample of older adults. The digital environments of MR devices have also been tested in previous studies that suggest it has the ability to trigger emotional reactions in users, and to immerse users in their use due to their colourful and high sensory based aesthetics. The benefits and research evidence of using MR devices with older adults was further elaborated on in Chapter 2 of this thesis. It is hoped that the use of the MR device allows for exploration on both intrinsic (e.g. motivation, enjoyment, perceived competency) and extrinsic (e.g. facilitations, accessibility) factors that influence activity participation.

This thesis also chose to conduct two experimental studies, one in a retirement village and the other in an aged care facility. By including both contexts, this thesis attempted to explore how different living environments, levels of health, and participant independence shape the ways older adults engage with and respond to a new MR intervention. Residential aged care provides insight into how interventions can be implemented in structured, supported environments where participation is often influenced by staff facilitation and established routines, while retirement villages allow examination of how older adults with greater independence and voluntary engagement respond to the same or similar interventions.

Therefore, the development of an improved understanding of the barriers and facilitators to activity participation has the potential to significantly enhance actual engagement in older populations, offering a way for researchers and others in the field of gerontology and mixed reality to consider user participation in older adult populations and a way to enhance user participation in various applications.

3.4 Aims

This thesis first sought to understand the current research findings on the UX of MR applications for older adults. Subsequently, the thesis aimed to explore the user experiences (UX) of older adults living in retirement communities and aged care facilities while using the EDNA Playboards MR system. By addressing this need, this program of work sought to determine whether MR systems, like ENDA-Playboards, can be leveraged to improve participation in activities among older adults living in these environments. For the purposes of this research, UX was evaluated using the Components of User Experience (CUE) model, which includes measures of the instrumental, emotional and non-emotional aspects of the application (Thüring & Mahlke, 2007).

3.5 Objectives

To address the overarching aim of this research, this thesis comprises three inter-related studies that collectively sought to understand how technology may be used to encourage participation in older adults:

i) **Systematic review (Study 1):** This study sought to develop a consensus of the literature to understand better to what extent mixed reality technologies have been used to support healthy ageing, and what the available research shows about its usability and effectiveness. Specifically, how has user experience of MR-related technologies been evaluated in recent studies involving healthy older adults, and to what extent have current mixed reality technologies been shown as usable in supporting active participation, particularly in enhancing social engagement, physical movement, and cognitive skills, and what does the literature reveal about their usability and effectiveness?

ii) **Mixed methods empirical study (Study 2):** This study involved residents from an Australian retirement community in Victoria and aimed to determine the experiences of these healthy older adults when using the EDNA Playboards mixed reality system. How do healthy older adults living in an Australian retirement community in Victoria experience the EDNA Playboards system in terms of promoting social engagement, physical activity, and cognitive stimulation, and what factors contribute to or detract from these positive outcomes? It was hypothesised that despite the novelty of the technology, the older adults would find the experience to be positive to their well-being.

iii) **Qualitative empirical study (Study 3):** This study expanded upon Study 2 by involving residents from an Australian aged care facility, seeking to determine how feasible it would be to integrate the EDNA Playboards system into an aged care setting and how accepted this type of technology would be. How is the EDNA Playboards technology accepted by older adults in an Australian aged care facility in terms of improving social engagement, physical activity and cognitive stimulation? It was hypothesised that while the older adults from the aged care facility would find the experience to be positive, this community would face different challenges and experience different benefits when compared to the retirement community sample.

Chapter 4 Study 1: User Experience of Mixed Reality-Based Applications for Healthy Ageing: A Systematic Review

This study has been published following peer review. The content has been reformatted for the purposes of this thesis. Full reference details for this study are: Lim, K. J., McGuckian, T. B., Cole, M. H., Duckworth, J., & Wilson, P. H. (2023). User experience of mixed reality applications for healthy ageing: A systematic review. *Cyberpsychology: Journal of Psychosocial Research on Cyberspace*, *17*(4), Article 5. https://doi.org/10.5817/CP2023-4-5

4.1 Abstract

Mixed reality (MR) technologies are being used increasingly to support healthy ageing, but past reviews have concentrated on the efficacy of the technology. This systematic review provides a synthesis of recent experimental studies on the instrumental, emotional and non-instrumental aspects of user experience of healthy older adults in relation to MR-related applications. The review was listed on PROSPERO, utilised a modified PICOS framework, and canvassed all published work between January 2010 to July 2021 that appeared in major databases (Scopus, PubMed, CINAHL, Web of Science, and the Cochrane Library). The literature search revealed 15 eligible studies. Results indicated that all included studies measured the instrumental quality of their applications, all but two studies measured the emotional reactions triggered by gameplay, and only six studies examined participants' perception of non-instrumental quality of the applications. All included studies focused on improving a health domain such as cognitive or physical training. This suggests that the instrumental quality of the MR applications remains the focus of user experience studies, with far fewer studies examining

the non-instrumental quality of the applications. Implications for game design and future research are discussed.

4.2 Introduction

Interactive digital technology has tremendous capacity to facilitate and promote physical activity, social participation and is seeing increasing application in healthy ageing. In particular, the use of gamified applications that incorporate Mixed Reality (MR) technologies -- which includes Augmented Reality (AR) and Virtual Reality (VR) technologies -- has gained interest in the health industry as a medium to enhance user engagement, motor rehabilitation and physical exercise (Cavalcanti et al., 2018). According to the World Health Organisation, healthy ageing is the process of developing and maintaining one's functional ability to enable well-being in later life (Michel & Sadana, 2017). This can include rehabilitation, as healthy ageing does not necessarily mean being free of disease. However, much of the research on the use of technology has been on rehabilitation. The focus of this review is instead on how MR technology can be used to support healthy older adults in remaining physically active and participating socially, potentially preventing the need for long-term care. Healthy older adults, for the scope of this paper, was taken as older adults with good health who were not hospitalised, part of rehabilitation trial or diagnosed with a disorder of ageing that impacts their physical and/or cognitive ability.

The application of MR and related technology to healthy ageing has been motivated by several significant changes in population demographics: an ageing population; an increase in life expectancy, and the need to redress the progressive decline in function with older age. Furthermore, there is concern that social and health inequalities may be exacerbated by a digital divide in society, where certain population groups, amongst them older adults, have unequal access to digital health technology (Latulippe et al., 2017). Older adults face barriers to accessing technology, including technology literacy, technophobia, computer anxiety, age-related physical differences and general acceptance of technology (Di Giacomo et al., 2019; Ijaz et al., 2022; Pang & Cheng, 2023).Without equity in access, older adults may be unable to fully benefit from the technological advancement in the healthy ageing field, which points to the importance of ensuring a high user experience of MR-related applications for healthy ageing. Hence, this systematic review aims to increase the understanding of how MR technology can be used to support healthy ageing in healthy older adults.

Some of the most frequently researched technologies in aged care are MR, AR, and VR applications, all of which involve the presentation of simulated digital environments. In the literature, these terms can be difficult to define precisely but are best conceptualised along a reality-virtuality continuum that spans complete immersion in a virtual environment at one end to being fully engaged in the real environment (but with digitally augmented elements) at the other end Milgram and Kishino (1994). More recently, Skarbez et al. (2021) have revised the reality-virtuality continuum to suggest that MR technologies go beyond visual digital displays, instead incorporating any technology that enables users to perceive both virtual and real content across different senses. This expanded definition of Skarbez et al. (2021) is adopted in our review and mirrors the current state of technology, e.g., motion capture technology (Liukkonen et al., 2015; Pyae et al., 2016) and haptics, including tangible user interfaces (Boletsis & McCallum, 2016; Meza-Kubo et al., 2014).

With the advent of digital technology in healthy ageing comes a need to better understand the experiences of older adults to ensure that their interests, needs and performance capabilities are accommodated. This is done through an evaluation of user experience (UX). UX is a multi-faceted term (Hassenzahl & Tractinsky, 2006; Saariluoma & Jokinen, 2014; Thüring & Mahlke, 2007) that encompasses both task-related (or instrumental) usability and user-perceived aspects (including emotional, hedonistic or aesthetic) (Hassenzahl & Tractinsky, 2006). Traditional models of usability were focused on the achievement of behavioural goals during the use of the application. Current conceptions of UX include an examination of the application's characteristics before, during and after its use (Hassenzahl & Tractinsky, 2006; Luther et al., 2020), as well as the subjective experiences of the user at each phase (Luther et al., 2020).

This review adopts the Component of User Experience (CUE) model of UX developed by Thüring and Mahlke (2007), which posits three main aspects of user experience: (i) the perception of the application's instrumental quality (e.g. usability), (ii) the emotional reactions triggered by the application (e.g. subjective feelings of the user), and (iii) the perception of its non-instrumental quality (e.g. visual aesthetics). Each component of UX can be assessed in different ways (Hassenzahl & Tractinsky, 2006; Saariluoma & Jokinen, 2014; Thüring & Mahlke, 2007). Instrumental quality of the application focuses on the ease of use of the application as perceived by the users, scheduling and implementation of the intervention protocol, and how participant restrictions such as physical or mobility limitations and safety concerns are addressed. The subjective component of user experience includes factors such as the level of immersion, sensory experience, sense of control, competency, challenge, feelings of empathy, positive and negative feelings, and behavioural involvement during and after play. Finally, the non-instrumental component covers aspects of aesthetics and subjective appraisal of the application's appeal. These are summarised in Table 1 below. The use of CUE model is essential to this review in that it places equal value in the instrumental quality of applications, which is what is traditionally examined in usability studies, and the emotional reactions and non-instrumental quality of application. This allows for a comprehensive assessment of the UX of MR applications used by healthy older adults.

Table 1 Components of User Experience

User Perception of Instrumental Quality of Application	**Emotional Reactions from Use of Application**	**User Perception of Non-Instrumental Quality of Application**
- Ease of use	- Level of immersion	- Visual aesthetics
- Duration of device use	- Sense of control	- Subjective appraisal of attractiveness/appeal of device and content
- Safety concerns	- Sensory experience	- Haptic quality
- Perceived usefulness	- Sense of efficacy	
	- Sense of competency	
	- Sense of challenge	
	- Social engagement	
	- Behavioural involvement	
	- Negative affects	
	- Positive affects	

While it is imperative to understand the needs and concerns of healthy older adults in the design of MR applications to maximise their benefits, few systematic reviews have focused on technology use by older adults in community and residential aged care settings. Rather, the central focus of the available reviews has been effectiveness of these applications, primarily on physical well-being and health outcomes, quality of life, motivation and social functioning (Buyl et al., 2020; Dermody et al., 2020; Miller et al., 2014). While MR technology shows promising benefits for physical health, studies included in these reviews were of low-to-moderate quality (Buyl et al., 2020; Dermody et al., 2020; Miller et al., 2014). This is due to small sample sizes, short trial duration, lack of longitudinal studies, and low quality (non-RCT) research designs. These reviews also suggested that most studies have focused on improving physical outcomes, while the impact of MR on other non-physical outcomes was typically overlooked. In recent work from 2022, reviews on this area have continued to focus on the effectiveness and outcomes of digital interventions in healthy ageing (Balki et al., 2022; Chu et al., 2022; Liu et al., 2022; Margrett et al., 2022; Suleiman-Martos et al., 2022). Notably, some of these reviews focus on field research, such as that of older adults in long-term residential care (Chu et al., 2022) and community-dwelling older adults (Suleiman-Martos et al., 2022), which is a welcomed development towards improved generalisability beyond the confines of research labs. Overall, these findings suggested that more research was required to ascertain the acceptance level and usability of MR applications by older adults.

Aspects of user experience in older adults have been addressed in two recent reviews of the literature, one on the use of VR for life enrichment (Thach et al., 2020) and the other on the feasibility of VR systems for physical activity (Miller et al., 2014). Both reviews showed that most studies were case studies with no comparators, and used a variety of outcome measures, limiting conclusions about feasibility for healthy ageing. More specifically, Thach et al. (2020) concluded that VR applications (like Oculus Rift TM, Samsung Gear VR TM and Nintendo Wii TM Games) were varied in design for enrichment purposes, defined as experiences that support older adults with maintaining their emotional needs and/or social connections. These applications ranged from immersive VR (like head mounted display such as Oculus Rift and Samsung Gear VR) to exergames such as Wii games. The authors suggested several design and implementation considerations to enhance user experiences. The first concerned the presence of facilitators, including trainers, aged care workers, or family members, who monitor activity to ensure the VR tasks were performed correctly and safely by the older adult. Second, they noted that healthy older adults preferred more active experiences and intuitive design features to render the VR devices simple to use and “age friendly”, e.g., ensuring that the devices are comfortable (Thach et al., 2020).

The review of Miller et al. (2014) showed that available studies (up to 2012) provided little evidence on the feasibility of home-based VR systems (mostly commercially available technologies such as Nintendo Wii games and motion capturing systems) to improve the physical health of older adults. Feasibility outcomes were reported inconsistently (e.g., recruitment information, retention rate, adherence and acceptability outcomes). The review did show, however, a strong retention and adherence rate (between 63% to 100%), based on six of 14 studies. More encouraging was the finding that unwanted side-effects were rare, including cybersickness and physical pain or over-exertion after MR use, provided that guidance and monitoring were in place, especially in the initial phase of use (Miller et al., 2014; Thach et al., 2020). Unfortunately, aside from conventional VR systems, both Miller and Thach failed to address use of (non-standard) MR applications for healthy ageing, such as bespoke solutions.

4.3 Objective

While there is growing interest in using MR and related technologies with older adults, the existing literature shows a focus on effectiveness outcomes, while overlooking usability and user experience. Even then, these reviews reveal low quality studies, a focus on conventional VR applications, and outcome measures of limited scope. Taken together, more emphasis is needed on the UX of MR-based applications for ageing in healthy older adults, especially to inform future design of these applications, larger scale evaluation studies and, ultimately, translation into viable solutions for active living.

The broad aim of the systematic review presented here was to examine the user experience (UX) of healthy older adults who enlist any MR-based technology for physical and social activity. This aim was achieved using a comprehensive three-factor model of UX, including the instrumental quality, emotional reaction and non-instrumental quality of the applications. The research questions addressed were as follows: How is user experience of MR-related technologies evaluated in recent studies involving healthy older adults? Are the currently available applications viewed as usable solutions by healthy older adults? The implications of findings for the design of future MR-based applications are discussed.

4.4 Method

This systematic review was completed in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines and the PRISMA checklist (provided in Supplementary Material, Appendix C) was used to ensure reporting of all relevant information (Page et al., 2021). The protocol was registered with the International Prospective Register of Systematic Reviews (PROSPERO, CRD42021266164) before the commencement of data extraction. Papers were searched, selected, evaluated, analysed, and synthesised according to the protocol described below.

4.4.1 Search strategy

A multi-database systematic literature search was conducted to identify articles published between 1 January 2010 and 31 July 2021, written in English, and indexed by the SCOPUS, PUBMED, CINAHL, WEB OF SCIENCE, or COCHRANE databases. The objective and search strategy were developed based on the PICOS framework: (i) Population: older adults above 60 years of age without a diagnosis of a age-related disorder, such as dementia or Parkinson's disease; (ii) Interest: any evaluation of user experience of MR applications in populations of older adults who have not been diagnosed with a disorder of ageing; (iii) Comparison: comparing with a non-MR application, non-older adults population or without comparison; (iv) Outcome: measures of user experience; (v) Study type: experimental and non-experimental studies.

Following this framework, relevant search descriptors were combined with the Boolean operators (OR, AND) to form the final search string as follows: ("older adults" OR elderly OR aged) AND ("virtual reality" OR "augmented reality" OR "computer aided" OR gaming OR e-games OR "mixed reality") AND (usability OR "user experience" OR feasibility).

4.4.2 Inclusion and exclusion criteria

The inclusion and exclusion criteria were detailed below and summarised in Table 2.

4.4.2.1 Participants

Studies involving participants aged 60 years or over were considered. Given our focus on ageing in healthy older adults, studies were excluded if they had a participant sample that included older adults who were hospitalised, evaluated as part of a rehabilitation trial or diagnosed with a disorder of ageing such as dementia or Parkinson's disease.

4.4.2.2 Interest

Studies that evaluated the user experience of MR/VR/AR and related technologies in support of healthy ageing were included in the review. As mentioned in the introduction, a MR application is one where a user can simultaneously perceive both real and virtual content and includes both AR and VR applications. AR-based applications integrate digital information layered with information about the physical environment, supplementing the real-world environment by augmenting the user experience with digitalised sensory input such as sound and visuals. Conversely, VR-based applications deliver computer-generated simulations of virtual environments with the use of immersive multimedia (Lee et al., 2019). For this review, applications termed ‘non-immersive VR applications’ were included as these would be considered MR applications. Applications reviewed may be designed for either individual or group-based programs. Studies that only evaluated the effectiveness of the MR/VR/AR applications were excluded from the review.

4.4.2.3 Comparators

Studies were eligible for inclusion if they had either: i) a comparison between the treatment group and active or inactive control interventions such as placebo, no-treatment, standard care, treatment as usual (TAU), or a waiting list; ii) a comparison with another form of intervention (other than TAU); iii) a within-group or pre-post comparison; or iv) no comparisons, such as case studies.

4.4.3 Outcomes

This review considered studies that evaluated the usability and/or user-experience of MR and related applications, captured via either quantitative (e.g., user experience questionnaires) or qualitative measures (e.g., interviews).

4.4.3.1 Types of studies

Peer-reviewed studies with experimental/controlled trials and non-experimental designs were considered in this review. Non-experimental designs include post-test only and pre-post designs. Experimental designs cover both randomised and non-randomised controlled trials using active or inactive control conditions. Studies were excluded if they were conference abstracts, theses, review papers or not written in English.

Table 2 Inclusion and exclusion criteria

Criteria	Inclusion	Exclusion
Participants	Aged 60+	Older adults who were hospitalised, part of rehabilitation trial or diagnosed with a disorder of ageing
Interest	Studies that evaluated UX of MR and related technologies, including 'non-immersive VR applications'	Studies that only evaluated effectiveness of MR and related applications
Comparators	Studies with either - Comparison between the treatment group and active or inactive control interventions - A comparison with another form of intervention - A within-group or pre-post comparison or - No comparisons	
Outcomes	Studies that evaluated the usability and/or user-experience of MR and related applications	
Types of studies	Peer-reviewed studies Papers written in English	Conference abstracts, theses, review papers Papers not written in English

4.4.4 Study selection and analysis

Results from the database search were included in a bibliographic database using the Covidence systematic review software (Veritas Health Innovation, Melbourne, Australia). Duplicates were identified and removed electronically and manually. Titles and abstracts of the papers retrieved using the search strategy were first screened for potential inclusion by two evaluators (JL, TM). The full-text of potentially eligible papers were retrieved and assessed for eligibility for inclusion by two independent evaluators (JL, TM). Where there was no consensus on independent reviews, papers would be discussed and a third assessor (PW) asked to provide a review as required before a decision was made on the eligibility of the study. All discrepancies in this review were resolved by consensus.

4.4.5 Data extraction and quality assessment

Data were extracted from the articles by one author (JL). Any uncertainty regarding data extraction was resolved by discussion among the authors. The following data were extracted: Bibliographic information (authors, title, journal, publication date), sample (participant demographics and recruitment setting), intervention (type of intervention, device(s) used, trial duration) and usability and user experience outcome measures.

The methodological reporting quality was assessed using an adapted Downs and Black (D&B) Checklist for the Assessment of Methodological Quality that was specifically modified by Wronikowska et al. (2021) for quality assessment of usability evaluation. A modified assessment was required as many of the studies that evaluated UX did not do so as part of an intervention, and hence standard quality assessment questions that pertain to an experimental design or RCT would not apply to these studies. The modified D&B Checklist has ten questions that examined the clarity of participant description, whether the sample chosen was representative of intended end-users, the inclusion of a clearly defined time period, evidence-based methods that were supported by peer-reviewed literature were chosen, that the results were clearly described and reflected the methods used.

Two evaluators (JL, TM) independently assessed the quality of the selected studies. Any discrepancies were discussed, and a third evaluator (PW) consulted if no consensus was reached after the initial discussion. The quality of the included studies was coded into levels of ‘low’, ‘medium’ or ‘high’ quality based on their design, conduct and analysis. High-quality studies were those that scored at or above eight out of ten points across the domains. Moderate-quality studies were those that scored a total of six or seven. Any papers that scored five and below were considered low-quality studies and were omitted from the analyses.

4.5 Results

4.5.1 Study selection

The flow of studies through the systematic review process is illustrated in Figure 3. The initial search of five databases yielded 2,233 publications. After removing 514 duplicates, the titles and abstracts of the remaining 1,719 publications were screened. Of these, 97 full-text articles were assessed for eligibility. In the final phase of screening, 81 articles were excluded, of which two (Heo & Ahn, 2019; Kim et al., 2005) were due to the inability to retrieve the full-text of the articles. Emails requesting the full text of these articles were sent to the lead authors, but no reply was received. Excluded articles: i) were conference papers (n=30); ii) did not have a focus on MR (n=18); iii) studied a clinical population (n=17); iv) involved a study sample younger than 60 years old (n=11); or v) were discussion papers (n=3). Of the 16 articles remaining for inclusion, two articles were found to have used the same sample (or part thereof) and, hence, were considered as one study (Pyae et al., 2017; Pyae et al., 2016). This led to 15 studies (16 articles) being included in the final selection.

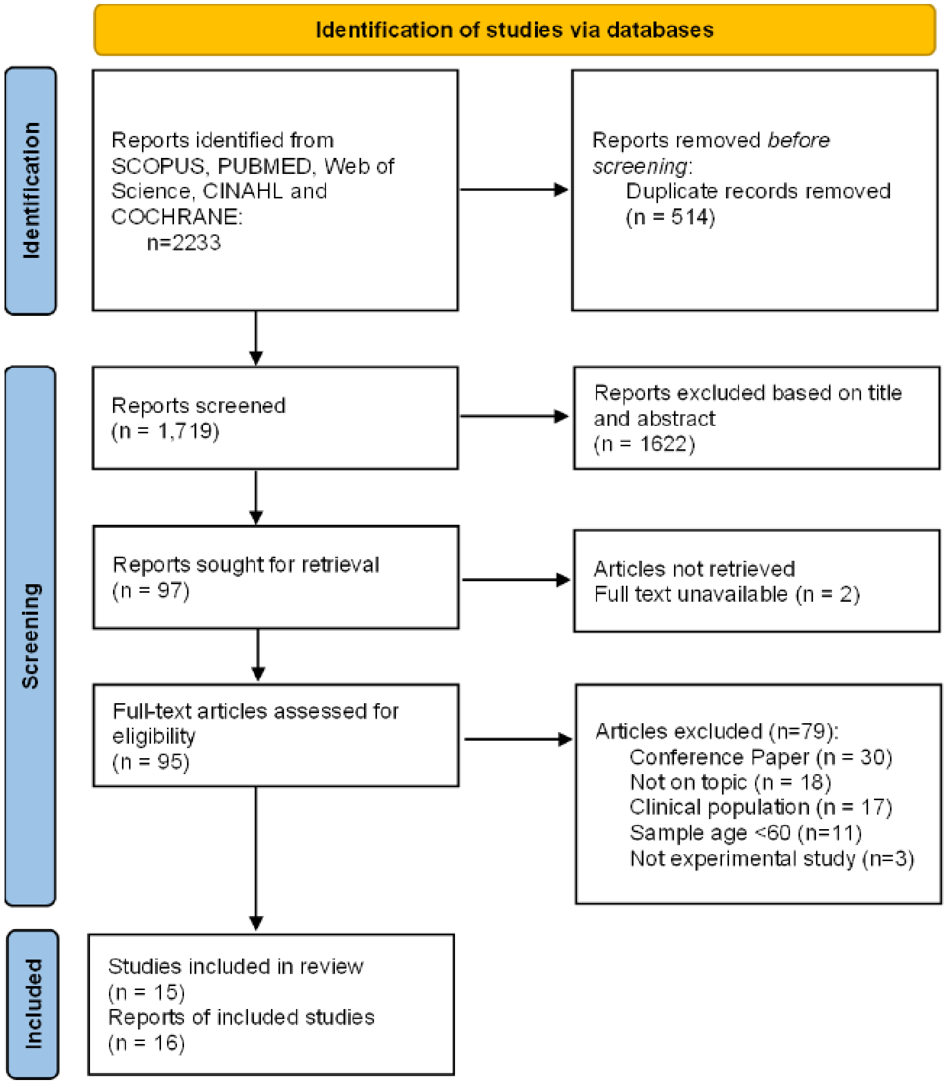

Figure 3 PRISMA flow chart of database search

4.5.2 Quality analysis

Results of the quality analysis indicated that most studies (n=12) were of high-quality, with the remaining three articles of medium-quality (Meza-Kubo et al., 2014; Santos et al., 2019; Valiani et al., 2017). These studies were marked down mainly due to insufficient data reported on UX evaluation methods, participant characteristics and results. The methodological reporting quality scores for these studies are summarised in the supplementary tables in Appendix C. Of the quality criteria, the included studies scored lowest on their reporting of the time period over which the study was carried out, as five studies were unclear on their trial period.

4.5.3 Data synthesis

Data was extracted from the included studies and presented in two tables for ease of comparison. The first table (Table 3) summarised the main characteristics of the included studies, while the second table (Table 4) summarised the main UX findings, as reported by the authors.

Table 3 Main characteristics of included studies

Author/Yr	Sample (age)(gender)	Country/ Recruitment Setting	Physical Hardware	Targeted Outcomes	Description of MR Application	Trial Schedule *Trial: no. of session* *Gameplay: X minutes*	UX assessment measure(s) *Qualitative* *Quantitative*
			Type of User Interface: Haptics Based MR Applications				
Boletsis and McCallum (2016)	n=5 (mean=67.6, range 61-75) (gender not reported)	not reported	Tangible cubes customised for intervention, tablet PC on base stand	Cognitive Training	Six mini AR games for cognitive training	Trial(s): 1 trial + 1 main session Gameplay: 20-25min (trial); 25-30min (actual)	*Quantitative:* GEQ; SUS; *Qualitative:* Semi-structured user interviews
Chen et al. (2018)	n=39 (mean=79) (15 male, 24 female)	Taiwan/ Community	Floor projector, interactive tables, touch screen computer	Cognitive and Physical Training	Three physical games and two cognitive exergames	Not stated	*Quantitative:* TAM questionnaire
Meza-Kubo et al. (2014)	n=6 (range=65-75) (gender not reported) and caregivers n=6 (35-55) (gender not reported)	not reported	Customised tangible interface	Cognitive Training	Tangible surface intervention designed for cognitive stimulation	Trial(s): 1 Gameplay: 10-min MR VS 10min augmented traditional board games	*Quantitative:* Customised TAM based questionnaire

Author/Yr	Sample (age)(gender)	Country/ Recruitment Setting	Physical Hardware	Targeted Outcomes	Description of MR Application	Trial Schedule *Trial: no. of session* *Gameplay: X minutes*	UX assessment measure(s) *Qualitative* *Quantitative*
Santos et al. (2019)	n=12 (mean = 75)	Community	Smartphone Application	Cognitive and Physical Training	AR card collection game for cognitive and physical stimulation	Trial(s): N.A. Gameplay: 2 weeks free-play	*Quantitative* GEQ
Wang et al. (2020)	n=30, (mean=81) (male=8, female=22)	Aged care	Customised tangible interface interactive device	Cognitive Training and Sensory Stimulatio n	Screen-based game designed for cognitive and sensory stimulation	Trial(s): not reported Gameplay: 15min Total duration: 40min	*Quantitative:* 2-part questionnaire based on SUS and Questionnaire for User Interface Satisfaction (QUIS) *Qualitative:* User interviews, expert interviews; In-field observations

Author/Yr	Sample (age)(gender)	Country/ Recruitment Setting	Physical Hardware	Targeted Outcomes	Description of MR Application	Trial Schedule *Trial: no. of session* *Gameplay: X minutes*	UX assessment measure(s) *Qualitative* *Quantitative*
			Type of User Interface: Exergame Applications				
Lee et al. (2021)	n=5; (mean age 69) (males=3, females=2)	Korea/ Community	Visual display, stationary recumbent cycle	Physical Training	Immersive cycling training system encouraging physical activity	Trial(s): 1 Gameplay: 20min	*Quantitative:* SUS, SSQ
Liukkonen et al. (2015)	n=19 (range=61-83) (male=9, female=10)	Finland/ Community (Rural and Urban)	'Extreme Motion' motion detector	Physical Training	One large muscle exercise game, one body maintenance game	Trial(s).: not reported Gameplay: under 15minutes	*Quantitative:* SUS, GEQ *Qualitative:* Observation records, participant interviews
Pyae et al. (2016) and Pyae et al. (2017)	Finnish Trial: n=21 (mean=71) (male=8, female = 13); Japanese trial: n=24 (mean=72) (male=12, female=12)	Finland and Japan/ Finnish Study: elderly service home; Japanese Study: health promotion centre	'Xtreme Reality' Technology	Physical Training	Skiing exergame for encouraging physical activity	Trial(s): not reported Finnish study: Gameplay: 5-10 minutes Japanese study: Gameplay: up to	(Both studies) *Quantitative:* GEQ, SUS *Qualitative:* post-gameplay interview

Author/Yr	**Sample (age)(gender)**	**Country/ Recruitment Setting**	**Physical Hardware**	**Targeted Outcomes**	**Description of MR Application**	**Trial Schedule** *Trial: no. of session* *Gameplay: X minutes*	**UX assessment measure(s)** *Qualitative* *Quantitative*
						20minutes (including demo)	
Valiani et al. (2017)	n=12 (range=76.3-84.7) (male=2, female=10)	Florida/Nursing home	Jintronix hardware, TV screen, Microsoft Kinect motion tracking camera	Physical Training	Virtual aerobic, strength and balance exercise designed for physical training	Trial(s): 2/wk x 4wks Gameplay: 30min	*Quantitative:* Customised feasibility and acceptability questionnaire; data from exergame platform
Zhang et al. (2021)	n=33(mean=70.9) (male=9, female=24)	Singapore/Community	Kinect V2 movement sensor, Full HD TV, laptop	Cognitive and Physical Training	Ping Pong exergame for cognitive inhibition training	Trial(s): 1/wk x 6wks Gameplay: 15-20min	*Quantitative:* SUS
Rebsamen et al. (2019)	n=12 (mean=72.3) (male=2, female=10)	Switzerland/ Community	SENSO exercise system (pressure sensitive platform)	Physical Training	set of nine high intensity interval exergames for physical training	Trial(s): 3/wk x 4weeks Gameplay: 19-35minutes	*Quantitative:* TAM, SUS *Qualitative:* Participants' general statements recorded during gameplay and when

Author/Yr	**Sample (age)(gender)**	**Country/ Recruitment Setting**	**Physical Hardware**	**Targeted Outcomes**	**Description of MR Application**	**Trial Schedule** *Trial: no. of session Gameplay: X minutes*	**UX assessment measure(s)** *Qualitative Quantitative*
							answering questionnaire
			Type of User Interface: AR/VR Headsets Applications				
Chan et al. (2020)	n=236 (mean=73.85) (male=56, females=180)	Hong Kong/Elder care centres	VR device, model not reported	Cognitive Training	VR cognitive stimulation activity	Trial(s): 1 Gameplay: 20-25min	*Quantitative:* SSQ, Positive and Negative Affect Score (PANAS)
Postal and Rieder (2019)	n=20 (range 60-81) (males=4, females=16)	Elder care centre	Oculus Rift, Kinect motion sensor Comparison: Smart 3D TV	Cognitive and Physical Training	Exergame designed to improve motor and cognitive abilities	Trial(s): 1 Gameplay: 30 seconds per device	*Quantitative:* Customised usability questionnaire
Soares et al. (2021)	n=10 (mean=70) (male=3, female=7) comparison group: n=11 (mean=22) (male=3, female =8)	São Paulo/ Community	Oculus Rift, Microsoft Kinect Sensor	Cognitive and Physical Training	Three virtual reaching tasks completed while walking on a virtual path	Trial (s): 1 Gameplay: 30min	*Quantitative* SSQ, satisfaction Questionnaire (customised), Use of Technology Questionnaire , International Physical

Author/Yr	**Sample (age)(gender)**	**Country/ Recruitment Setting**	**Physical Hardware**	**Targeted Outcomes**	**Description of MR Application**	**Trial Schedule** *Trial: no. of session* *Gameplay: X minutes*	**UX assessment measure(s)** *Qualitative* *Quantitative*
Syed-Abdul et al. (2019)	n=30 (range 60-95) (male=6, female=24)	Aged care centre	Vive HTC VR system	Physical Training	Exergame with nine applications targeting physical stimulation	Trial(s): 2 sessions/wk x 6wks Gameplay: 15minutes	Activity Questionnaire *Quantitative:* Adapted TAM Scale

*GEQ: Game Experience Questionnaire

**SUS: System Usability Scale

***TAM: Technology Acceptance Model Scale

*****SSQ: Stimulator sickness questionnaire

Table 4 Main UX findings in included studies

Author/Yr	Main Findings – Instrumental UX	Main Findings – Emotional UX	Main Findings – Non-Instrumental UX
		Type of User Interface: Haptics Based MR Applications	
Boletsis and McCallum (2016)	Average system usability score (70.5; SUS) Users experienced loss of depth perception when interacting in the real world while watching the output on the tablet's screen There is a need to simplify interaction techniques to prevent confusion between actual and AR markers	Overall high scores of Positive affect, Immersion and Challenge (iGEQ) Some mini-games had high values of Negative affect and Tension and low Flow (iGEQ) System errors contribute to negative feelings of confusion, uncertainty and tension	N.A.
Chen et al. (2018)	Participant's prior experience in computer use had little to no impact on perceived usefulness (TAM2) Perceived ease of use was not related to usage behaviour, potentially because participants had limited prior experience in technology	Perceived playfulness and usefulness were positively related to intention to use and usage behaviour	Satisfaction with output quality (game interface and appearance) was correlated with perceived playfulness (enjoyment of application) Output quality was correlated with usage behaviour for cognitive games, suggesting its importance in designing cognitive games
Meza-Kubo et al. (2014)	All participants perceived the application as easy to use and useful	High perceived enjoyment of the application, with higher enjoyment of entertainment game versus cognitive game, potentially due to more familiarity with the entertainment activity Overall level of anxiety was low for all participants, but older adult participants had slightly higher level of anxiety than	N.A.

Author/Yr	**Main Findings – Instrumental UX**	**Main Findings – Emotional UX**	**Main Findings – Non-Instrumental UX**
		the younger relatives who accompanied them on the trials Participants reported high levels of intention to use.	
Santos et al. (2019)	25% attrition rate (3 out of 12) after one week due to health reasons and difficulties with device use Participants reported difficulties in understanding the game controls Game rules and goals were easily understood	Participants liked the level of challenge and reported high levels of engagement, satisfaction, motivation to play and enjoyment Participants reported weak sense of social presence and involvement with other people (GEQ)	Participants liked the game's visual style but disliked the game music
Wang et al. (2020)	Participants reported a high level of perceived usability, with sufficient level of perceived ease of use and perceived usefulness Participants and expert interviews indicated that the use of device can be improved with simpler and more intuitive controls and clearer instructions on usage	Participants reported finding the game interesting and experienced joy while gaming Participants indicated that using the device can improve their relationships with others and increase their willingness to join public activities Participants worried about forgetting how to play the game	Participants reported finding the device attractive Participants reported satisfaction with the colour brilliance and richness of game, with clearly perceived audio and visual stimuli Participants indicated a need to reduce the amount of information shown on the game graphics.
Type of User Interface: Exergame Applications			
Lee et al. (2021)	High system usability scores (94.60; SUS), indicating high levels of perceived acceptability and ease of use Low levels of cybersickness with minor symptoms of nausea or disorientation (SSQ)	N.A.	N.A.

Author/Yr	Main Findings – Instrumental UX	Main Findings – Emotional UX	Main Findings – Non-Instrumental UX
Liukkonen et al. (2015)	Game A (large muscle exercise game) failed to reach minimum acceptable usability (SUS :58.29) while Game B (body maintenance exercise) was at average level (SUS: 79.44) Item analysis suggested Game A was perceived as too complex and cumbersome; Authors also noted that the pace of Game B was calmer Interviews suggest most participants felt they could play the games without help, but some participants felt they may need help with home use due to being unaccustomed to the technology	Overall, more positive emotional experience in Game B (higher scores of Positive affect, Competence, Immersion, Flow and lower Negative affect; GEQ) Both games had low levels of psychological involvement with the other participants (i.e., social presence)	N.A.
Pyae et al. (2016) and Pyae et al. (2017)	Both Finnish and Japanese participants perceived the game positively in terms of perceived usability Comparison of results suggested greater acceptability by the Japanese participants Both groups did not experience disorientation after gameplay Participants from both groups indicated a need for visual cues due to their poorer eyesight and lack of experiences in digital gameplay and indicated a preference for voice-	Both Finnish and Japanese participants reported similarly high levels of positive affect in-game and post-game Japanese participants reported significantly higher level of perceived negative affect, tension and tiredness than Finnish participants although overall perceived negative affect was still low The Japanese groups perceived the game as more challenging than Finnish participants Both groups reported average levels of Flow, Immersion and Competence,	Both groups of participants indicated a preference for games simulated in real-world environment and that relates to sports and real-world activities Participants reported enjoying controller-free gameplay

Author/Yr	Main Findings – Instrumental UX	Main Findings – Emotional UX	Main Findings – Non-Instrumental UX
	based instructions in their own language Qualitative interviews indicated that some participants had experienced minor symptoms of cybersickness	indicating moderate levels of interest in gameplay Qualitative interviews indicated that low achievement in the first instance of gameplay would decrease motivation to continue playing in the future Novice game players reported a preference for simple gameplay over cognitively challenging gameplay Participants reported a fear of getting injured while playing the game, indicating a need to ensure that gameplay is designed to minimise physical risks	
Valiani et al. (2017)	Participants were able to complete 86.3% of the total sessions with acceptable level in the quality of movements	Participants reported a global appreciation score of 91.7%, indicating high level of acceptance. Difficulty level of the intervention was slightly lower than the expected minimum level.	N.A.
Zhang et al. (2021)	Participants with and without prior experience in electronic device usage both reported an above-average level of system usability with well-understood game objectives (SUS > 68)	N.A.	N.A.
Rebsamen et al. (2019)	No reported adverse events and 8% participant attrition rate 91% protocol adherence rate High levels of acceptance rate (TAM) and satisfaction (SUS: 93.5) and perceived usefulness	Participants found games to be highly enjoyable Qualitative findings suggest combining physical training with games was a motivating factor	Qualitative findings suggest gameplay can be more engaging, such as with the inclusion of music Qualitative findings found that participants wanted more

Author/Yr	**Main Findings – Instrumental UX**	**Main Findings – Emotional UX**	**Main Findings – Non-Instrumental UX**
	Qualitative findings suggest gameplay and usage of device were easily understood	Qualitative findings also suggest gameplay can be made more challenging to increase motivation	visual and auditive feedback while playing to increase engagement
		Type of User Interface: AR/VR Headset Applications	
Chan et al. (2020)	Minimal adverse events from VR activity, only 1.4 % of participants had severe simulator sickness (SSQ) Only minimal supervision required for VR use after initial training No significant difference in drop-out rates between VR (28.7%) and paper-and-pencil activities (19.8%)	Mostly comparable feelings of negative and positive affects between VR and paper-and-pencil activities (PANAS) Participants were significantly more excited with paper-and-pencil activity	N.A.
Postal and Rieder (2019)	No significant difference in perceived ease of use, ease of task execution, clarity of procedures and level of comfort between immersive headset and 3D TV device Observation of the sessions indicated that participants were uncomfortable when using 3D devices due to unfamiliarity with technology 40% of participants expressed that having a training session to familiarise themselves with the gameplay would increase their performance	Participants' interest in the gameplay was independent of their task performance, with users perceiving the application as interesting and beneficial	Observations of gameplay indicate that more intuitive visual and aural feedback is required to aid older adult users in understanding tasks

Author/Yr	Main Findings – Instrumental UX	Main Findings – Emotional UX	Main Findings – Non-Instrumental UX
	20% of participants had persistent difficulties in spatial orientation (e.g., not perceiving the need to open arms wider to accomplish task goal)		
Soares et al. (2021)	Low feasibility, with only 20% of older adult participants completing all three tasks, compared to 81.8% of young adult participants All older adult participants had mild cybersickness symptoms, with 8 participants stopping use of the system after first signs of cybersickness Execution of the tasks without supervision is not recommended due to the need for a safety harness Technical issues in the system could have contributed to high incidence of cybersickness	Older adult participants were more motivated to practice the game and recommend it to others when compared with young adult participants Most participants reported that they would not play the game at home due to difficulties in setting up the device and safety harness	N.A.
Syed-Abdul et al. (2019)	Perceived usefulness and ease of use predicted users' intention to use	Perceived enjoyment is a better predictor of intention to use than perceived usefulness, suggesting that enjoyment is an important motivator	N.A.

4.5.4 Population included in the review

While the included studies all involved healthy older adults aged over 60 years, there was considerable variation in the sample sizes (n=5 to n=236), with seven of the included studies involving fewer than 15 participants each. Similarly, there was a large difference in the reported mean participant age (67 to 81 years). Five of the studies included the age range without reporting the mean age (Liukkonen et al., 2015; Meza-Kubo et al., 2014; Postal & Rieder, 2019; Syed-Abdul et al., 2019; Valiani et al., 2017), with Syed-Abdul et al. (2019) reporting the widest age range of these studies (60-95 years). None of the included studies utilised random sampling. Seven of the studies recruited participants from the community, six recruited from aged care centres or homes, and two studies did not include details of their recruitment (Boletsis & McCallum, 2016; Meza-Kubo et al., 2014). One study specifically compared results between Western (Finnish) and Eastern (Japanese) cultures (Pyae et al., 2017) while four studies were conducted in an Eastern culture (Hong Kong, Korea, Singapore and Taiwan).

4.5.5 Types of technologies utilised

The included MR studies can be sorted into three main categories: studies that used a primarily haptics-based, exergame or AR/VR headset interface. Five of the studies used haptics-based applications; four papers used customised tangible devices (Boletsis & McCallum, 2016; Chen et al., 2018; Meza-Kubo et al., 2014; Wang et al., 2020), while one paper used a customised phone application (Santos et al., 2019). Six of the studies were exergames, with all using commercially available motion-detection systems such as Microsoft Kinect TM, SENSO TM system, 'Xtreme Reality' TM and 'Extreme Motion' TM technology (Lee et al., 2021; Liukkonen et al., 2015; Pyae et al., 2017; Pyae et al., 2016; Rebsamen et al., 2019; Valiani et al., 2017; Zhang et al., 2021). Two of the four AR/VR headset applications used the Kinect movement sensor in conjunction with the Oculus Rift TM (Postal & Rieder, 2019; Soares et al., 2021), one used the Vive TM VR system and one did not state the device model (Chan et al., 2020).

The Kinect system was used in four studies across exergame and AR/VR headset user interfaces and was the most commonly used commercially-available technology. All studies involving AR/VR headset technology used commercially available hardware, while three of the five haptics-based applications utilised a customised interface.

4.5.6 Outcomes targeted in the interventions

Of the included articles, six interventions focused on improving physical outcomes, five on both physical and cognitive outcomes, three primarily on cognitive outcomes, and one on cognitive outcome and sensory stimulation. All six of the interventions that focused on improving physical outcomes can be described as exergames, ranging from skiing (Pyae et al., 2017; Pyae et al., 2016), aerobics and light exercises (Syed-Abdul et al., 2019; Valiani et al., 2017), dance (Liukkonen et al., 2015), high-intensity interval training (HIIT) (Rebsamen et al., 2019) and cycling (Lee et al., 2021). This overlaps with the type of interventions used by studies that targeted both physical and cognitive outcomes, with three of the five studies also based on exergames (Chen et al., 2018; Postal & Rieder, 2019; Soares et al., 2021; Zhang et al., 2021). Other than exergames that are like non-virtual exercises, exergame intervention could also be like the gaming task designed by Soares et al. (2021), which required participants to virtually reach out for objects while walking on a virtual path. Differing from exergames, Santos et al. (2019) designed an AR card collection mobile game that encourages participants to venture outside of their homes for cognitive and physical stimulation.

Of the interventions that focused on cognitive outcomes, two used customised, tangible objects with gameplay like that of boardgames (Boletsis & McCallum, 2016; Meza-Kubo et al., 2014), while one used an immersive VR experience that allows users to virtually view different scenery (Chan et al., 2020). The study by Wang et al. (2020) was the only intervention that explicitly stated that it targeted sensory stimulation together with cognitive training and involved the use of a screen-based musical game that encouraged users to play a game to generate songs that sounded nostalgic to them.

4.5.7 User experience

Most of the included studies (n=11) utilised a quantitative measure of UX in the form of questionnaires, four studies (Boletsis & McCallum, 2016; Liukkonen et al., 2015; Pyae et al., 2017; Pyae et al., 2016; Wang et al., 2020) reported both quantitative and qualitative measures (interviews, focus-group discussion, observations). None of the included studies used a purely qualitative measure of user experience. Of the questionnaires used, the System Usability Scale (Brooke, 1996) was used by almost half of the included studies (n=7). Three of these studies used the Game Experience Questionnaire (IJsselsteijn et al., 2013) in conjunction with the System Usability Scale. Details of the quantitative and qualitative measures used in each study can be found in Table 3. The UX of the included interventions can be assessed through their instrumental quality, emotional responses from the use of intervention, and non-instrumental quality, as elaborated on in the introduction.

4.5.7.1 Instrumental quality

The trial schedule utilised by the studies was inconsistently reported, with four studies not clearly stating the number of gameplay sessions (Chen et al., 2018; Liukkonen et al., 2015; Pyae et al., 2017; Pyae et al., 2016; Wang et al., 2020). Four studies examined the UX through more than one session of gameplay. Zhang et al. (2021) trialled their Ping Pong application once weekly for six weeks, Valiani et al. (2017) trialled their aerobics exergame application twice weekly for four weeks, Rebsamen et al. (2019) trialled their HIIT exergame thrice weekly for four weeks, and Syed-Abdul et al. (2019) trialled their VR exergame twice weekly for six weeks. Studies with multiple trials were similarly all exergame-based, which may explain the methodological choice of having multiple trial sessions, with a consensus that the health impact of exercise is best shown with consistent engagement over time.

The duration of gameplay also varied widely, from 30-seconds of gameplay (Postal et al., 2019) to around 30-minutes (Boletsis & McCallum, 2016; Rebsamen et al., 2019; Valiani et al., 2017). Most studies utilised approximately 20 to 30 minutes of gameplay. The longest duration of trial was by Santos et al. (2019), who examined a mobile game application that measured participants over two weeks of free-play on the app.

Where reported, included papers described mild to no adverse reactions such as cybersickness. Chan et al. (2020) was the only paper to report its drop-out rate and suggested that drop-out rate was low when the MR application was compared with traditional gameplay. Several studies suggested the need for better communication with older adults, including a need for a clearer explanation of device use (Boletsis & McCallum, 2016; Santos et al., 2019) and more visual and aural feedback to increase understanding and immersion (Postal & Rieder, 2019). There is also a need to customise the level of gameplay to a comfortable level for older adults. This includes adjusting the game pace (Liukkonen et al., 2015), difficulty level (Soares et al., 2021) and using settings that were more familiar to older participants (Liukkonen et al., 2015; Syed-Abdul et al., 2019).

4.5.7.2 Emotional reaction

Examining the emotional reactions triggered by gameplay, all included studies suggested that their application was perceived to be enjoyable. However, there were differing views on whether enjoyment of gameplay or perceived usefulness was a bigger motivating factor. Syed-Abdul et al. (2019) found that the enjoyment level perceived by older adults increased intention of use more than its perceived usefulness, and Postal and Rieder (2019) found that participants' interest in gameplay was independent of their task performance during the trial, suggesting that enjoyment was an important motivator. In contrast, Chen et al. (2018) found that participants' acceptance of the game was more dependent on the perceived usefulness by the gamer than perceived enjoyment.

Few papers reported social presence in gameplay, and those that did, reported a low level of social presence and involvement with other users (Liukkonen et al., 2015; Santos et al., 2019).

4.5.7.3 Non-instrumental quality

Six studies reported non-instrumental factors such as users' appraisal of the devices' aesthetics (Chen et al., 2018; Postal & Rieder, 2019; Pyae et al., 2017; Pyae et al., 2016; Rebsamen et al., 2019; Santos et al., 2019; Wang et al., 2020). These studies indicated that when non-instrumental factors are examined, older adults expressed a need for intuitive visual and aural feedback to increase their engagement (Postal & Rieder, 2019; Rebsamen et al., 2019), yet without too much information shown on the game graphics (Wang et al., 2020). Participants also indicated a preference for games simulated in real-world environment and are related to sports and real-world activities (Pyae et al., 2017; Pyae et al., 2016). Furthermore, participants indicated that the output quality impacted their enjoyment of (Chen et al., 2018) and engagement with the game (Rebsamen et al., 2019).

4.6 Discussion

This systematic literature review provides an overview of the user experience of healthy older adults with MR applications that are designed to enhance their physical activity and social interaction. The results provide evidence to support use of MR technology in this population across a range of applications that include haptics, exergame and AR/VR headset interfaces. Although the quality assessment indicates that most studies were of high-quality, the diverse range of MR applications, UX measures and health outcomes made it difficult to compare results across studies. Results showed that instrumental quality and emotional reactions to MR-based applications were commonly measured, while non-instrumental factors were not. Overall, the instrumental and emotional quality of the investigated MR applications were high. The discussion below considers this pattern of results and its implications for the design of MR applications for healthy ageing.

4.6.1 Do the included studies measure all aspects of UX?

A main research objective of this paper was to find out how the user experience of MR-related technologies was evaluated in recent studies involving healthy older adults. While all 15 studies measured the instrumental quality of their applications, and all but two measured emotional reactions triggered by gameplay (Lee et al., 2021; Zhang et al., 2021), only six studies examined non-instrumental qualities of the application(Chen et al., 2018; Postal & Rieder, 2019; Pyae et al., 2017; Pyae et al., 2016; Rebsamen et al., 2019; Santos et al., 2019; Wang et al., 2020). The limited information on non-instrumental qualities makes it challenging to understand how the aesthetics of the applications may affect participants' level of engagement and usage behaviour.

When comparing UX measurements between different types of MR applications, we observed that studies on AR/VR headset applications had largely neglected measurement of non-instrumental UX. This finding was surprising given that the aesthetics of AR/VR headset applications, where game design focuses on the visuals of the immersive virtual environment, would likely impact the UX of a MR application. Many of the AR/VR headset applications were pre-designed games that did not appear to be customised specifically (or easily) for older adults (Soares et al., 2021; Syed-Abdul et al., 2019). For example, the same virtual reaching task was tested on both young and older adults (Soares et al., 2021). In comparison, when customised interfaces were used, measurements of non-instrumental UX were more likely, exemplified by Chen et al. (2018) and Wang et al. (2020) in the haptics-based application category. Both studies showed that game attractiveness, audio and visual output quality were associated with user satisfaction.

4.6.2 How was the UX of MR application perceived by healthy older adults?

Based on the findings of studies that measured non-instrumental quality of the MR applications, games that mirror real-life activities and sports, such as simulation of skiing, cycling and walking outdoors (Lee et al., 2021; Pyae et al., 2016; Soares et al., 2021), were reported to appeal to the users. While it has been suggested that older adults may prefer such games (Pyae et al., 2017), the precise reason for this preference remains unclear; five of the six studies that assessed non-instrumental quality did not examine the players' perception on the internal content of gameplay. Instead, these studies focused more on the quality of visual and auditory outputs from the devices per se--enjoyment of gameplay was associated with the richness and quality of visual and auditory outputs (Chen et al., 2018; Pyae et al., 2017; Pyae et al., 2016; Rebsamen et al., 2019; Wang et al., 2020). It appears that the familiarity of game content appealed more to the older adult users: with familiarity comes a sense of comfort that may enhance both engagement and motivation (Zhang et al., 2019). The positive impact of familiarity is even more important for older adults who have less technology experience (Hwang et al., 2011), although further research is required to confirm this hypothesis.

In relation to instrumental quality, few studies reported adverse impacts of the MR applications on their users, suggesting MR applications are generally safe to use. There were, however, some isolated instances where gameplay induced feelings of unease and/or mild nausea. For example, challenges were evident in the study by Soares et al. (2021), where 80% of the older adults could not complete all three game tasks due to mild cybersickness symptoms. In addition, the included papers have generally indicated a high level of perceived system usability, perceived usefulness, and perceived ease of use, further supporting their use with older adult populations. An exception is the study of Liukkonen et al. (2015), which reported that one of their games was perceived as too complex and cumbersome by the older adult users, such as confusion about the game objectives and finding the game speed to be too fast, leading to a low usability score. Together, although adverse events are uncommon, developers should continue to carefully test their applications to ensure game design accommodates the physical and cognitive capabilities of older adults and their past experience with MR technologies, relative to younger adults.

In relation to the emotional quality of applications, an intriguing connection is evident between game complexity on the one hand, and levels of engagement, motivation and performance on the other for older adults. In game design, the level of challenge is known to impact user engagement. In younger student populations, Hamari et al. (2016) found that the challenge of the game can increase engagement when learning such games. With older participants, the study of Pyae and colleagues (2017) showed that older adults may perceive less challenging games as more enjoyable, and that games that were too difficult at first use may reduce their motivation to keep playing (Pyae et al., 2017). Games that are too complex may also hinder the older participants' ability to participate in gameplay (see Liukkonen et al., 2015 and Soares et al., 2021). This may be particularly evident when there are differences in computer literacy within the older adult population, with some just beginning to use digital technologies and others having kept up with the latest technologies (Tyler et al., 2020). By comparison, two studies have indicated that the amount of user-interaction complexity in their game design motivated gameplay (Rebsamen et al., 2019; Santos et al., 2019). These mixed results prompt further research on how game complexity may impact the emotional quality of the MR application.

Specifically, future research should investigate how the level of challenge affects motivation for gameplay, and how best to balance the need to scale game complexity for training purposes with the need to keep older adults motivated and using the devices. A Dutch study on the motivations of older adults participating in VR training suggested that both enjoyment and challenge, conceptualised as the drive to perform, were intrinsic motivators (De Vries et al., 2018). The concept of challenge was associated with receiving positive visual feedback, so that participants were aware when they perform well, and with a game speed that is fast enough to increase challenge without overstressing older adult participants (De Vries et al., 2018). By comparison, Subramanian et al. (2020) showed that older adults were intrinsically motivated by the enjoyment of exergame play and not by the level of challenge, unlike younger adults (Subramanian et al., 2020). Both studies did agree, however, that enjoyment and perceived effectiveness of the game were important motivators for older adults (De Vries et al., 2018;

Subramanian et al., 2020). Future research can also look into the use of dynamic difficulty adjustment (DDA) in game design (Ang & Mitchell, 2017; Cantwell et al., 2012). DDA is where the complexity level of the game is balanced against each user's performance and skill. This also allows players of different levels to play together. There is little available data about how DDA works with healthy older adult users, but some studies have looked into using DDA in rehabilitation exergames for older adults (Pezzera & Borghese, 2020; Smeddinck et al., 2013). In this review, a third of the studies were based in an Eastern culture (Chan et al., 2020; Chen et al., 2018; Lee et al., 2021; Pyae et al. 2016; Pyae et al., 2017; Zhang et al., 2021), while 27% were based in a Western culture and the remainder (40%) provided insufficient detail to be certain of their setting. There is insufficient information on cultural differences in the included studies to form a commentary on the cultural impact on UX, with only Pyae et al. (2017) comparing participants across different cultures, it would be beneficial to understand how the participants' environments impact their experience of MR applications. Future research should investigate cultural and socio-economic factors that influence UX of MR applications for healthy ageing.

4.6.3 What are the considerations for future game design?

The lack of information of non-instrumental quality of the MR applications for healthy ageing is concerning because MR technology is being enlisted to provide both an entertaining and attractive way for older adults to stay active. By overlooking aesthetics in game design, even simple games that are user-friendly may not attract and engage users in the longer term, thereby reducing their potential health benefits. De Schutter and Abeele (2015) have boldly proposed that focusing primarily on the benefits and accessibility of gameplay diminishes the intrinsic value of gaming. More useful and meaningful is a game design framework that takes into account the aesthetic and ergonomic preferences of the players themselves (De Schutter & Abeele, 2015).

Indeed, when included as game co-designers, older adult participants identify aesthetics as essential elements of fun and attractive gameplay (Havukainen et al., 2020). Taken together, it is recommended that future game design seriously considers the aesthetics of the application.

Instrumental quality of MR applications may be enhanced in the future by ensuring clear user instructions, improving both the user's sense of control when interacting with the virtual environment (Witmer & Singer, 1998) and intuitiveness of game control. Studies that used participant interviews found that improving the clarity of instruction and intuitive design of user interfaces and controls can enhance the usability of applications (Boletsis & McCallum, 2016; Liukkonen et al., 2015). Several studies used trained facilitators on-site to explain game process and answer any questions the participants had during game play (Chan et al., 2020; Meza-Kubo et al., 2014). The earlier systematic review by K. S. Thach et al. (2020) also showed that UX was improved when facilitators were around to provide guidance on the usage of the applications. As well, the clarity of instructions can also be improved by having a guided game tutorial session before actual gameplay (Pyae et al., 2016), which provides an opportunity for users to learn and familiarise themselves with the interface (Liukkonen et al., 2015), and is especially important when older adult users may be unfamiliar with technology. Liukkonen et al. (2015) also suggested that a longer play session would give older adult users more time to learn the game, which may help them to relax and immerse themselves in gameplay.

With respect to the fidelity of study design, user experience was only examined across one session of gameplay in most studies, with limited data on user experience after extensive use of the MR application. It was also common for studies to use a small sample size, impacting the methodological quality of studies and generalisability of results. Eleven out of 15 studies utilised only quantitative measures of UX, missing an opportunity for deeper insight into the older adults' experience of gameplay by including qualitative measures of UX. All studies reviewed had a focus on improving aspects of health like cognition or physical activity. This focus may reflect the assumption that ageing is a period of decline in cognitive and physical abilities (De Schutter & Abeele, 2015), instead of a life-stage like any other that can be enjoyed and offer new opportunities for game play and socialising. To redress this assumption, future research should investigate the non-instrumental qualities of user experience. Games that are designed for play (both competitive and cooperative) rather than for improved health could be a positive addition to the discourse on MR applications that promote healthy ageing.

In general, it would benefit game development if older adults themselves were enlisted as co-designers, as they are the ones who best understand their experience of game use (De Schutter & Abeele, 2015; Havukainen et al., 2020). The concept of co-designing was not explored by any of the included studies in this review. Involvement of older adults as co-designers from the initial conceptualisation phase of game design will help game developers scale the level of challenge according to their needs and preference, design an interface that is attractive to them, and ensure that game controls are intuitive and easily understood.

4.6.4 Limitations

Wide variation in the type of MR application and use of less rigorous research designs has precluded a meta-analysis of results. We anticipate that heightened interest in MR technology will see a much larger body of work in the near future, supporting meta-analysis.

Our systematic review excluded conference papers, while studies published in languages other than English were also omitted due to challenges in professionally translating the papers. It is acknowledged that this exclusion may introduce bias in the results. In effect, several more recent (non-journal and non-English) papers were excluded from this review.

4.6.5 Strengths

The strengths of this review lie in providing a comprehensive look at how studies concerning MR-applications for healthy ageing have analysed the different aspects of UX - the instrumental, emotional and non-instrumental components. This provides researchers and practitioners with a better understanding of how technology may be perceived by older adults, going beyond perceived functional benefits to identify gaps in the research and design of MR-related applications. The studies included in this review were carried out across different countries and cultures, and showed the vibrancy of the research in this area.

4.7 Conclusion

Results of this systematic review have indicated that the instrumental quality of the MR applications remains the focus of UX studies, with far fewer studies examining their non-instrumental quality. Encouragingly, these studies show promising results on conventional aspects of instrumental quality and emotional experience. The neglect of non-instrumental quality is, however, surprising given such aspects of UX are most likely to impact the experience and behaviour of older adults, especially when using audio-visual-based MR applications, such as AR/VR headset applications. Co-design frameworks are a useful approach to game design that may help redress this limitation.

Future research needs to examine the multi-faceted nature of UX, especially its non-instrumental qualities, and track user experience across a longer period of use to confirm its usability and acceptance level. In doing so, research should consider the use of UX questionnaires that examine all three components of the CUE model of UX (Thüring & Mahlke, 2007), such as the CUE questionnaire (Minge et al., 2017).

Chapter 5 Extended Methodology

In this thesis, empirical studies two (Chapter 6) and three (Chapter 7) shared the same mixed-method research design, participant selection criteria, questionnaire and interview questions, data collection, and data analysis procedures. While the study populations were carefully described in the individual studies, they are also introduced here for completeness. This chapter provides additional information to explain the rationale behind the methodological choices.

The studies included in this thesis follow the same theoretical foundation of the fPRC and CUE, and were both designed to measure the same constructs of active participation and multi-faceted interpretation of UX, each operationalised identically, despite having two different samples. Hence, the same methodology was applied to each study as much as possible to ensure internal consistency, a coherent research design and increased internal reliability. Keeping the research methodology consistent also reduced confounding variables and strengthened the validity of any cross-study comparisons made in the General Discussion of this dissertation, and any differences in results would more likely indicate variations in the two samples rather than methodological differences. This approach not only allowed for valid comparisons but also enabled the identification of the unique needs and characteristics of each community (retirement community vs. residential aged care facility), providing more nuanced insights into each population’s experiences and requirements. Findings from each study were then integrated and synthesised in Chapter 8 to form a general discussion on the overall utility and UX of MR applications for older adults.

5.1 Participants

Both studies in this thesis recruited older adults in good health above 60 years of age. Participants were required to have the cognitive ability to give informed consent and have sufficient physical, visual, and hearing ability to engage in at least a half-hour activity. This included being able to hold and manipulate objects on a table surface while seated or standing and having well-preserved or corrected-to-normal vision to locate and interact with tangible objects and each other. Individuals were excluded if they were below the age of 60, were hospitalised or part of a rehabilitation trial, and/or if were diagnosed with a disorder of ageing that significantly affected their cognitive and/or motor skills (e.g., Alzheimer's or Parkinson's disease). The studies differed in the recruitment site, with Study 2 basing the research on older adults living in a retirement village in regional Victoria, while Study 3 was conducted in an aged care facility in inner city Melbourne. Eleven people participated in Study 2 (M±SD age=78±7.94 years), while ten residents participated in Study 3 (M±SD age=87±4.7 years).

While both represent community-based samples, there are demographic differences between older adults living in retirement villages and those living in aged care facilities. Each cohort has different physical and psychological needs and expectations of their living environment, therefore it is important to consider these individual groups separately to understand better how to improve the opportunities and support that are provided. Retirement village residents are typically relatively healthy, independent-living, and financially secure, but may have chosen to live in a community with others of their age due to changes in their social network. In some cases, people living in retirement villages may have lower levels of perceived social support from their family and friends or have previously lived in a neighbourhood with lower social cohesion; hence, a retirement village may be perceived to foster social interactions and engagement (Crisp et al., 2013; Graham & Tuffin, 2004). Based on the results of an Australian study, they may also choose to relocate to a retirement village due to anticipating a decline in health, and would prefer a home environment that has accessibility features and is situated in close proximity to medical facilities (Crisp et al., 2013).

Compared to retirement village residents, older adults living in aged care facilities typically have more significant health challenges and require the medical and personal care assistance provided by these environments. A study by Ambagtsheer et al. (2020) involving 592 adults aged 75 years and over who were living in Australian aged care facilities found that approximately 90% of the older adults met criteria for frailty (44%) or pre-frailty (46%). Furthermore, individuals living in aged care facilities are more often: i) female, due to their longer life expectancy; and ii) older, with 54% of individuals entering permanent residential aged care in 2021 to 2022 being 85 years or older (Australian Institute of Health and Welfare, 2024a).

These differences in the demographics of people living in retirement villages compared with aged care facilities emphasises the importance of carrying out separate research in each community setting to provide comprehensive insights into ways to encourage healthy ageing in these two environments.

5.2 Equipment and data collection

5.2.1 EDNA Playboards

The Elements by Dynamic Neural Arts system (EDNA Playboards) is a multiplayer, co-located, non-immersive, gamified and interactive MR experience. This system has been validated in earlier research by Duckworth et al. (2015) and Rogers et al. (2021) in areas of rehabilitation.

The EDNA Playboards system belongs to the surface computing subset of MR-based digital interactive experiences. It consisted of a 55-inch multi-touch screen mounted on a table, coupled with an integrated computer and marker-based tracking system. An external speaker connected to the tabletop display provided clear audio throughout the space. EDNA Playboards features a collection of four hand-held objects known as tangible user interfaces (TUIs), each with a distinct colour and shape, and a specific arrangement of three raised conductive touch points at the base. The triangular formation of these touch points enables the software to accurately monitor the TUI's position, centre, and rotation when held by users. This allowed users to engage with virtual environments presented on a flat digital display table through a variety of movements, including reaching, grasping, lifting, sliding, and placing.

EDNA Playboards allows up to four participants to engage in each game. The digital environment is crafted to facilitate various forms of interaction, whether collaborative or competitive. Four games were used in this study (Figure 4): i) Mixer, a game that required players to match objects and place them onto specific shapes so as to trigger audio-visual effects; ii) Pangles, a puzzle game where players must strategically place objects to completely surround the borders of a target shape, developing their problem-solving and spatial reasoning skills; iii) Paint Wars, a competitive game where players swipe and touch to control a spaceship that collects coloured shapes, with the victor determined by who accumulates the most shapes; and iv) Resonance, where players discover audio-visual elements through the exploration of a musical interface. Each of these games are described in more detail in Chapter 6 (Study 2).

Figure 4 Games included in EDNA Playboards

Ageing brings about changes in physical abilities (Tieland et al., 2018), and older adults, as a population, are often considered to have a lower level of computer literacy (Van Deursen, 2020), which may necessitate choosing digital activities that have accessibility features for older adults. An inclusive design is important for the studies within the thesis, as ageing can negatively impact overall gross motor skills and sensory acuity. As a result, some older adults may prefer to sit rather than stand for long periods or might require adjustments to audio-visual elements for their comfort. The design and functionality of EDNA Playboards was such that it is an inclusive choice for older adult players.

An important component of an inclusive game is the ability to customise the set-up and gameplay to tailor the experience to each individual's abilities and skills (Garcia & de Almeida Neris, 2022). EDNA Playboards provides users with the option to sit or stand while engaging in the device's activities, depending on their physical capability and personal preferences. Importantly, having both sitting and standing participants in the same game session does not affect the overall gameplay. The hand-held tangibles are designed with ergonomic principles, such as ensuring the handles are large enough to be easily gripped and seen, lightweight, and operate through straightforward and familiar gestures akin to the use of a pen. Music from the device plays through a speaker with adjustable volume, ensuring clear audibility for everyone. EDNA Playboards utilises an assortment of large design components with high colour contrast, visual elements that may help with visual focus, legibility and task performance (Zhou et al., 2022). These design considerations decrease the likelihood of physical discomfort caused by the games.

5.2.2 Questionnaires

As part of quantitative data collection, each participant was invited to complete a questionnaire that included the Virtual User Experience Questionnaire (VUE-Q; Witmer et al. 2005; Witmer & Singer, 1998), Game Experience Questionnaire (GEQ) Core, Post-Game and Social Presence (IJsselsteijn et al., 2013). Possibly due to the relatively new nature of the UX research field, few of the existing game or user experience questionnaires have been fully empirically validated, making it difficult to find highly validated questionnaires in general (Johnson et al., 2018), and no validity data was explicitly found for older adult populations at the time of writing this thesis. In the absence of measures that were validated with older adults, the GEQ was chosen for this thesis, as it has been extensively used by other papers in the healthy ageing area (see below), and the VUE-Q, which has been used to test an earlier iteration of EDNA Playboards. Further explained below, the two questionnaires were also chosen as they were able to measure aspects of active participation, and the instrumental, non-instrumental (emotional) and aesthetics components of user experience. User experience (UX) is a multi-faceted term (Hassenzahl & Tractinsky, 2006; Saariluoma & Jokinen, 2014; Thüring & Mahlke, 2007), that includes three main aspects: the perception of the application's instrumental quality (e.g. usability), the emotional reactions triggered by the application (e.g. subjective feelings of the user), and the perception of its non-instrumental quality (e.g. visual aesthetics). This multi-faceted approach also fits the Component of User Experience model of UX (Thüring & Mahlke, 2007) and The Family of Participation-Related Constructs (fPRC), proposed by Imms et al. (2017), that were used as the theoretical foundation of this paper.

The GEQ is a game and user experience questionnaire with seven subscales that include sensory and imaginative immersion, flow, competence, positive affect, negative affect, tension, and challenge. Flow, when a user is fully immersed and engaged in the activity and the social presence sub-questionnaire, how users feel socially engaged with others in the same activity, may indicate active engagement; competency and challenge, where a user perceived whether they have the skill to engage in the activity and the difficulty it requires, may measure both active participation and usability; positive affect, negative affect and tension measures emotional and aesthetic components of UX. Factorial analysis of the GEQ suggested that its theorised structure is partially supported, but it was determined that three of its seven constructs (namely negative affect, tension and challenge) had too much overlap, with the authors suggesting that these be combined into one construct (Johnson et al., 2018). Nonetheless, the GEQ was included as part of this study as it has been extensively used in human-computer interaction research in general, and more specifically in UX studies of MR applications for healthy older adults (Boletsis & McCallum, 2016; Liukkonen et al., 2015; Pyae et al., 2017; Santos et al., 2019). Its multidimensional approach provides a comprehensive assessment of user experience (IJsselsteijn et al., 2013), leading to a better understanding of the complex, multi-faceted nature of UX than single-dimension measures. The GEQ has also been used in different countries such as Japan and Finland (Pyae et al., 2017), in both urban and regional contexts (Liukkonen et al., 2015), and in community samples (Liukkonen et al., 2015; Pyae et al., 2017; Santos et al., 2019), supporting its use across different participant populations. This fits the demographics of participants in Studies 2 and 3, with both involving community samples, Study 2 based in a regional setting, and Study 3 being situated in an urban setting.

VUE-Q was previously used in an evaluation of EDNA Resonance, a version of EDNA designed for individuals with acquired brain injury, thereby increasing its reliability and validity for evaluating a similar application. VUE-Q includes components of familiarity, enjoyment/engagement, instrumental quality /controllability /ease of use, non-instrumental qualities, health and well-being benefits, social engagement and immersion. A key component that necessitated the use of the VUE-Q in this study was that it measures the aesthetics (non-instrumental) component of UX in addition to the application's instrumental usability and emotional impact. The addition of the aesthetics component differs from the other questionnaires commonly used in UX evaluations, such as the GEQ and System Usability Scale (SUS). The VUE-Q component of instrumental quality/controllability/ease of use measured usability, while components of immersion, engagement/enjoyment and social engagement, which can be interpreted as measurements of active engagement of the users.

5.2.3 Semi-structured interview

In addition to the questionnaires, participants were invited to participate in a semi-structured interview either on a one-to-one basis or as a small group, depending on the participant’s preference. This ensured that the participants were comfortable and open to sharing their thoughts on the EDNA Playboards, potentially leading to richer data. Allowing a choice in the interview format also respects the participant’s autonomy and ethically aligns with the principle of informed consent. The use of a semi-structured interview format also allowed for flexibility in the discussion while ensuring that main areas of UX are covered. The interview was designed to explore six key areas, each targeting different dimensions of the participants' experiences and providing a nuanced understanding of their thoughts and feelings surrounding EDNA Playboards. The questions used in the interview were:

i. Points of interest: i.e., What parts or aspects of EDNA Playboards did you find interesting? Can you please explain why you found it interesting?

ii. Design feedback: i.e., What design features of the EDNA Playboards’ games did you like the most? Why did you like them?

iii. Experience feedback: i.e., What was the best part of the experience? What was the worst part of the experience? Would you like to play with more applications like this in the future, and why?

iv. Movement awareness: i.e., Were you aware of your movements while using EDNA Playboards? Do you see any relationship between your movements and the EDNA Playboards display or environment? If so, what did you notice?

v. Social participation: i.e., Did you engage or interact with others during the session? How did you engage or interact with others?

vi. Other remarks: i.e., Would you recommend using EDNA Playboards to others? Was there anything about the experience that was uncomfortable? What design features would you like to change or add?

5.3 Data analysis

For this thesis, Studies 2 and 3 sought to use a mixed-method design, combining quantitative questionnaires and semi-structured interviews. This approach was selected as it was considered to provide a comprehensive understanding of the older adults' experiences (i.e., user experience; UX) with using the EDNA Playboards system by integrating quantitative and qualitative data to create a richer picture. Utilising a mixed-method increased validity and generalizability as the data from each method both complement and contextualise the findings, allowing for cross-validation of the results. The following sections describe the specific analyses used for the quantitative and qualitative components of this research.

5.3.1 Quantitative data analyses

In line with a previous study utilising the VUE-Q (Rogers et al., 2021), the raw subscale scores were converted into percentages. Scores of 70% and above were considered high and positive, scores of 50% and above were classified as medium, and scores of 40% and below suggested low performance. For GEQ scores, means and standard deviations were calculated to provide an overall understanding of the user experience and its variability across multiple domains within this older adult sample.

5.3.2 Qualitative data analyses

Semi-structured interviews were conducted with the participants and the interview transcripts qualitatively analysed. Voice recordings of interviews were transcribed and subsequently uploaded into NVivo. Three researchers independently reviewed and analysed the transcripts in full to code and cluster key concepts. Following these independent analyses, the research team worked collaboratively on the qualitative analysis by sharing their individual assessments, further reviewing the transcripts, and refining the coding and clustering of key concepts. Potential themes were then derived from these codes and reviewed collectively by the researchers to ensure consensus on the finalised themes. No predetermined limit was set on the number of codes or themes that could be derived from the interview transcripts. The qualitative approach used in this research was based on the reflexive thematic analysis method described by Braun and Clarke (2006) and was guided by a worked example (Byrne, 2022) to ensure compliance with this protocol. The primary objective of reflexive thematic analysis is to conduct a systematic and rigorous examination of qualitative data while recognising the subjective nature of interpretation. This framework allowed for flexibility in data exploration as no pre-established codes or theoretical viewpoints were used, allowing for flexibility and openness in data exploration without prior assumptions. An iterative process was followed for coding and theme development. Initially, codes were refined and organised into potential themes. These themes were reviewed against the full dataset and revised further until clear themes were formed. This iterative process ensured the themes were grounded in the data and supported by evidence.

In summary, the quantitative results provide an overall view of the older adults' gameplay experiences as per the CUE theory, such as analysing the degree of positive emotion and challenge, while the interviews gave a better understanding of the underlying reasons behind why it may be so, including how the environment may have influenced their experience. This was important to identify the barriers and supports to participation, as suggested by the fPRC theory.

5.4 Ethics approval

This was a joint study by the Australian Catholic University and RMIT and was approved by both universities' Human Research Ethics Committees. The HREC number under ACU is: 2022-2863R. The ethics approval letter is attached in Appendix B.

Chapter 6 Study 2: User experience of EDNA Playboards game system in community-dwelling older adults

6.1 Abstract

The aim of this study was to explore the experience of healthy older adults while using a digital interactive technology, designed to encourage physical and social activity, and cognitive stimulation. Specifically, their use of the EDNA Playboards system, a large multi-user system comprising a set of both collaborative and competitive interactive games using tangible interfaces was examined. A mixed-methods research design was used. Eleven residents (*M*±*SD age*=78±7.94 years, six males and five females) from a retirement village in Australia participated in the study. Quantitative and qualitative findings from this study indicated an overall positive game experience, with participants perceiving social and cognitive benefits, and a preference for clear task goals, suitable levels of challenge, extra familiarisation time and audiovisual effects that are identifiable rather than abstract. These preferences provide some important insights for game designers who are tailoring interactive systems for older adults.

6.2 Introduction

The number of older adults in the global population is on the rise (World Health Organization, 2024), with estimates from the World Health Organisation (WHO) indicating that the proportion of the population aged 60 and above will nearly double from 12% in 2015 to 22% by 2050. Additionally, the number of people aged 80 and older is anticipated to triple, reaching 426 million (World Health Organization, 2024). Currently, in Australia, one in six people are aged 65 and over (Australian Institute of Health and Welfare, 2023), and older adults are projected to make up around 38% of the total population by 2050 due both to low birth rates and increasing life expectancy (Rudnicka et al., 2020). Therefore, healthy ageing has become an important focus in public health and gerontology research (Fleury et al., 2022). This focus goes beyond simply addressing the diseases associated with old age, and includes developing and maintaining high functional ability, physical health, and well-being in older age (Aronson, 2020; Fleury et al., 2022). This study addresses the issue of how new digital technology can be used to facilitate social engagement, cognitive stimulation and physical exercise among residents living in a retirement village.

Ageing brings about changes in cognitive, motor, and social interaction, which can have a detrimental effect on participation and quality of life. Research has shown that older adults often experience a decline in cognitive functions, that may present as memory impairment, reduced working memory and slower processing speed (Williams & Kemper, 2010). As well, there are age-related declines in coordination, balance, and loss of muscle mass, which can increase their risk of falling, sustaining injuries, and hospitalisation (Tieland et al., 2018). Socially, older adults may face difficulties in maintaining social connections after leaving the workforce, loss of family or friends, and physical limitations that prevent them from participating in social events, which can induce a sense of social isolation and impact quality of life (Krueger et al., 2009). Importantly, these factors interact, which can either exacerbate the rate of decline or present opportunities to better maintain health and function. For instance, a higher level of social engagement and physical activity is associated with better cognitive function and emotional well-being (Krueger et al., 2009; Williams & Kemper, 2010).

There is a pressing need for innovative approaches, including the use of new technologies, to foster healthy ageing. Gamified Mixed Reality (MR) interactive experiences for healthy older adults, in particular, may offer a fun, engaging way to foster healthy ageing in terms of improving cognitive, physical, and social skills (Lim et al., 2023). In this paper, MR refers to a range of technologies that combine the physical and digital environment, from Virtual Reality (VR) that utilises head-mounting displays to Augmented Reality (AR) applications that often uses large-screen projection and hand-held tangibles that increases sensory immersion (Lim et al., 2023; Skarbez et al., 2021). Immersion refers to the degree to which a system can engage users in a digital experience through technologies that impact the user's perception of reality by blending digital components into the real-world setting (Slater & Wilbur, 1997).

In the context of interactive experiences, "gamified" refers to the integration of game elements or mechanisms into digital experiences, leveraging the intrinsic motivational aspects of games to encourage user participation, learning and enjoyment (Condino et al., 2022; Seaborn & Fels, 2015). The benefits of gamified MR interactive experiences can be seen in the results of several studies. For example, Wais et al. (2021) has shown that a virtual reality (VR) spatial wayfinding game intervention led to a significant improvement in long-term memory capacity of healthy older adults when compared with a placebo control group. The authors hypothesized that the game's effectiveness may be due to the immersive nature of the novel learning experience offered by 3D functionality of the head-mounted VR display, which allowed for building of richer memory networks, but this may need to be ascertained with comparison of the same intervention in a non-VR application. Moreover, MR applications can help improve motor skills and encourage physical exercise, a fundamental aspect of maintaining physical well-being. In a randomised controlled trial of a MR application for active, community-dwelling older adults, Gonçalves et al. (2021) showed that participants receiving one MR session and one session of traditional exercise per week had significant gains in upper-body strength compared to the control group who underwent two weekly traditional exercise group sessions. In addition, there was also a significant increase in lower-body and upper-body strength from pre- to post-intervention.

Shared, surface computing using interactive tabletop displays provides a medium for social interaction and physical activity. In the general population, a multi-user tabletop interactive storytelling system (Alofs et al., 2015) and a fish-themed video game played on a tabletop tangible user interface (Yoon et al., 2004) have been designed to encourage social interaction even between players not previously known to each other. Systematic reviews on digital and AR applications designed for older adults also indicated promise in the use of touch-based surface computing (Buyl et al., 2020; Lim et al., 2023). EDNA Playboards is a game system adapted from a previous intervention for clinical adult population called Resonance (Duckworth et al., 2015), with demonstrated efficacy on functional performance and social interaction. Given its intuitive design and aesthetic features, the EDNA Playboards system may also encourage cognitive stimulation, physical activity and social interaction in healthy older adults.

6.2.1 Design considerations

Designing MR applications for older adults that promote activity and participation requires careful consideration of human-computer interaction and related factors. Key considerations include ways to avoid physical discomfort, age-related differences in physical and cognitive functioning, and potential cybersickness associated with some MR applications (Drazich et al., 2023). For example, designs that allow for user-specific customization of the auditory (e.g. increasing volume) and visual elements (cleaner interface or reduction of graphics) of an application can mitigate age-related changes in hearing and vision, while applications that can be used on mobiles may mitigate gross-motor difficulties faced by some older adults (Williams et al., 2013). Without the prospect of adverse physical reactions, older adults will be more inclined to participate in MR applications, reaping their potential benefits (Drazich et al., 2023). Involving older adults in the research process of designing a MR application for their use would be critical in understanding their needs and in turn being able to create applications and interactive experiences that they would want to continue participating in (Mannheim et al., 2019).

Making allowances for older adults' unfamiliarity with current digital technology, intuitive interfaces and user-friendly game designs can help bridge the digital divide (Riggins & Dewan, 2005). Encouraging multi-player experiences, especially games where players are co-located, may alleviate feelings of isolation and foster a sense of community that can extend beyond game sessions. In addition, co-located multiplayer games appear to be more favourably regarded by older adults than online multiplayer games, as suggested by their lower levels of enjoyment compared to younger counterparts while playing online multiplayer games (Salmon et al., 2017). Ultimately, factoring in these considerations into game design not only enriches the user experiences of older adults but also contributes to their overall quality of life.

6.2.2 Gaps in current research

The prevailing focus of current systematic reviews revolves around evaluating the efficacy of MR applications, primarily examining aspects such as physical well-being, health outcomes and quality of life (Buyl et al., 2020; Dermody et al., 2020; Miller et al., 2014). While these reviews indicate promising advantages for physical health, the studies encompassed within them were assessed to be of low to moderate quality due to a limited sample size and the use of non-RCT (randomised controlled trials) study design. A recent systematic review by Lim et al.

(2023) further revealed several gaps in the research on the user experience (UX) of older adults in relation to mixed-reality applications. First, most researchers focused their investigation on the instrumental quality of the MR applications, such as aspects of usability, with few studies exploring a more comprehensive evaluation of UX. A comprehensive assessment of UX would also include the emotional responses evoked by the application and its aesthetic quality, as suggested by Thüring and Mahlke (2007) in their Component of User Experience model. Using a comprehensive understanding of UX is important as games for healthy older adults should go beyond their potential health benefits. These games should be an entertaining and attractive way for older adults to socialise and stay active, which sets them apart from typical interventions such as exercise routines. Focusing solely on the benefits and accessibility of an application, while ignoring its engagement level, could potentially undermine the application's effectiveness. If users do not find the application engaging or interesting, they may not use it at all, ultimately negating its benefits. Furthermore, Lim et al. (2023) suggested that approximately 70% of included studies on MR applications for healthy ageing (11 out of 15) utilised only quantitative measures of UX. This is a missed opportunity, as the use of qualitative measures brings about several advantages.

Qualitative measures, such as interviews, offer richer contextual insights by allowing space for participants to share personal, contextual and environmental factors that could influence their behaviours and preferences. The use of qualitative methods enables researchers to explore beyond the functionality of the applications, but also the subjective experience of the users. Oftentimes, quantitative approaches alone, such as the use of questionnaires, are not able to capture the complexity of user experience. Qualitative methods also align with a human-centred design approach by ensuring that users’ perspectives are heard and considered in the design process (Norman, 2013). This is particularly important when designing applications for older adults, as their needs and preferences are less clear due to the lack of studies in this area, compared to studies on health and rehabilitation applications (Dermody et al., 2020).

6.2.3 The EDNA Playboards system

The applications that form part of the Elements by Dynamic Neural Arts system (EDNA Playboards) is a multi-player (co-located) system designed by Duckworth, Wilson and colleagues, and validated in earlier studies by Duckworth et al. (2015) and Rogers et al. (2021). A set of hand-held objects (or tangible user interfaces-TUIs) are used to interact with a set of virtual environments presented on a flat digital display table via reach-to-grasp, lifting, sliding, and placing movements.

Prior to EDNA Playboards, the original EDNA system was introduced as a single-user application, designed for rehabilitation of upper-limb function in patients with Traumatic Brain Injury (Mumford et al., 2010; Mumford et al., 2012) and stroke (Rogers et al., 2019). Thereafter, a multi-user system (called EDNA-Resonance) was developed for co-located rehabilitation using a combination of collaborative, cooperative and competitive applications (Rogers et al., 2021). Within each virtual environment, the difficulty level can be customised to meet the patient's individual capabilities and preferences, including both physical and cognitive challenges. The multi-user EDNA-Resonance system consists of four games; i. Synchro Shapes, a game that required the player to place matching objects onto designated shapes with synchronous timing, either solo using both hands or in collaboration with a partner; ii. Pangles, a puzzle game solved by getting players to place the objects in a way that completely enclosed the borders of a target shape, which required problem-solving and mental rotation skills; iii. Resonance, where players uncover audio-visual elements and compose artistic effects through exploration of a musical interface; and iv. Paint Wars, a competitive game where players must use touch and swipe movements to gather coloured shapes, with the victor being the player who accumulates the most shapes. Three out of four games were identical in the EDNA-Resonance and EDNA Playboards system, the gamified MR application examined in this study (see Figure 4, page 80). In EDNA Playboards, Synchro Shapes was replaced with a similar music-based activity named Mixer that eliminated the need for synchronised actions. Detailed description of the EDNA Playboards games can be found in the methodology section of this paper.

Past research on EDNA-Resonance has shown positive user experience and ease of use (Rogers et al., 2021), with the prospect that its use can be expanded to foster activity and participation in healthy older adults. The multi-user EDNA-Resonance was found to have a positive UX, with participants and therapists reporting a high level of enjoyment, social engagement, and efficacy (Rogers et al., 2021). Indeed, the multi-user applications that are designed to encourage social interaction differ from others for older adults that have an individual focus on the improved cognitive and physical health of users (Lim et al., 2023).

6.3 Objective

This study aimed to investigate the UX of older adults who are living independently while using EDNA Playboards, a multi-user interactive tabletop device tailored to enhance the physical and cognitive skills of users, and social interaction. A mixed-method design was used to study how healthy older adults perceive the EDNA Playboards application in a comprehensive way, including the usability, aesthetic and emotional reaction components of UX. Given previous studies have mostly relied on quantitative analysis or focused only on instrumental aspects of UX, this research provides valuable insights into the user experience of healthy older adults.

6.4 Methodology

6.4.1 Design

A mixed-method design was used in this study combining the use of quantitative questionnaires and semi-structured interviews. This approach provided a more comprehensive understanding of the UX of the EDNA Playboards system, where quantitative data and qualitative data were integrated to form a richer picture. This was particularly important as there were limited studies on older adults who are living independently, and using a mixed-method approach was useful in conducting exploratory analysis. There was also increased validity and generalizability as the limitations associated with each method were addressed and findings cross-validated.

6.4.2 Participants

The participants were older adults in good health above the age of 60 residing in a retirement village. Inclusion criteria included; i) having the cognitive ability to give informed consent; and ii) sufficient physical, visual and hearing ability to participate in half an hour of activity. For example, participants were required to have the fine motor ability to hold and manipulate objects on a table surface while seated or standing, and well-preserved (or corrected to normal) vision that allowed them to locate and interact with the tangible objects and with each other. Exclusion criteria included; i) individuals below the age of 60; or ii) older adults who were hospitalised, part of a rehabilitation trial or diagnosed with a disorder of ageing. A participant information sheet was provided and written informed consent was obtained from all patients before participation. This was a joint study by the Australian Catholic University and RMIT and was approved by both universities' Human Research Ethics Committees.

Twelve residents from the retirement village indicated interest in participating in the study. One resident was unwell on the day of data collection and eleven participants were recruited (*M*±*SD age*=78±7.94 years). There were six male and five female participants. On average, the participants have lived in the village for slightly less than two years (23 months).

6.4.3 Setting

Participants were recruited from a retirement village located in regional Victoria, Australia. This development consists of 170 occupant-leased dwellings with 1 to 3 bedrooms. Residents, most aged above 55, live independently in villas or apartments within the village. Beaches and shops are within walking distance and a village bus provides access to the nearest towns. This study was conducted in a large pavilion (approximately $25m^2$) located in the central social complex of the retirement village.

6.4.4 Experimental Task: EDNA Playboards

The EDNA Playboards system was used for this study, which included a 55-inch, tabletop-mounted multi-touch screen and integrated computer and marker-based tracking. A speaker was connected to the tabletop display to project audio clearly across the room. Four objects (TUIs) were included with the system. Each TUI came in a different colour and shape, with a unique constellation of three raised conductive touch points on the object base. The resulting triangle formed from the three touch points enable the software to track the position, centre and rotation of each TUI. EDNA Playboards allows a maximum of four co-located users to participate in each game. When played in a group, the digital environment was designed to enable users to interact cooperatively, collaboratively, or competitively. Four games were designed and used in this study. A summary of the games used in this study is included in Table

5, while an in-depth discussion on the design of EDNA Resonance can be found in Duckworth et al. (2015).

Table 5 Game mechanics and skills usage in EDNA Playboards

Games	Game Mechanics	Skills Utilised
Mixer	Type: Exploratory music-making Users place matching TUIs on target shapes to trigger audio-visual effects. Multiple TUIs can be placed at the same time to produce music. Users can swipe the screen using the TUIs to stop the audio-visual effect. This game also serves to introduce users to the use of TUIs and the touch-screen.	Social Skills: Collaboration. Users work with each other to produce pleasing auditory effects. This includes discussing how each audiovisual effect can be triggered. Cognitive Skills: Attention and problem-solving. Users explore Virtual Environment to trigger auditory and visual effects to compose music. Physical Skills: Self-initiated upper body movements to move the torso and upper limbs (gross motor) and placing the TUI on screen (fine motor)

Games	Game Mechanics	Skills Utilised
Pangles	Type: Puzzle solving Geometric target shapes are shown on screen. Each TUI has a matching target of the same colour. When TUIs are placed on the screen, lines are projected from them on the screen. The aim is to manipulate the TUIs so that the projected lines enclose the borders of the target shapes. Correct placement of the TUIs is indicated by lighting up the target.	Social Skills: Collaboration. Users discuss solutions together and may exchange TUIs or ask to switch positions to complete the puzzle. Cognitive Skills: Problem solving and mental rotation skills. Physical Skills: Self-initiated movements including possibly moving to another position around the table (lower body movements; gross motor) or stretching and bending across the tabletop (gross motor), and placing of TUIs (fine motor) to complete the puzzle.

Games	Game Mechanics	Skills Utilised
Paint Wars	Type: Competitive token collection Using touch and swipe gestures, users shoot out coloured trails to collect coloured shapes (tokens). TUIs can be rotated to control direction of the paint trails which attract shapes towards each player's home base. Users can disrupt their competitors' trails by blocking their trails with new paint or finger-swiping competitors’ trails away.	Social Skills: Interactive. Users can verbally encourage or even mislead competitors to achieve their goals. Cognitive Skills: Divided and selective attention; Planning skills. Users must pay attention to their own and competitors’ paint trails while strategising. Physical Skills: Response selection. Users grasp, place and swipe using the TUIs (fine motor movements) at discretion to achieve game goals

Games	Game Mechanics	Skills Utilised
Resonance	Type: Exploratory music making TUIs placed on the screen emit radiating lines that intersect to form various enclosed shapes. Moving and rotating the TUIs changes the sounds produced. Touching these shapes with a finger produces audiovisual effects.	Social Skills: Collaboration. Users work with co-users to produce pleasing auditory effects. For example, discussing and negotiating number of TUIs to be placed, and which auditory effect to include Cognitive Skills: Attention and problem-solving. Users explore VE to trigger auditory and visual effects to compose music. Physical Skills: Self-initiated movements including grasping the TUIs (fine motor) and moving around the device (lower limbs, gross motor).

6.4.5 Measures

Virtual user experience questionnaire (VUE-Q; Witmer et al. 2005; Witmer & Singer, 1998). The user experience of EDNA was assessed using the VUE-Q, a 20-item adaptation of the Presence Scale (Witmer et al., 2005; Witmer & Singer, 1998). The VUE-Q has seven subscales: Familiarity (e.g. 'I am familiar with using computer technology'), Enjoyment/Engagement (e.g. 'Using the system in general, I enjoyed using the system'), Social Engagement (e.g. 'I enjoyed using the system with others'), Immersion (e.g. 'I lost track of time while using the system'), Ease of Use (e.g. 'It was clear what

I needed to do to complete the task'), Health/Well-being benefits (e.g. ‘I saw health and well-being benefits from playing with this type of system’) and Aesthetic Quality (e.g. ‘I like the look and design of the system ‘). Each item is rated on a Likert scale ranging from 1 to 5 (from strongly disagree to strongly agree). VUE has previously been used by Rogers et al. (2021) to examine the user experience of the EDNA-Resonance system, a predecessor of EDNA Playboards.

Game Experience Questionnaire (GEQ) Core, Post-game and Social Presence (IJsselsteijn et al., 2013). GEQ was used to understand the participants' experiences during and after the gameplay and to assess their game experience during a gameplay session. Three GEQ modules were used. The GEQ in-game module is used to assess a player’s game experience during a game-play session. It included seven components: Sensory and Imaginative Immersion, Flow, Competence, Positive Affect, Negative Affect, Tension, and Challenge (de Kort, IJsselsteijn, & Poels, 2007; Poels, de Kort, & IJsselsteijn, 2007). The GEQ post-game questionnaire was used to assess how users felt after they had played the game (IJsselsteijn et al., 2015a, 2015b). It has four components: Positive Experience, Negative Experience, Tiredness, and Returning to Reality. The GEQ social presence questionnaire was used to assess the degree of social presence experienced by individuals in a virtual environment. Components included empathy, negative feelings and behavioural involvement. Each item was rated on a Likert scale ranging from 1 to 7. Higher mean scores indicated a more positive user experience related to the domain measured. For this study, the 7-point scale of the GEQ was categorised into descriptors, with 1 categorised as extremely low, 2 as very low, 3 as low, 4 as moderate, 5 as high, 6 as very high, and 7 as extremely high. GEQ has been extensively used in UX studies of MR applications for healthy older adults (Boletsis & McCallum, 2016; Liukkonen et al., 2015; Pyae et al., 2017; Santos et al., 2019). Participants indicated no difficulties in completing the questionnaires at the end of the session.

Semi-structured interview questions. A semi-structured interview was used to gather in-depth qualitative insights from the participants. The interview covered six areas, designed to explore various aspects of their experiences and perceptions regarding EDNA. These were: i) Points of interest (e.g. What part or aspects of EDNA Playboards did you find interesting?); ii) Design feedback (e.g. What design features of the EDNA Playboards' games did you like the most? Describe any feelings you had about these design features); iii. Experience feedback (e.g. What was the best part of the experience? What was the worst part of the experience?); iv. Movement awareness (Were you aware of your movements while using EDNA Playboards?); v. Social Participation (e.g. Did you engage or interact with others during the session?); and vi. Other remarks (e.g. Would you recommend using EDNA Playboards to others? Was there anything about the experience that was uncomfortable? What design features of EDNA Playboards would you like to change or add?).

6.4.6 Procedures

Participants were allocated into three groups of three to four users for a gameplay session of at least thirty minutes, facilitated by one researcher and observed by two researchers. Participants engaged in four different games. Participants were permitted to sit or stand at any point of time during gameplay. At the end of the session, participants answered a series of questionnaires that were followed by a semi-structured interview. Three researchers conducted the interviews. The semi-structured interviews were voice-recorded on the interviewers' phones.

6.4.7 Data Analysis

6.4.7.1 Quantitative analysis

Descriptive statistics were used to summarise the user experience of older adult who are living independently, as measured by their responses to the VUE-Q and GEQ questionnaires.

Following a past study using the VUE-Q (Rogers et al., 2021), raw scores of the subscales were converted into percentages, with 70% and above considered as high and positive, 50% and above as medium, and 40% and below as low. Means and standard deviations were computed for the GEQ scores, which provided an overall understanding and variability of the user experience of this older adult sample across multiple domains.

6.4.7.2 Qualitative analysis

Braun and Clarke (2006)'s approach to reflexive thematic analysis was used in this qualitative analysis. This method of thematic analysis has been extensively utilised, and the worked example by Byrne (2022) was used to ensure that the reflexive thematic analysis protocol was adhered to. Reflexive thematic analysis aimed to offer a systematic and rigorous analysis of qualitative data while recognising the subjective nature of interpretation. In this approach, there were no predetermined codes or theoretical perspectives. This flexibility allowed researchers to explore the data in an open and unbiased manner, allowing for the emergence of unexpected themes without a priori assumptions. An iterative process was used to code and develop themes. Initially, codes were refined and grouped into potential themes. These themes were then reviewed against the entire dataset and further refined until coherent themes were established. This iterative process ensured that themes were grounded in the data and supported by evidence. Using this iterative approach, voice recordings of interviews (n=11) were transcribed into a word processing software before being uploaded into NVivo. The interviews ranged from 15-25 minutes. Three researchers conducted the qualitative analysis. The researchers (JL, PW, MC) reviewed and analysed each interview transcript in full to generate codes for discussion (open-coding). Subsequently, the research team collaborated on the analysis, sharing their individual assessments and refining the coding and clustering of key concepts. Potential themes were grouped from the initial codes, reviewed again collectively, and consensus was sought amongst the researchers before finalizing the themes. There was no pre-determined limit of codes and themes. Each quote could be coded in multiple ways, but each code has more than one reference (Braun & Clarke, 2006).

6.5 Results

6.5.1 Quantitative results

The result of the VUE-Q questionnaire was presented in Table 6. Most of the indices of the VUE-Q were in the high range (above 70%), indicating a positive user experience. The Immersion index was in the 'medium' category, indicating that the participants had a moderate experience of feeling engrossed in the gameplay.

Table 6 Virtual User Experience (VUE-Q) Mean, Percentage Total and Category scores

VUE-Q Domain	Mean (*M*)	Standard Deviation (*SD*)	Percentage (*%*)	Category
Familiarity	3.91	1.14	78.18	High
Enjoyment/Engagement	3.91	1.96	78.18	High
Social Engagement	3.82	1.21	76.36	High
Immersion	3.24	2.76	64.85	Medium
Ease of Use	3.67	2.29	73.45	High
Aesthetics Quality	3.73	1.04	74.55	High
Health/Well-being Benefits	3.94	1.33	78.79	High

For the GEQ, mean scores on the Core, Post-Game, and Social Presence questionnaires are presented in Table 7. As shown, the highest score for the Core questionnaire was Positive Affect, and the lowest was Negative Affect, suggesting that participants enjoyed the gameplay. The next highest scores were Immersion and Flow, two important components of game design known to affect user engagement, as they measure how absorbed and involved users were in the virtual environment. The pattern of low negative emotions and high positive emotions continued for measures in the Post-Game and Social Presence questionnaires. The Challenge index of the Core questionnaire was also relatively low with a higher variance than reflected in other measures.

Table 7 Game Experience Questionnaire (GEQ) Mean Score and Standard Deviation

GEQ Domain	Mean (*M*)	Standard Deviation (*SD*)	Category
Core			
Competence	4.82	0.59	High
Immersion	5.05	0.67	High
Flow	4.18	1.07	Moderate
Tension	1.82	0.72	Very Low
Challenge	2.73	1.10	Low
Negative Affect	1.64	0.88	Very Low
Positive Affect	5.73	0.61	Very High

GEQ Domain	Mean (*M*)	Standard Deviation (*SD*)	Category
<u>Post-Game</u>			
Positive Experience	3.68	0.82	Moderate
Negative Experience	1.21	0.41	Extremely Low
Tiredness	1.59	1.28	Very Low
Returning to Reality	1.36	0.48	Extremely Low
<u>Social Presence</u>			
Empathy	5.61	0.77	Very High
Negative Feelings	2.02	0.53	Very Low
Social Behaviour Involvement	4.39	1.14	Moderate

Summarising the quantitative results, participants rated EDNA Playboards highly on most VUE-Q and GEQ sub-scales. Assessment of the Immersion component of user experience in the VUE-Q was the lowest among the different components. This appeared to differ from the results of the GEQ, where Immersion was one of the highest scoring indices. Of note was that the Tiredness index of the post-game questionnaire was low. This was important as a challenge in designing MR applications for older adult users was to ensure their physical well-being, and to be stimulating without being too taxing physically or cognitively (Lee et al., 2019). The high variance and relatively lower Challenge index of the GEQ-Core questionnaire are explored in the discussion section.

6.5.2 Qualitative Results for Post-Game Interviews

Five themes were identified from the narrative accounts of the participants' experience of using EDNA Playboards, summarised in Table 8 (including examples of the participants' quotes).

6.5.2.1 Theme 1: Ease of Use

The older adult participants found the hand-held tangibles comfortable and easy to manipulate, accommodating both seated and standing play. Visual and auditory needs were met, with participants expressing clear understanding of the tangibles and hand gestures on the tabletop surface. This aspect of EDNA's design contributed to a positive user experience, facilitating interaction with the tabletop interface.

6.5.2.2 Theme 2: Perceived Benefits

All participants reported recognising the cognitive benefits of engaging with EDNA, appreciating its potential to keep them mentally sharp and stimulated as the games involved problem-solving. The social aspect of playing with others was also highly valued by the participants, with some participants expressing hope that the social aspect of EDNA can lead to stronger friendships. The perceived benefits led most of the participants to express a high desire to continue using the system as part of their routine.

6.5.2.3 Theme 3: Preferred Game Mechanics

All participants expressed a distinct preference in game mechanics, favouring the collaborative and competitive aspects of the games. About half of the participants expressed feeling frustrated when playing the exploratory Resonance music game. Possible reasons for this preference are discussed further in the discussion section.

6.5.2.4 Theme 4: Challenge

While all interview responses indicated an overall enjoyable session, participants varied in their responses to the level of challenge presented by EDNA's games. More than half of the participants indicated that the level of challenge was appropriate, a small number of participants experienced frustration due to difficulty in understanding the games, and a similar small number of participants expressed concerns about potential boredom after achieving initial goals.

6.5.2.5 Theme 5: Aesthetic Preferences

The participants enjoyed the bright colours of EDNA but indicated a preference for music that aligned more closely with what they were familiar with in real-life environments. Further discussion of these qualitative results findings is presented in the subsequent section.

Table 8 Themes identified in thematic analysis

Themes	Quotes
Ease of Use	"You had that the four things [the hand-held tangibles] that you choose one or the other, was quite intuitive." "Really comfortable, the environment was a very safe environment." "If I moved the design on the table moved, so you controlled it with your movements. […] We were all very much involved with the machine and its movements."
Perceived Benefits	"It is good to use your brain in different ways as well. You're exercising parts of your brain that you're probably wouldn't have done otherwise, yeah."

Themes	Quotes
	“I'm not a big game player. We quite often do puzzles (like) jigsaw puzzles, which are just one person, really. So, it was nice to interact with other people. I'm not a game player on a phone for instance. I don't sit for hours playing games on phones so... this is a more unique experience.”
	“[The best part of the games was] working with the others… As we say, we're not close. We're not friends in that sense. We're all here on the same sort of journey together, and you know, we're comfortable in each other's company. And that heightened the experience, I think. I think we were quite happy to be admitted, to collaborate and to work together, and to see what others were doing and particularly to rejoice in other ones doing well too.”
Preferred Game Mechanics	“I suppose the movement from outright competing with people, with the debating, to collaboration with the switch. And I think both of those have a place.”
	“The last one was frustrating because... Umm, the first two I felt I was able to achieve something. I'm a person who likes to have a score, a level, an outcome. The last one gave me nothing, you know, sort of walked away with, “Well what have I… What have I actually achieved by doing that? Does that make sense?”

Themes	Quotes
	“A bit too challenging…because of having other people doing it as well… As somebody else said, if you'd be doing it on your own, you'd probably would be able to work things out.”
Challenge	“Fun, fun. But then. Becoming very bored.” “There were so many different variables. Maybe just to introduce those and then play with it in another section.”
Aesthetic Preferences	“Nice colours: the (one) with the arrows with the laser…has got a bit of a colour in. Yeah, really good.” “I thought it was very good use of colour which makes you switch your mind to hand movement to eye, movement to switching your mind to shapes and you know getting coordinating activities, I had no difficulty with that” “It's like (they) was (sic) looking for violin, you know, like they should be.”

6.6 Discussion

The aim of this study was to examine the user experience of older adults residing independently while trialling EDNA Playboards, a collaborative tabletop device designed to improve users' physical and cognitive abilities, as well as encourage social engagement. Quantitative data suggested that participants generally rated EDNA favourably across most VUE-Q and GEQ sub-scales. Notably, participants reported low levels of tiredness in the post-game questionnaire, indicating that the design of EDNA Playboards was successful in addressing physical well-being concerns for older adult gamers. The relatively high variance and lower Challenge index of the GEQ-Core questionnaire are discussed below. Qualitative (or narrative) accounts described five main themes of Ease of Use, Perceived Benefits, Preferred Game Mechanics, Challenge and Aesthetic Preferences. These core themes are discussed in detail below, highlighting the high level of comfort perceived by the participants and the value placed by the participants on receiving cognitive stimulation through play. The social aspect of playing with others was highly appreciated, though some difficulties arose in exploratory games where explicit game goals were preferred by the participants. While participants generally enjoyed the session, some experienced frustration or expressed concerns about potential boredom after initial achievements.

6.6.1 Usability as perceived by older adult participants

In this study, the older adult participants indicated that the objects/hand-held tangibles were comfortable to use and manipulate, which can be taken to indicate that the design of EDNA had addressed the needs of older adult players. The most significant age-related impairments that affect how older adults play and perceive digital games are a reduction in visual and auditory capacities as well as a loss of motor skills (Ijsselsteijn et al., 2007). They were able to reach across the tabletop surface when necessary, and there was enough space for them to move around the table if they chose to. The design of EDNA also allowed players to play standing, sitting down or in combination in group play. The interviews indicated no difference in ease of use between the two players who played while seated compared with those who stood. In visual and auditory needs, participants indicated that they could view and hear the games clearly.

Participants also expressed that they found it straightforward to comprehend the use of hand-held tangibles and direct touch on the tabletop surface, allowing them to effectively execute their desired actions within the games. EDNA was designed to achieve this through a combination of game mechanics, ease of manipulation, and responsiveness of the device to the participants' interactions. This intuitive design of EDNA is important to the user experience. An intuitive design, which is when the interface functions as expected by the user, requires less mental load and user training, and increases user satisfaction (Naumann et al., 2007). For example, the participants reported that they had no difficulties using a combination of placing and rotating the hand-held tangible to complete a puzzle in Pangles. There was also a low level of post-game tiredness experienced by the participants as reported in the GEQ, making it likely that the design of EDNA was intuitive and had a high ease of use perceived by the users.

6.6.2 Older adult users' perceived benefits of playing EDNA Playboards

As mentioned, games may provide an effective and enjoyable way to promote healthy ageing. The quality of life of older adults is influenced by their cognitive, physical and social well-being (Aronson, 2020). In interviews, our participants expressed their desire to stay cognitively active. They reported being able to see the cognitive benefit of playing with EDNA, particularly the Pangles puzzle game as they could see that there were increasing level of challenge after each round which tested their problem-solving skills. Other research has similarly found that older adults have a positive attitude towards the cognitive benefits of gamified MR applications (Duplàa et al., 2017; Kaufman et al., 2016; Seah et al., 2018). While the participants reported observing themselves to be stretching and moving while playing, they did not report a need for physical stimulation through gameplay. Presumably, this was not reported because they are already living an active lifestyle at the retirement village.

Participants also appreciated and enjoyed the social aspect of playing with others, as evidenced by both the interviews and high social engagement and involvement ratings of the VUE-Q and GEQ (Tables 2 and 3). Past studies have indicated that fostering social interaction is a valued component of gameplay for older adult players (De Schutter & Vanden Abeele, 2010; Duplàa et al., 2017), specifically through group play and online multiplayer elements (Duplàa et al., 2017; Kaufman et al., 2016). In the current study, eight of the eleven participants reported that the best part of gameplay was their involvement with other people, with some stating that they do not have many friends of similar age. Despite living in the same retirement village, two participants mentioned that while they were friendly acquaintances, they did not know each other well prior to the game session.

The multiplayer nature of EDNA gave participants an opportunity to interact with others, and it may be inferred that playing games (like EDNA) as a group may encourage a sense of community. Indeed, the retirement village does offer other facilities for social play (e.g., billiard table and table tennis), but currently no gamified MR applications. The participants also suggested that EDNA could be used to help residents who are socially shy to connect with others or to play with their grandchildren when they visit. This indicated that they could see a place for EDNA in their residential village among other facilities. Similarly, a study on independently living older adults indicated that engaging in an 8-week multi-player Wii Bowling tournament set up across multiple locations significantly reduced their level of loneliness and increased their level of social connectedness (Schell et al., 2016). Schell and colleagues (2016) also found that engaging in the tournament not only fostered connections within the game setting but also extended participants' social networks beyond the regular sessions, such as having conversations, dining out, and playing other games with their newfound acquaintances from the tournament.

Other work has shown that even for games that do not require direct social interaction to play (like digital Bingo), participants report experiencing and valuing the social interaction (Seah et al., 2018), which emphasised the importance of perceived social benefit.

The benefit of using games for health is valued most by participants when it occurs incidentally as part of the game and is experienced as an enjoyable way to promote health. Like the interviews, the results of the GEQ and VUE-Q indicated a high level of perceived health benefits and social engagement. What was also clear is that the participants enjoyed the games, with a high level of enjoyment, positive affect and positive experience, and low levels of negative affect. Taken together, our older participants perceived EDNA as a fun and beneficial healthy ageing activity, meeting the goal of games for healthy ageing (Cavalcanti et al., 2018).

As well, their level of enjoyment did not appear to be impacted by the moderate level of immersion they reportedly experienced on the VUE-Q. The EDNA Playboards, as a tabletop design, differs from fully immersive MR applications like VR headsets. This moderate level of immersion may not be perceived as a negative outcome, as while fully immersive technology can enhance the game experience, some older adults may also experience anxiety or discomfort due to the sensory experience (Healy et al., 2022).

To further enhance the perceived health benefits of playing games, participants recommended receiving feedback on their progress. This might allow them to better judge whether they need to engage in more play sessions to improve their physical and cognitive abilities. Overall, most participants agreed that playing games is an enjoyable and engaging way to improve their overall well-being, and that they would recommend it to others.

6.6.3 Balancing challenge, frustration and enjoyment in games for older adults

Games engage players through challenge and competition but balancing the level of challenge and frustration experienced by older adult players emerge as crucial for maximising game enjoyment. This has to be tailored to the characteristics of the target user, in this case older adults (Kaufman et al., 2020). Responses from the interviews indicated that the session was an enjoyable experience overall for the participants. However, deeper analysis of the data indicated that participants could be further divided into groups who either i) felt frustrated due to the game difficulty at times; or ii) expressed concerns that they may feel bored after achieving the initial goals of the game. There is limited data on balancing motivation and different challenge needs in a multi-player context. However, in single-user games, research indicated a need to design games that suit the cognitive and physical comfort level of older adults by moderating the game duration while incorporating new elements to prevent boredom. Jeremic et al. (2019) found that when trialling exergames with older adults, the participants felt discouraged from playing when the games were too fast and complicated, and when they were required to concentrate on both cognitive and physical tasks simultaneously, especially within a constrained timeframe. In an educational game, Sauvé and Kaufman (2019) found that the sense of challenge experienced by older adults can be sustained by offering short games and allowing players their choice of game duration. They also found that motivation of the participants can be increased when they played a game that has familiar rules, in this case the Solitaire card game, but incorporating new elements such as rewards for meeting goals (Sauvé & Kaufman, 2019).

6.6.4 Game mechanism and how they impact enjoyment

In this study, participants demonstrated a clear enjoyment and understanding of two EDNA Playboards games, Pangles and Paint Wars, which offered clear collaborative or competitive objectives. However, they found the Resonance game more frustrating and less engaging, expressing a desire to play without peers due to confusion, lack of achievement, and loss of control. This highlighted the importance of clear goals and a sense of achievement for older adults in game experiences, as indicated by their enthusiasm for challenging levels and concern about potential boredom.

In the data collection session, participants showed that they intuitively knew they had to reach across the table to solve a puzzle (Pangles) or team up against another player to gain more points (Paint Wars). In contrast, while the participants reported liking the Resonance game, they found it more frustrating and less engaging than the other games. Resonance is designed for group play, but participants voiced a desire to attempt the game without the involvement of their peers. Participants provided three reasons, including that; i) their confusion was due to a lack of clarity of what they should do in the exploratory game; ii) they did not feel a sense of achievement after playing it; iii) they felt a loss of control as each of the four players were trying their own methods of playing instead of collaborating. During the session, it was observed by the researchers that this translated into behaviour where some participants either continued playing continuously, leading to chaotic music, or they chose not to play on the device and observed from the side.

From this contrasting game play experience, it was inferred that older adults may prefer games with a clear goal, such as when Pangles and Paint Wars were clearly collaborative or competitive. Without a clear game agenda, this also led to the lack of a sense of achievement after playing the game. The interviews indicated that feeling a sense of achievement and progress was important to the participants. This can be noted by their enthusiasm in wishing to challenge even more difficult levels of Pangles by continuing to play for a longer period of time as the challenge level increases progressively, and their concern about feeling bored during gameplay.

It was also hypothesised that having a clear, shared goal could have simplified how participants interacted socially. That both types of game were popular suggested that participants were comfortable with both collaborating and competing when the social and game rules were clear. What appeared to disorient them was when they were unsure how to interact and play together, as in the case of the Resonance game, due to the omission of specific game tasks. This discrepancy can be partially explained as the Resonance game was designed to be more akin to a musical instrument to facilitate collaborative play rather than a goal directed competitive/cooperative game.

Collaborative play was new to the participants. This was commensurate with the findings of a survey of more than 400 adults aged over 55 years (Kaufman et al., 2016). Specifically, analysis of their experience with playing digital games indicated that most of them played alone, and those who played with others mostly did so with friends and family members (Kaufman et al., 2016). The participants could have struggled in Resonance partly because they were without prior experience of co-playing to create musical compositions. They could also have preferred playing alone to avoid the embarrassment of not knowing how to structure the sounds in meaningful and relatable/attractive sound compositions with others, especially as it was noted earlier that participants reported not knowing each other well, despite spending several years in the same residential facility. As with any musical instrument, the facilitation of structured learning to familiarise the participants with the nuances of the interface would likely be required.

6.6.5 Aesthetic Preferences of Older Adult Participants

This study highlighted the importance of considering aesthetic preferences and emotional safety in game design for older adults. While participants expressed appreciation for the visual elements of EDNA Playboards, they suggested replacing abstract digital sounds with more familiar musical instruments or nature-inspired sounds. This preference for familiarity may stem from the participants' nostalgic memories.

The participants reported a clear liking of the visual elements of EDNA, describing it as colourful and interesting. EDNA uses a range of bright colours and large icons in geometrical shapes that are familiar to users of any age. The design seeks to make the games visually pleasing and accessible to older adult players. It was noted that participants agreed that the technological aspect of how the device produced abstract music was clever and sophisticated.

Participants did, however, suggest that the more abstract digital sounds could be replaced with more familiar musical instruments such as violin, piano or percussion instruments, or nature-inspired sounds. Participants indicated that they grew up with musical instruments in their environment, even if they were not musicians. Research on nostalgic memories, defined as a sentimental longing for one’s past, indicates that it may be utilised by older adults to regulate their emotions, especially when feeling emotionally unsafe due to perceived social- or self-threat (Fleury et al., 2022). Linking back to the above discussion of how the Resonance game may have triggered a sense of discomfort, it is hypothesised that participants may have felt especially drawn to the idea of using familiar sounds as a means of feeling safe. This preference for familiar game content was also consistent with the findings of other games designed for older adults (Meza-Kubo et al., 2014; Pyae et al., 2017; Sauvé & Kaufman, 2019). In EDNA Playboards, the Resonance game can be perceived as an instrument. However, it was dissimilar to other musical instruments familiar to the participants, like the violin and drum. Most classical instruments were designed to be played by a single player. The Resonance game required participants to play on one "instrument", the tabletop, simultaneously. They have had no experience with such music-making mechanisms. These aesthetic preferences can be an important consideration for game designers and researchers, as nostalgia and emotional safety contribute to healthy ageing by improving emotional, physiological, and behavioural regulatory capabilities (Fleury et al., 2022).

6.6.6 Limitations and future research

While this study has provided valuable insights into older adults' perspective of MR-based interactive experiences, certain study limitations may have influenced the findings and should be acknowledged. This study focused on the overall user experience in a half hour game session, which may have limited participants' ability to fully explore and develop skills with the EDNA Playboards. The session length was designed as an introduction to the EDNA Playboards system. A longer play duration and having multiple sessions, particularly for the exploratory games, may have provided additional opportunities for skill acquisition and deeper engagement.

While the study was open to participants above the age of 60, the final sample had mostly participants who were above 70. Hence, the findings may only be applicable to a subset of older adults, and more research is required to explore whether user experience differs between different older adults of various ages.

This research has provided some of the first impressions on engaging older adults in a gamified MR interactive experience, and at the same time highlighted possible interesting directions for future research. The current study indicated that activities with clear goals may be preferred over exploratory, open-ended creative activities such as Resonance. This could be related to the sense of achievement felt by the participants upon completing a game goal.

Investigating how the sense of achievement influences motivation and continued participation in MR applications could provide insights into game design strategies that sustain long-term engagement in older adults. Future research could also compare user engagement level between goal-oriented and exploratory activities to understand each design's impact on older adults' UX.

Another possible area of exploration is whether the order of games played could impact how much the participants enjoyed them. In this study, participants played four games in a specific sequence. The first game served as a tutorial to familiarize them with the application, followed by a collaborative game, then a competitive one. An exploratory music game was introduced last. This study hypothesised that the game sequence could have primed the participants to anticipate a clear objective for the final game, similar to the previous ones. The unexpected nature of the exploratory game could have influenced their enjoyment, especially considering that the competitive and collaborative games resembled traditional boardgames which the participants were familiar with.

6.6.7 Design recommendation

Findings from this study has suggested that ensuring an optimal balance between challenge and accessibility is crucial for creating engaging and enjoyable game experiences for older adults. The older adults' perceived need for cognitive stimulation can be met by balancing the challenge level to avoid excessive frustration while still promoting enjoyable gameplay. For game designers, research has suggested that a satisfying game experience can be achieved through balancing an adequate level of game difficulty with straightforward navigation and display that is intuitive and user-friendly (Sauvé et al., 2019). Having a degree of challenge is particularly important as participants also indicated a need for cognitive stimulation while living in the residential village. The difficulty in multi-player games is that it may be impossible to find a level of challenge that would suit everyone. Despite the possible lack of consensus regarding the optimal challenge level, several suggestions for the facilitation of gameplay can be deduced from this study and that of past studies on games for older adults to provide scaffolding. For the EDNA Playboards, having facilitators of the game provide a demonstration of each activity in addition to verbal instruction was useful in allowing participants to understand the games. To lessen performance pressure, players could be offered the opportunity to test out competitive games without receiving points. For music-generating games, providing a song demonstration may provide participants with a guide and goal that they can move towards. These steps could reduce the frustration level of participants who struggled with the games and could possibly enable participants to be more confident to progress to a higher level of challenge, reducing boredom.

Finally, an attractive application helps to sustain user interest. For older adult players, brightly coloured graphics and large icons enhance the aesthetic appeal of the games while games with real-world elements can elicit positive feelings of nostalgia. Music selection for the games is particularly important, when abstract electronica sounding music can be uncomfortably foreign to older adults.

6.7 Conclusion

This paper presents the UX evaluation of EDNA Playboards, a multiplayer MR interactive experience, in a cohort of healthy older adults living in a retirement village. Quantitative and qualitative findings from this study indicated an overall positive user experience, with the participants perceiving social and cognitive benefits from engaging in the game session. In particular, the participants indicated a hope that the use of gamified MR applications may foster a sense of community and encourage interaction between residents of the retirement village. The study also underscores the importance of considering the older adults' preference when designing game mechanism and aesthetics components of a digital interactive experience to ensure accessibility and enjoyment for older adult users. These findings highlight the potential of MR-based applications as a tool for encouraging social engagement and cognitive stimulation in ageing populations and it is hoped that more research can continue to be put into designing tailored MR interactive experiences for older adults.

Chapter 7 Study 3: Exploring the use of EDNA Playboards in aged care setting

7.1 Abstract

This study explored the experiences of older adults engaging with EDNA Playboards in an aged care facility in Australia, contributing to the growing body of research on the use of mixed reality (MR) interactive experiences in ageing populations. Ten residents (M±SD age = 86.6±4.7 years) attended approximately half an hour of session where they engaged in the use of EDNA Playboards, playing in groups of three or four. The sample consisted of four male and six female participants. Participants were interviewed post-session and these interviews were transcribed and qualitatively analysed via a reflexive thematic approach. The findings indicated that participants had an overall positive user experience (UX) with the EDNA Playboards system, particularly appreciating the cognitive challenge the activities provided. Participants emphasised the need for guidance when first introduced to the gamified interactive experience, preferring a slower and quieter introduction to avoid feeling overwhelmed. They valued clear instructions on game objectives before playing, reflecting a desire for structure and understanding in unfamiliar situations. Social engagement was also an important factor in their positive experience. While the visual elements, particularly the brightly coloured shapes, were engaging, the auditory aspects of gameplay were perceived as confusing, as recognising and appreciating the need for overlapping sounds proved difficult. The participants expressed interest in continuing to use EDNA Playboards. The results highlighted older adults' openness to the novel experience, which was driven by a strong desire for increased cognitive stimulation in their home environment.

7.2 Introduction

Ageing can lead to declines in cognitive functions, motor skills, functional abilities, sensory perception and social interaction, negatively impacting participation and quality of life (Billino & Pilz, 2019; Jayakody et al., 2018; Krueger et al., 2009; Tieland et al., 2018; Williams & Kemper, 2010). As people age, they are increasingly vulnerable to frailty and chronic diseases, including hypertension, osteoarthritis, and coronary heart disease (Weiss, 2011). Furthermore, they may experience a decline in cognitive abilities, which present as memory problems, diminished working memory, and slower processing speeds (Williams & Kemper, 2010). Their mobility may also be impacted by age-related reductions in coordination, balance, and muscle mass, which heighten the risk of falls, injuries, and hospitalisation (Tieland et al., 2018). As they age, older adults may encounter challenges in maintaining relationships due to experiencing the loss of a spouse or their friends, or due to experiencing physical limitations, deteriorating health, and/or a reduction in income, all of which may hinder participation in social activities (Hajek & König, 2020; Krueger et al., 2009). Collectively, these experiences lead to the perceived or actual loss of their support system and feelings of isolation and loneliness (Hajek & König, 2020). Further, older adults who are forced into retirement due to circumstances including health reasons, having to look after an ailing family member, or workplace policies that have mandatory retirement ages are known to experience stronger feelings of loneliness compared to those who have never worked or who have voluntarily retired (Hagani et al., 2024; Shin et al., 2020).

For some older adults, these age-related changes may advance to the point that they can no longer perform activities of daily living without additional support. In Australia, with an ageing population where one in six individuals are aged 65 years or older (Australian Institute of Health and Welfare, 2023), aged care support has evolved to encompass a wide array of services designed to support the health, well-being, and quality of life of older adults. The system in

Australia includes residential aged care facilities that provide support and accommodation for individuals assessed as needing higher levels of care, as well as home care and home support options. Home care services are designed to assist individuals in their own homes, while home support focuses on helping with daily living tasks, allowing older adults to live independently both at home and in the community. The term 'residential aged care', often used in Australia, is synonymous with nursing homes or long-term care facilities in other countries (Sanford et al., 2015). Residential aged care differs from home care and home support in that it provides full-time accommodation and care for older adults who are no longer able to live independently in the community.

With ongoing improvements in the diagnosis and management of common age-related health issues, Australia has seen a steady shift in its demographic and an increased demand for aged care services. The latest Australian data were reported in 2024 and indicated that, in 2022-2023 alone, there were almost 317,000 admissions to aged care services in Australia, of which close to 25% were to residential aged care facilities (Australian Institute of Health and Welfare, 2024a). It is crucial to recognise that the needs of older adults living in residential aged care may be more complex than those of the general older adult population. In terms of health and functional status, older adults who experience more complex health challenges that require ongoing personal medical care are often admitted to residential aged care facilities due to the high-level support that these facilities offer (Sluggett et al., 2017). According to a study by Ambagtsheer et al. (2020), which involved over 500 individuals aged 75 years and over and who were living in Australian aged care facilities, around 90% met the criteria for frailty (44%) or pre-frailty (46%). This result was similar to that of Theou et al. (2016), who found that in a study of close to 400 people residing in six Australian aged care facilities, 85% had mild to severe levels of frailty. High rates of frailty in residential aged care were likely influenced by the high portion of people aged 85 years and over (54%) who entered these facilities between 2021 and 2022 (Australian Institute of Health and Welfare, 2024).

Under this context of additional health needs, aged care facilities provide a structured and communal living environment for these adults who can no longer live independently in their own homes. A comprehensive literature review exploring the characteristics that would maintain the quality of care of aged care facility residents indicated that social relationships, a sense of community, and supporting their health and well-being were among the key considerations (Cleland et al., 2021). To this end, researchers have been looking to design technological innovations that can support older adults' social and physical needs to expand the focus beyond looking after the residents' health and basic needs (Thach et al., 2020). For example, interactive virtual reality technology may be used as a tool to involve residents in activities, especially when they might otherwise choose to isolate themselves (Baker et al., 2020). Similarly, this study sought to explore how EDNA Playboards, a mixed-reality application, may support the cognitive and social needs of older adults living in residential aged care facilities.

7.3 Objective

Older adults living in residential care facilities generally have complex needs (Ambagtsheer et al., 2020; Sluggett et al., 2017) and tailored research is needed to understand better the unique health and social needs of those who are living in these environments. As such, this study sought to evaluate the experiences of people living in an aged care setting after using the EDNA Playboards, to determine the acceptance and applicability of this system in aged care environments.

7.4 Methodology

7.4.1 Design

Similar to Study 2, this study was also designed to be mixed methods, where participants would take part in a game session followed by a semi-structured interview and the completion of a questionnaire. While all participants of Study 2 (Chapter 6) completed the questionnaires and reported no difficulties in doing so, only 1 participant of Study 3 completed the questionnaires, leading to the omission of the quantitative data analysis for Study 3 due to a lack of data. Participants of Study 3 were unable to complete the questionnaire while the researchers were on site for data collection, as they followed a daily centre schedule that did not allow for time after the interview to complete the questionnaire. They were given the questionnaire to complete at their own pace, but ultimately, only one participant submitted the questionnaires despite email reminders to the aged care centre.

Therefore, the results presented in this study were principally derived from a qualitative research design using semi-structured interviews. This approach enabled an in-depth analysis of the user experience (UX) with the EDNA Playboards system and facilitated exploratory analysis. The qualitative approach was particularly valuable given there is limited qualitative research on gamified Mixed Reality applications (Lim et al., 2023). To comprehensively evaluate the participants' experiences with using the mixed-reality application, qualitative data was collected via semi-structured interviews that, in accordance with the Component of User Experience Model, discussed the usability, emotional reaction, and aesthetic components of the users' experiences (Thüring & Mahlke, 2007).

7.4.2 Setting

Participants were recruited from a residential aged care facility in inner city Melbourne, Australia that provided accommodation and care services for individuals aged 65 years and older. Data collection was conducted within the aged care facility, in one of the common rooms designated for leisure activities. Given that this area was familiar to participants, this setting facilitated natural interaction between the participants and the EDNA Playboards, providing realistic insights into their user experience.

7.4.3 Participant recruitment

The participants were older adults aged 65 years and over who resided in a residential aged care facility. To participate in this research, residents were required to meet the following specific inclusion criteria: i) have the cognitive capacity to provide informed consent, as determined by the staff of the aged care facility and by the participants' ability to understand and sign the printed consent form prior to attending the session; and ii) have the physical, visual, and auditory abilities to engage in at least a 30-minute activity. This included the fine motor skills needed to handle and manipulate objects on a table while either sitting or standing, and vision and hearing (corrected to normal, if necessary) adequate for interacting with objects and each other. Individuals were excluded if they were: i) under 65 years old; ii) hospitalised; iii) involved in a rehabilitation trial; or iv) diagnosed with a physical, neurological, or medical condition that might prevent their participation in this study (as self-disclosed by the participants).

The inclusion and exclusion criteria were communicated to the aged care facility staff, who identified potential residents meeting these criteria and invited them to attend a gaming session on a specified date and time. Participation in the session was voluntary.

Ten residents (M±SD age=86.6±4.7 years) from the residential aged care facility participated in the study, which included three sessions conducted over two days. There were four male and six female participants. All participants received an information sheet and provided written informed consent prior to participation. This study received joint approval from the Human Research Ethics Committees of both the Australian Catholic University and RMIT (HREC: 2022-25582-18339).

7.4.4 EDNA (Elements by Dynamic Neural Arts) Playboards system

The study utilised the EDNA Playboards surface computing system, which comprises a 55-inch multi-touch tabletop screen, an integrated computer, and marker-based tracking of tangible user interfaces (TUIs). An external speaker was used to broadcast audio clearly across the room. The TUIs were each uniquely coloured and shaped, with raised conductive touch points on the object bases. This configuration allowed the software to accurately track each TUI's position and rotation. Furthermore, participants were able to interact with the system’s touch screen using their fingers, to swipe, pinch and tap (see Table 9 for elaboration of device mechanics). Each EDNA Playboards system supports up to four users simultaneously, enabling interactive play that can be cooperative, collaborative, or competitive. Four custom-designed activities were incorporated into this research.

Table 9 Mechanics and skills usage in EDNA Playboards

Activity	Mechanics	Skills Utilised
Mixer	Type: Exploratory music-making. Users place matching TUIs on target shapes to trigger audio-visual effects. Multiple TUIs can be placed at the same time to produce music. Users can swipe the screen using the TUIs to stop the audio-visual effect. This game also serves to introduce users to the use of TUIs and the touch screen.	Social Skills: Collaboration. Users work with each other to produce pleasing auditory effects. This includes discussing how each audiovisual effect can be triggered. Cognitive Skills: Attention and problem-solving. Users explore a Virtual Environment to trigger auditory and visual effects to compose music. Physical Skills: Self-initiated movements, mainly placing objects on screen.
Pangles	Type: Puzzle solving. Geometric target shapes are shown on screen. Each TUI has a matching target of the same colour. When TUIs are placed on the screen, lines are projected from them on the screen. The aim is to manipulate the TUIs so that the projected lines enclose the borders of the target shapes. Correct placement of the TUIs is indicated by lighting up the target.	Social Skills: Collaboration. Users discuss solutions together and may exchange TUIs or ask to switch positions to complete the puzzle. Cognitive Skills: Problem solving and mental rotation skills. Physical Skills: Self-initiated movements including possibly moving to another position around the table, or stretch across the tabletop, to complete the puzzle.

Activity	Mechanics	Skills Utilised
Paint Wars	Type: Competitive token collection. Using touch and swipe gestures, users shoot out coloured trails to collect coloured shapes (tokens). TUIs can be rotated to control direction of the paint trails which attract shapes towards each player's home base. Users can disrupt their competitors' trails by blocking their trails with new paint or finger-swiping competitors' trails away.	Social Skills: Interactive. Users can verbally encourage or even mislead competitors to achieve their goals. Cognitive Skills: Divided and selective attention; Planning skills. Users have to pay attention to their own and competitors' paint trails while strategising. Physical Skills: Response selection. Users grasp, place and swipe at discretion to achieve game goals
Resonance	Type: Exploratory music making. TUIs placed on the screen emit radiating lines that intersect to form various enclosed shapes. Moving and rotating the TUIs changes the sounds produced. Touching these shapes with a finger produces audiovisual effects.	Social Skills: Collaboration. Users work with co-users to produce pleasing auditory effects. For example, discussing and negotiating number of TUIs to be placed, and which auditory effect to include Cognitive Skills: Attention and problem-solving. Users explore the virtual environment to trigger auditory and visual effects to compose music. Physical Skills: Self-initiated movements including grasping the TUIs and moving around the device.

Notes. TUIs: tangible user interfaces

7.4.5 Measures

Semi-structured interview questions. To gather qualitative insights, a semi-structured interview was conducted. The interview covered six areas aimed at understanding the different facets of the participants' experiences and perceptions towards the EDNA Playboards

Follow-up questions were asked to explore the participants' responses in greater depth. These areas included:

i. Points of interest: i.e., What parts or aspects of EDNA Playboards did you find interesting? Can you please explain why you found it interesting?
ii. Design feedback: i.e., What design features of the EDNA Playboards' games did you like the most? Why did you like them?
iii. Experience feedback: i.e., What was the best part of the experience? What was the worst part of the experience? Would you like to play with more applications like this in the future, and why?
iv. Movement awareness: i.e., Were you aware of your movements while using EDNA Playboards? Do you see any relationship between your movements and the EDNA Playboards display or environment? If so, what did you notice?
v. Social participation: i.e., Did you engage or interact with others during the session? How did you engage or interact with others?
vi. Other remarks: i.e., Would you recommend using EDNA Playboards to others? Was there anything about the experience that was uncomfortable? What design features would you like to change or add?

7.4.6 Procedures

The participants were divided into three groups, each consisting of three to four users, for approximately half an hour of gameplay. The session was facilitated by one researcher, with two additional researchers observing. The participants played the four different games and had the freedom to sit or stand as they wished. Following the gameplay, participants engaged in the semi-structured interview. Of the ten participants, three participants were interviewed at the same time (i.e., as a group), as they reported a preference to do so, while six participants were interviewed individually. One participant had to attend a centre activity right after the game session and was not interviewed. This resulted in seven interviews in total that collected experiences of nine participants. The interviews were conducted by three researchers and the audio of each was recorded using the interviewers' phones.

7.4.7 Analysis

This study employed Braun and Clarke (2006)'s reflexive thematic analysis for qualitative data. Known for its rigorous and systematic approach, this method emphasises the subjective interpretative nature of qualitative analysis. To ensure adherence to the protocol, the worked example presented by Byrne (2022) was followed. The process involved six distinct phases: familiarisation with the data, generating initial codes, searching for themes, reviewing themes, defining and naming themes, and producing the final report. Reflexive thematic analysis is characterised by its flexibility, as it does not rely on pre-established codes or theoretical frameworks. This allowed the researchers to explore the data without bias, enabling the discovery of unexpected themes. An iterative process was used where initial codes were refined and organised into potential themes. These themes were then re-evaluated against the entire dataset and refined further until well-defined themes emerged, ensuring they were data-driven and evidence-supported.

The interviews (n=7), lasting 13-35 minutes each, were transcribed and analysed. Three researchers (JL, MC, TM) were involved in the analysis. In line with Braun and Clarke's approach, each researcher independently read and generated initial codes. The NVivo software (v.14; Lumivero, Denver, CO, USA) was used to facilitate the coding process. The independent coding process decreased the chances of individual researcher bias dominating the analysis.

After this, discrepancies in coding were noted, such as where there were different interpretations of the same quotes, and these areas were further discussed and the codes refined by the team. In the next phase of analysis, themes were then identified collaboratively, with potential themes suggested, reviewed and agreed upon collectively. Ten group meetings of approximately 1-hour each were taken to complete the qualitative analysis process. There was no predetermined limit on the number of codes or themes, and quotes could be coded in multiple ways, ensuring a thorough and nuanced analysis (Braun & Clarke, 2006).

7.5 Results

Five themes were identified from the semi-structured interviews regarding the participants' experience of using EDNA Playboards.

7.5.1 Sensory experience of playing with EDNA Playboards

Participants found the visual elements of the experience engaging, particularly when interacting with the brightly coloured shapes used in EDNA Playboards. The participants consistently expressed their enjoyment of EDNA Playboards' visual features, describing them as vibrant and engaging, especially pointing out the visual elements they noticed solving visual puzzles. The use of vivid colours and familiar-looking geometric icons in the games made them visually appealing and accessible to older players.

In contrast, participants felt the auditory aspects of gameplay were more confusing, as recognising overlapping sounds proved difficult. While the participants appreciated the device's technology for producing abstract music as clever and sophisticated, they found it to be overwhelming at times, suggesting that it "might be too much of a good thing". They mentioned that it was more challenging to focus on sounds and that visual patterns were easier to detect. The sensory experience became overwhelming due to loud, overlapping noises, which detracted from the overall clarity. Overall, the visuals provided a novel, enjoyable experience, while the complex soundscape caused some frustration and sensory overload.

7.5.2 Openness to novel experience

The interviews suggested that the participants were open to the experience of using the EDNA Playboards despite some initial discomfort from the challenge of mastering the game. The participants highlighted that while they may not have fully grasped the game, the experience has the potential for fun and indicated a willingness to continue playing with EDNA Playboards. The participants were initially unfamiliar with the technology and agreed to try the activity out of curiosity. By the end of the session, they had developed a genuine interest in exploring the system. However, they emphasised the need for guidance when learning something new, which relates to the next theme on providing support.

7.5.3 Supporting play by clarifying game objectives and providing on-hand support

The participants expressed a need for guidance when learning the games, preferring a slower, quieter introduction to avoid feeling overwhelmed. They emphasised the importance of clear instructions on objectives before playing, highlighting their desire for structure and understanding in unfamiliar situations. While EDNA Playboards was designed mainly for collaborative games, with only one competitive game, the participants also reported some confusion around whether the games' objectives were all meant to be competitive, suggesting a need for more clarity regarding the games' objectives.

7.5.4 The importance of social engagement as part of gameplay

The participants expressed an interest in playing with their peers. In particular, they expressed interest in enjoying the process as a group over an extended play session, perhaps with breaks for tea and chats. However, some participants expressed frustration in response to another participant's consistent questioning about the game mechanism, and would have preferred fewer distractions and the opportunity to listen more carefully to instructions and to focus on playing.

7.5.5 The potential for cognitive stimulation to foster participation

Lastly, participants reflected on their strong desire for cognitive stimulation. Participants reported feeling that their cognitive abilities were deteriorating due to a lack of challenging activities and expressed enthusiasm for engaging in something new and different. They appreciated the challenge level of the games as both comfortable and interesting. Even when they felt they did not fully understand the games, they appreciated the games and the opportunities they represented to combat cognitive decline.

7.6 Discussion

This study aimed to explore the experiences of older adults living in a residential aged care setting as they played on EDNA Playboards, a collaborative tabletop device designed to enhance physical and cognitive abilities while encouraging social interaction. Qualitative feedback provided by the participants through interviews revealed five key themes: Sensory experience of playing with EDNA Playboards, openness to novel experience, supporting play by clarifying game objectives and providing on-hand support, the importance of social engagement as part of gameplay, and the potential for cognitive stimulation to foster participation. These central themes are further examined in the context of the environment that the participants lived in, as described by them in the interviews.

A growing body of research on the use of MR technologies in residential aged care has highlighted that these residents desire interesting experiences and find MR activities to be novel and enjoyable (Baker et al., 2020; Hosseini et al., 2023). Participants of this study reported that they "came for a new experience" (Resident G) and that they "enjoyed it because it was something totally new and [they] would like to do it again" (Resident H). Aged care residents may find conventional aged care facility activities to be uninteresting, as these activities tend to be set at the same basic level of difficulty that everyone can participate in instead of tailored to different levels of abilities. Baker et al. (2020), in their study of a VR application in an aged care facility, suggested that the residents may show self-isolating behaviour or withdraw from social engagement in response to dull activities, despite desiring social connection. Similarly, the residential aged care environment, as described by interviewees of this study, appeared to not have fully addressed the participants' need for activities that bring about cognitive and social stimulation. While expressing their appreciation for the support given by the staff, they also reported experiencing a deep fear of cognitive decline, and a sense of social isolation and stagnating in the environment. Several participants expressed a sense of frustration and feeling as though they were merely "filling time until [they] die" (Resident D). The participants described how they tried to maintain daily routines that included intellectual stimulation, such as reading, doing crossword puzzles and having conversations with their fellow residents. However, they witnessed and experienced in themselves a gradual decline in their cognitive and physical faculties, stating that "Life here is very, very. I don't know what the word is, but it drags you down. Drags you down. Blunts you, makes you think everything is blocked" (Resident H). Observing and interacting with others in the facility led to them feeling afraid of losing their mental acuity, in turn causing them to interact with other residents less. This was especially evident when one resident expressed unease about interacting with peers who struggled to engage in conversation. For example, one resident mentioned, "It's quite frightening just sitting in a room sometime and knowing that a lot of the people around you cannot answer a question clearly. Haven't absorbed a question clearly just in ordinary conversation that will go on at any stage at all. I find it quite frightening, you know, because you're hanging on to your brain, your intellect.”. The resident went on to explain that she has tried to retain as much of her old habits as possible to keep cognitively stimulated, and trying a new activity reminded her of how much she feared losing herself, saying “I read a tremendous amount […] and it's not that I'm wanting to sort of know everything, but I feel it's important to sort of keep doing the things that I've always done all my life. And maintain them at the level I used to, which is... they're getting harder and harder, and what I found about [using EDNA Playboards] was that these thoughts are coming to me.” (Resident E). This underlying fear of their vulnerability to cognitive decline appeared to simultaneously drive their desire for new cognitively and socially interesting activities and fuel their concern that their cognitive and physical limitations have impacted their ability to engage in such activities.

In the case of the EDNA Playboards activity, the participants reported that there was an initial excitement about the new technology and a willingness to try something new and unfamiliar upon signing up for the study, saying “I am a little bit excited about the technology. I always want to try something for me, even if I never seen [it before]” (Resident D). Another resident stated that “...before [signing up for the study], I wanted to think before I say no, I don't like it, but probably sometimes I say to just try it. Try it and see it” (Resident F). This initial excitement was accompanied by some scepticism as: a) they did not typically enjoy playing games; ii) they lacked prior knowledge and experience around the mixed reality technology; and iii) they worried about their ability to engage fully in the games. However, as the session progressed, these participants reported finding themselves increasingly drawn to the games. They desired to figure out how to make the games work and actively participate in them, despite their self-perceived lack of skill. Their excitement was conveyed in their responses to the interview questions, which included “You know, on various levels, I didn't get anywhere near bringing it all together. Yeah, but I have you know, a recognition that if you do get it together and you know you can win games or just play around with it. It would be a lot of fun. And there's potential. Anything that [is] sort of introduced to you when you're 85 that seems like a lot of fun. Yay, I'm all for it.” (Resident F). There was a level of challenge here, where the participants described trying very hard to pick up the games while still feeling they may not have completely understood, but the discomfort was not to the extent that they felt reluctant to try again, “[The challenge level] was, to me, comfortable. It was testing. Yeah, but [the activity was] great, interesting” (Resident H). It could have helped that they reported seeing the potential for enjoyment and that there was fun to be had even if they had not felt confident in their gaming skills or were unsuccessful with winning in the one competitive game in EDNA Playboards. The participants felt excited about the possibilities it offered and surprised that new-to-them technology had the potential to bring them joy in old age. In the interviews, the participants reported that by the end of the session, they could see the value in playing with EDNA Playboards and were quite engaged, such as when one of them said “I suppose I have to admit I'm not a person who plays games. But I mean by the end of the session I wanted to, you know, to get the thing to work to have the lines come up and you know, and to participate in it and make it work. I mean, I could, you know, see that was all good stuff” (Resident G). Ultimately, their interest in the MR technology remained strong, regardless of their perceived lack of proficiency or skill level in using it. The participants demonstrated their openness to novel experiences by being willing to sign up to an EDNA Playboards game session despite having some reservations. They ultimately decided it was important to them to give it a try firsthand before forming an opinion.

While the participants had a desire for companionship, and noted social interaction as one of the perceived benefits, their desire for social connectedness was tempered by frustration of having their learning interrupted by others, as they found that they "… just wanted to listen … want[ed] to hear what we were asked and encouraged to do instead of being interrupted by [another participant's questions about the game]. It was distracting" (Resident G). The social connectedness that EDNA Playboards seeks to provide was at times uncomfortable for these residents who may be more used to co-existing in the aged care facility. As seen in an earlier quote, the participants' descriptions of their failed attempts to have conversations with their peers suggested that interacting with each other in their daily life was uncommon. When they tried to collaborate, the researchers noted that they became competitive or tried to direct each other's gameplay, which inadvertently disrupted their enjoyment. One participant recalled that they saw "… a sort of division" while playing in a group, although that was also "an observation, something more as part of the experience" (Resident H) when asked if the social element would stop them from enjoying the game. Despite being unaccustomed to collaborative games, the participants did express a desire for companionship, suggesting they would "like to get into it in a bit. A whole gentle afternoon, coming, going and getting a cup of tea. Listening to [others using EDNA Playboards]." (Resident I). Essentially, having an extended game session together without trying to outdo each other and connecting by watching each other play.

The interviews emphasised the older adults' need for guidance and a more gradual introduction to EDNA Playboards. They described finding themselves in an unfamiliar situation that felt overwhelming partly due to the vividness and auditory complexity of the games while also influenced by their difficulty in collaborating with their fellow residents in the game. This is despite enjoying the visual intricacies of the games. As a participant said, “I would need a slower introduction or a quieter introduction. Not necessarily on my own, but not with everybody playing at once and all the noise going. […] It's got the intricacy of the shapes, you know, forming and reforming and the sounds […] I could see it all coming together and I think the coming together would be a very pleasant experience. But I was just a bit overwhelmed by everything happening, but I was sufficiently impressed to want to come back” (Resident G). A slower and quieter introduction to the EDNA Playboards, as requested by the participants, would be beneficial to their learning process.

In addition, more guidance and support may help with the process. The participants expressed that having the facilitators at the game session was helpful, that they “need somebody who actually knows what it’s all about, not let us loose in unknown territory” (Resident H). The residents indicated that they would prefer having someone who has a clear understanding of the EDNA Playboards managing the game sessions and who could offer them support, where needed. With these types of supports in place, the residents felt that they would eventually become proficient and independent, with one participant believing they would eventually “become good with it” (Resident C). In the context of MR activities, these facilitators would support the older adults by guiding discussion, customising activities to align with the users’ needs, contribute to the social experience, and ensure that activities are conducted safely and effectively (Baker et al., 2020; Waycott et al., 2022). As older adults typically show lower proficiency and comfort levels with new technology compared to younger age groups (Barnard et al., 2013), and need to be equipped with more technology skills to engage effectively in the activities (Thach et al., 2020), facilitation by the staff of the aged care facility becomes critical for the success of implementing MR activities (Hung et al., 2023).

The participants expressed a strong desire for cognitive stimulation and having something new and different to challenge their thinking. They emphasised the need for activities that stretch them cognitively, which they felt were lacking in their routine activities, “We need something new. Something different … something to stimulate” (Participant B). They also perceived the benefit of engaging in activities that may initially be difficult to comprehend but ultimately lead to mental growth, indicating that they “need our brains to be stimulated in some way, even if we don't understand it, it will make us think”. The consensus was that they desired a significant change to invigorate their minds and prevent cognitive decline in their current environment. To this end, they expressed a desire to learn the fundamentals of the games through studying the rules of the games and suggested a more traditional approach to learning like doing “the old-fashioned thing [and going] back and study[ing] the rule book” (Resident E), rather than learning through exploration of the games. They also wanted to know the aim and purpose of each of the games and, in the interviews, they sought clarification about the overall nature of the games - whether they were team-based and collaborative, or competitive in nature. For example, one resident commented that they were not “really sure whether [they were] in a team situation or whether [they were] competing” (Resident B). The participants were accustomed to games with clear rules and game objectives, such as bridge and chess, and which are a different medium to MR games. The participants’ previous lack of exposure to MR activities would have contributed to their confusion and highlighted the importance of appropriate gameplay orientation for these types of devices.

The visual and musical elements of EDNA Playboards sought to make the games interesting while encouraging collaboration between players, thereby increasing the potential of enjoyment and social engagement. While the participants of this study expressed a strong appreciation of the visual aspects of EDNA Playboards, they reported mixed feeling about the musical elements; appreciating their novelty while also describing their overwhelming nature. They explained their preference for the visual elements, indicating that “drawing the visual patterns [is] what made it sort of a new experience. And trying to expand the colours, align the colours … the visual things most interesting … [the] sounds were more confusing” (Resident G). However, the residents remarked that the “sounds in themselves [were] intriguing, you know and to hear them raise in volume and then decrease and how that fits into what else is going on” (Resident H). Nonetheless, participants felt that it was easier to recognise the visual patterns compared with the auditory patterns, recalling that “it was hard to concentrate on sounds, but [visual] patterns are much easier to pick up” (Resident E). Unlike the visual stimuli, which could blend and swirl together, the residents indicated that the overlapping sounds were confusing, “it did seem as if we were to recognise some sounds as well. But the sounds were becoming overlapping. There was too much of a good thing” (Resident G). These results were comparable to that of a similar study conducted on the user experiences of EDNA Playboards with healthy older adults living in a retirement village (Chapter 6). While the participants of this separate study did not specifically dislike the auditory elements of the EDNA Playboards, they indicated a preference for the visual elements. The participants involved described a preference for more natural sounds and suggested that the auditory elements of the system might be improved (Chapter 6). However, while the participants of the current study shared similar reservations towards the auditory elements of the EDNA Playboards, they did not describe wanting to replace the audio with something different.

The confusion felt by the participants regarding the auditory elements may be due to the collaborative nature of some of the activities. The EDNA Playboards was tested in a group session where up to four participants played on the device simultaneously and collaboratively. Two of the activities (Mixer and Resonance) uses mechanism similar to that of a multi-contributor art and music activity. One resident reflected on their experience, noting that, for the music activity, "it felt like something much better to do one at a time rather than to have several people. You create your own sound patterns, without being interrupted by other people" (Resident G). Despite this, a multi-sensory game design approach may still be beneficial in games for older adults, as the use of multi-sensory stimuli may effectively compensate the decline in sensory processing brought about by ageing (Laurienti et al., 2006). Nonetheless, the EDNA Playboards games may need to be modified or simplified to allow greater ease of processing information and to address the participants' confusion regarding the auditory elements. This could be through having a longer and slower initial learning period, as suggested earlier, or providing a quieter game environment by modifying the auditory stimulation in each game or reducing the number of people playing each time.

While the intention of this study was to use a mixed-methods approach, conducting mixed-method research in aged care facilities presents unique challenges when it pertains to filling in the questionnaires. To improve future studies, researchers should consider implementing data collection strategies that balance the need for genuine, real-time experiences with the risk of participant fatigue. One possible approach is to span data collection over multiple days and conduct quantitative and qualitative data collection over shorter sessions. However, this can pose other issues as the participants' experiences with the system may become historical, which could influence their recollection. A shorter questionnaire customised to the UX of EDNA Playboards may also shorten the time taken to complete the data collection, but this may mean that the measures used might not have been tested for reliability prior to data collection. Therefore, a trade-off exists between capturing genuine, on-the-spot user experiences and managing participant fatigue.

To conclude, this study focused on the experience of older adults trialling the use of EDNA Playboards in an aged care facility, and it contributes to the existing literature on the use of MR in older adult populations by analysing the user experience through the users' own words. Qualitative findings indicated that the participants were very open to the novel experience due to their strong need and desire for more cognitive stimulation. As an exploratory study, the generalisability of the findings is limited by the small sample size drawn from a single aged care facility and the single MR session. However, the adopted study design provides important preliminary insights into the suitability of MR systems, like the EDNA Playboards, for these types of environments and the opportunity to modify several factors that may impact the player experience before expanding implementation. Designing and evaluating technology for older adults can be ethically challenging due to the heterogeneity of the older population, power imbalances between research and technology designers and the older participants, potential for reinforcing ageism if internally-held values are not reflected on, and exclusion of certain groups of older adults from participation, such as those whom are less tech-savvy or healthy (Waycott & Vines, 2019). These ethical considerations may be best addressed by considering the older adults' views throughout the research and design process. Future research should consider examining the possible benefit of modifying several factors, namely having a slower initial learning period, providing trained facilitators onsite, and increasing clarity on the goals of each game by providing a rulebook that the participants can study in their own time, while supporting them in their desire to ultimately enjoy the games independently.

Chapter 8 General Discussion

This chapter provides a general discussion of the thesis, including a summary of the main findings, current insights, strengths and limitations, and recommendations for future research.

8.1 Summary of findings

Worldwide, many older adults fail to meet recommended physical activity guidelines (Izquierdo et al., 2021). This is worrying, especially considering that staying active in old age is associated with numerous health and well-being benefits such as increased life satisfaction, improved quality of life, better self-perceived health, reduced psychological distress, lower risk of chronic diseases, and improved cognitive functioning, supporting older adults in maintaining their independence and mobility (McPhee et al., 2016; Vozikaki et al., 2017). This thesis sought to explore the use of gamified MR applications tailored for older adults to encourage active participation, as the use of such novel approaches has potential cognitive, physical and social connectedness benefits for older adults.

To gain a deeper insight into the various factors that affect participation in older adults, the fPRC model (Imms et al., 2017) was used as a framework for understanding the facilitators and barriers to participation. This approach ensured that internal and external influences on participation were considered. Chapter 1 discussed how addressing both internal and external factors is essential for promoting and maintaining physical activity and social involvement in older adults. The *fPRC* framework (Chapter 1, Chapter 3) defined participation as comprising both *attendance* and *involvement*. While older adults may attend activities, true participation requires meaningful engagement. Identifying the intrinsic and extrinsic factors that facilitate or hinder involvement therefore requires exploring the older adults' subjective experiences through the use of qualitative and experimental based studies.

In relation to MR technology, a thorough understanding of older adults' user experience (UX) with MR applications is crucial. Utilising the fPRC theoretical framework in UX research allowed for an evaluation of older adults' experiences while participating in MR activities. In Chapter 2, the thesis introduced the Components of User Experience (CUE) framework (Thüring & Mahlke, 2007), which offered a structured method to assess user experience by considering the instrumental/usability component, emotional reaction component, and aesthetics/non-instrumental aspects of the applications. In turn, these dimensions of UX can be understood as factors influencing participation in activities. By integrating the fPRC theory with UX research based on the CUE, this thesis provides insights to enhance the design of MR technology, ensuring it is more inclusive, user-friendly, and supportive of older adults' participation in activities.

Most past research on the use of gamified MR applications with older adults appeared to focus on either a clinical population or on its efficacy as a therapeutic aid, making the feasibility and UX for non-clinical populations of older adults uncertain. To address this research gap, three inter-related studies were conducted as part of this thesis. Firstly, a systematic review sought to understand recent research finding on MR-based applications' usability and effectiveness when used by older adults (Chapter 4). The overarching goal of the systematic review was to evaluate the user experience (UX) of healthy older adults who use any MR-based technology for engaging in physical and social activities. Next, EDNA Playboards, a gamified MR-based interactive experience, was tested in two settings to explore its acceptance by older adults and their experiences while using it in: i) a mixed methods empirical study involving residents from a retirement community (Chapter 6); and ii) a qualitative empirical study with residents from an aged care facility (Chapter 7). Briefly summarising some of the key findings, participants of Study 2 (Chapter 6) perceived social and cognitive benefits from using the EDNA Playboards system and hoped that continued use of the device may help foster a sense of community and encourage social interaction between members of the retirement village. Participants of Study 3 (Chapter 7) recognised the cognitive challenge that engaging with the EDNA Playboards system offered and expressed interest in continuing use of the application. Detailed insights from the findings of this thesis are discussed later in the General Discussion.

The systematic review (Chapter 4) highlighted several gaps in the understanding of how older adults interact with MR applications. These included the need for more comprehensive assessments of usability and emotional responses elicited during the interactive experience, the frequently overlooked role of non-instrumental qualities in encouraging user engagement, and the notably low levels of studies that reported social interaction among participants across studies included in the systematic review. The methodology of the empirical studies (Studies 2 and 3; Chapter 6 and 7) were built on this current state of research in the area of MR-based applications and therefore had a focus on the use of qualitative data collection which gave the participants the space and flexibility to share their thoughts on the aspects of the game experience that were most important to them, not just what researchers may think of as important to their user experience.

The systematic review (Chapter 4) on the experiences of healthy older adults with MR applications provided evidence to support the use of these technologies in older populations. Overall, the instrumental and emotional qualities of the investigated MR applications were high, with older adults enjoying the applications and finding little to no adverse impacts (Lim et al., 2024). The review identified that most included studies reported only mild to no adverse effects, such as cybersickness. Several papers underscored the need for better communication with older adult users, particularly through providing clearer explanations and instructions to facilitate understanding. Study 2 and 3's research methodology directly addressed the systematic review's finding about older adult users' need for better communication by incorporating tailored support during the EDNA Playboards session. Facilitators of Study 2 and 3 provided both verbal and visual instructions and, where necessary, demonstrations to scaffold participants' learning. For Study 3 this approach was particularly important to support the participants, who were mostly aged 85 and above, in enjoying the EDNA Playboard activities. The importance of providing facilitation and support was emphasised by the participants' request for a slower pace (Study 3) and their desire for clarity in game mechanism and goals (Study 2 and 3).

On the domain of emotional response, the review indicated that most included studies reported that older adult users perceived high levels of enjoyment, though the studies often did not include a deeper exploration of the factors contributing to these positive reactions. They also found mixed results on how game complexity (challenge) may impact the level of user engagement and motivation, which warranted the need for more research into how challenge may impact the UX in older adult population. The findings from Studies 2 and 3 similarly found that both sets of participants expressed enjoyment while engaged with the EDNA Playboards and expressed interest in continuing to use the device after the end of the study. An attempt was made to extend these findings through qualitative data collection (semi-structured interviews), with findings suggesting that a sense of achievement after completing a designed task (e.g., solving a puzzle, winning a game) in EDNA Playboards (Study 2), the desire to be cognitively stimulated (Study 2 and 3), and social interaction through the shared activities (Study 2 and 3) were factors that could have led to the enjoyment of EDNA Playboards. This provided a more nuanced understanding of the positive emotional reactions triggered by EDNA Playboards that may link to the design elements of digital interactive experiences.

The systematic review also revealed a lack of studies focusing on the aesthetic aspects of UX. Among the few studies that do explore this area, the findings suggest that older adults tend to prefer game content that they find familiar, and which resembles real-life experiences or content (Lim et al., 2023). The review also found that older adults appreciated intuitive visual and auditory feedback. Even among studies that included aesthetic UX, few studies considered older adult users' perceptions regarding the internal content of gameplay. Rather, these studies primarily concentrated on the quality of visual and auditory outputs from the devices themselves. The included studies did suggest that older adults' enjoyment of MR-based applications was linked to the richness and quality of these visual and auditory elements. However, this approach, which focused on hardware quality, overlooked the *preferences* of older adults, an internal factor which the fPRC (Chapter 1) emphasised as one of the significant influences on continued engagement and participation in activities. Taking into account the systematic review's findings that there is a research gap in the understanding of older adults' preferences, Study 2 and 3 included explorations of older adults' perceptions of the aesthetics of EDNA Playboards. Even without explicit questions on the auditory and visual elements of EDNA Playboards, participants of the two empirical studies had expressed strong opinions on these elements, suggesting how important aesthetic preferences were to older adult users. These preferences are elaborated on later in this general discussion under the section Current Insights and reinforce the idea that non-instrumental qualities of UX play a central role in shaping the UX of older adults and should be considered when designing MR applications or interactive experiences for older adult users.

Another contribution of this thesis lies in its attention to the social interaction between users of the MR-based interactive experience. The Systematic Review had found that few studies reported on social involvement during gameplay, and when they did, they typically reported a low level of social presence. In contrast, the EDNA Playboards was designed as a multi-user interactive experience, and the methodology of the empirical studies reflected this design and explored the older adult participants' social experience during the interactive session by using the GEQ Social Presence questionnaire and through semi-structured interview questions about their reflection on the social aspects of engaging in EDNA Playboards.

The findings of this research offered a detailed analysis that explicitly addressed the core objectives established at the beginning of this thesis. Overall, the findings of this thesis highlighted a positive UX that supported the use of a gamified MR application with older adults. Each study provided research insights that reflected the complex and varied experiences of older adults, increasing evidence-based understanding of how best to support this population, and these insights are elaborated on in the next section.

8.2 Current insights

This research has shed light on key factors influencing older adults' engagement with MR applications, particularly in the context of their participation and user experience while engaging in gamified applications. However, gaps remain in our understanding of how best to tailor these applications to encourage active participation through a high-quality user experience. Three areas that may warrant further exploration are music preferences and sensory needs, level of challenge, and socialisation.

8.2.1 Music preferences and sensory needs

This thesis found that older adults' sensory needs and music preferences influenced their engagement with MR applications, particularly in music-based activities. Older adult users' music preference was not mentioned by any studies included in the systematic review of this thesis, making the studies of this thesis potentially one of the first to highlight the importance of older adults' music preference in impacting their UX of a MR application. The importance of music design in MR application was evident across both participant groups, where the older adult participants found the digital music used in EDNA Playboards to be unique and interesting, but not their preferred choice in auditory stimulation. Delving into past studies on the music preferences of older adults, studies have suggested that as individuals age, they are increasingly drawn to jazz and 'unpretentious' music (music which is straightforward and accessible, like country or folk music), while increasingly disliking contemporary music (Bonneville-Roussy et al., 2017). Interestingly, older adults' preference for country and jazz music styles appeared to have stayed stable across time, with an earlier study by Jonas (1991) on music preferences of nursing home residents indicating similar music preferences to those reported in later studies (Bonneville-Roussy et al., 2013; Bonneville-Roussy et al., 2017). This could be a reason as to why the older participants of this study did not appreciate the abstract, digital music of EDNA Playboards.

Nevertheless, it should be noted that the music preferences of the participants were not explicitly studied in this thesis. While previous studies have explored older adults' general preference in music genres, there is a need for more targeted studies on older adults' music preferences in the context of MR applications and collaborative play. This is especially so, as aesthetic preferences are an important part of UX (as part of the CUE model; Chapter 2), and it would benefit MR application designers to consider the sensory preferences of older adults.

While the focus of this study was not on the sensory perception ability of older adults, ageing brings about a range of functional changes, including declines in visual perception, visual motion perception, and visual attention (Andersen, 2012; Billino & Pilz, 2019; Kim et al., 2014), hearing loss, reduced sensitivity to high-frequency sounds, and lowered speech perception ability (Jayakody et al., 2018; Taitelbaum-Swead & Fostick, 2016). With respect to visual perception, research is ongoing to understand the extent and variability of functional changes evident in older populations (Billino & Pilz, 2019), as it is well understood that there are large individual differences within the older adult population (Agnew et al., 2020). However, the age-related changes to an individual's sensitivity to certain frequencies of sound (Jayakody et al., 2018) may help explain why participants reported greater difficulty in perceiving musical changes. Older adults may also find that they have more difficulty in understanding speech (i.e., speech perception skill) due to cognitive and perceptual changes, separate from hearing functionality (Jayakody et al., 2018; Profant et al., 2019), and this challenge is particularly so in noisy environments that have fluctuating background sounds that vary in volume and content over time (Taitelbaum-Swead & Fostick, 2016). The EDNA Playboard's games have dynamic, response-based music and sound effects, which may have impacted the participants' ability to hear and process speech and auditory information. Any confusion resulting from being unable to process what their fellow players were saying would then impact their ability to collaborate with others and affect their willingness to engage in the activity together. Despite this, a multi-sensory game design approach may still be beneficial in games for older adults, as the use of multi-sensory stimuli may effectively compensate for the decline in sensory processing brought about by ageing (Laurienti et al., 2006). Nonetheless, the EDNA Playboards games may need to be modified or simplified to allow greater ease of processing information and to address the participants' confusion regarding the auditory elements. This could be through having a longer and slower initial learning period, as suggested earlier, or providing a quieter game environment by modifying the auditory stimulation in each game or reducing the number of people playing each time. The hardware of the application can also potentially be modified such that each participant may initially have their own headset that is linked to an individual TUI, so that they may explore how their actions affect sound and visual aspects of the application without being influenced by the other players. As they become more confident, they might take the headsets off and play collaboratively. These suggestions would require more testing and research to ascertain whether they could improve older adults' ability to participate in the use of the MR applications.

8.2.2 Challenge level in activities and motivation of older adults

The level of challenge presented in activities emerged as a critical factor influencing engagement among older adults. The findings of this thesis indicate that when given accessible opportunities and suitable support, older adults exhibit a strong desire to learn and adapt to new technology. This inclination remains, regardless of the participant's age and includes individuals over the age of 85, who not only showed a remarkable willingness to embrace new experiences during the sessions of EDNA Playboards, but also benefited from the enjoyment that came through 'play' and social interaction with their peers.

Understanding the motivations of older adults appears fundamental to fostering their participation and engagement in activities. This is in line with the fPRC theory (Imms et al., 2017), where it is understood that individuals may be physically present in an activity without actively engaging in it. It is hence important to understand what may motivate older adults to not just be physically present but continue to stay immersed and engaged in the MR activity. Through the qualitative interviews, this thesis found that many older adults seek to feel cognitively engaged in their communities, striving to maintain their independence amidst changing physical and cognitive abilities, which brought them fear. This led them to pursue avenues for (and be open to) cognitive stimulation, which can be significantly enhanced via the provision of appropriately challenging activities. This motivation is closely tied to the level of challenge presented to them, as lack of new game elements and short game duration that are too easy may lead to boredom, while those that are overly difficult can lead to frustration (Jeremic et al., 2019; Sauvé & Kaufman, 2019). Striking the right balance is essential for not only enhancing engagement but also for promoting a sense of accomplishment and ongoing learning. However, as far as research goes, there appears to be a lack of information on what level of challenge is desired by older adults. This may be due to individual differences in the preferences and abilities of different people, as well as the wide variety of activities available to them, which collectively lead to difficulties in generalising results to a wider population. It is therefore suggested that, in addition to further research to establish a deeper understanding of whether there is a consensus in the level of challenge preferred by older adults, application designers and researchers may explore activities where customisation of challenge is possible. For example, by allowing a choice in difficulty level at the start of each game or allowing adjustments of the speed at which each activity is played. This may help particularly in group-based activities, allowing individuals to socially engage with others without feeling too overwhelmed by the activity. Furthermore, as suggested in the qualitative analysis, providing facilitators that can provide demonstration of the activity and assist individuals who are struggling may help to close the gap between ability levels.

8.2.3 Socialisation

The findings of the systematic review indicated that most MR applications for other adults have an emphasis on physical health improvement, and it appeared that older adults' physical health was the focus of most of the technology designed for them. While there are important benefits to keeping older adults healthy and active (Chapter 1), the participants of Study 2 and 3 did not mention the potential physical benefits of engaging in EDNA Playboards as important to their experience. Instead, their desire for a closer community, more interaction with others, and their loneliness can be clearly seen in the research findings (Chapter 6 and Chapter 7). Loneliness in older adults can have significant physical consequences, with a nationally representative longitudinal survey suggesting that older adults who experience loneliness tend to have a shorter life expectancy (three to five years less on average) compared to their peers who do not perceive themselves as lonely (Malhotra et al., 2021). The negative physical health impact remained true even for older adults who were 'sometimes lonely' compared to those who perceived themselves as 'never lonely', while the negative health impact was worse for those who were 'mostly lonely' (Malhotra et al., 2021). With other studies similarly suggesting that loneliness and social isolation are a clear and major risk factor for physical and psychological health in older adults, correlating with death, psychological and cognitive disorders, (Donovan & Blazer, 2020; Kemperman et al., 2019; Ong et al., 2016), reducing loneliness in older adults can be an important part of preserving their overall health.

However, despite the older adult participants expressing desire for social connectedness, some participants of Study 3 initially found the social aspect of EDNA Playboards to be unfamiliar or even uncomfortable. This discomfort appeared to stem from a broader context in which the participants alluded that interpersonal interaction among residents was relatively uncommon. For example, the participants' past experiences of unsuccessful attempts at conversation with other residents hinted at a general pattern of co-existing rather than socially engaging with fellow residents within the aged care environment. This may have led to the research findings of Study 3 that indicated that during group gameplay, the participants' efforts at collaboration sometimes led to competition or attempts to control others' actions, which occasionally disrupted the overall enjoyment of the session. Nevertheless, despite the challenges of social interaction in a multi-user interactive experience, the participants continued to express their desire for companionship and shared experience. Some participants envisioned the potential of EDNA Playboards as part of a relaxed, communal activity where gameplay could naturally weave into an afternoon of casual interaction, suggesting their openness to social engagement when facilitated gently and at their own pace. These findings suggest that multi-user MR systems can foster meaningful social interaction and potentially combat feelings of social isolation often reported in older populations, and that this perceived benefit is a factor that would encourage participation in activities. However, some older adults may require some facilitation of social interaction to ease the discomfort of interacting with their peers. This highlights the importance of designing interactive experiences that not only allow but encourage social play in older adults.

The multi-player game mechanism of the EDNA Playboards was specifically designed to encourage socialisation among participants through collaborative and competitive play. Based on the results of this thesis, older adults across studies have expressed enjoyment in such social play and especially showed enjoyment in competitive games (e.g. Paint Wars in the EDNA Playboards). They showed relatively less interest in collaborative music games (e.g. Resonance in the EDNA Playboards). While no study on game mechanism preference was found on non-clinical populations of older adults, research in older adult rehabilitation may provide useful parallels. In the work of Pereira and his colleagues, who looked at the use of multi-user rehabilitation games played on interactive touch surfaces for older adult stroke patients (Pereira et al., 2021; Pereira et al., 2019), it was shown that different game modes affected user engagement and social involvement. Across both studies, their findings indicated that competitive play tended to increase flow and challenge (i.e. active participation), whereas collaborative play fostered more sustained social interaction and may be more suited for encouraging social participation. However, the authors also found that the results on collaborative games may be mostly explained by the personality of the participants, with more extroverted participants feeling more empathy and are behaviourally more involved when playing in a collaborative game mode (Pereira et al., 2019).

Similarly, a study by Baur et al. (2023) found that, in a sample of stroke patients undergoing game-based rehabilitation, game modes affected levels of engagement and enjoyment. Participants rated a competitive air hockey game as more interesting, and exercised with more effort, than when playing a collaborative game, indicating higher levels of active participation and enjoyment while playing competitive games. The participants were unfamiliar with each other, and found that co-player games were as motivating as single-player games, suggesting that unfamiliarity with fellow users (such as in the case of some of this thesis' participants) may not affect game participation motivation. Together, these studies suggest that the balance between competitive and collaborative game modes affects and shapes both the emotional engagement and social experiences of multi-player interaction, and that incorporating each mode may bring about their own advantage although more research is required in this area to establish clearer direction between game mode and its impact on participation. Incorporating competitive gameplay elements may boost active participation and cognitive engagement, while collaborative gameplay may encourage social engagement and connectedness between participants, even when they may be unfamiliar with each other. MR systems like the EDNA Playboards can thus draw on these gaming elements to design user experiences that are both socially, cognitively and emotionally engaging for older users.

8.3 Research limitations

Although this thesis has identified several valuable insights into factors influencing older adults' engagement with MR-based applications, it is important to acknowledge the limitations of this thesis to refine future investigations concerning ageing and MR applications.

While the fPRC and CUE were integrated and used to assess participation while using the EDNA Playboards, it is important to consider some of the potential shortcomings of this framework. For example, although the fPRC adopts an ecological perspective, it still places a strong emphasis on individual attributes such as motivation, preferences, and skills. This focus may underestimate the impact of structural and systemic barriers that can limit opportunities for participation. Furthermore, the model may not fully account for cultural differences in how participation is valued or expressed. What constitutes meaningful involvement in one cultural context may not directly translate to another culture, as participation can be shaped by collective norms and relational expectations. In the case of this thesis' older adults, some participants have expressed a desire and enjoyment in watching others play, and while perhaps not traditionally considered personal or active engagement, to these participants, watching their fellow older adults play is a form of immersion in the activity as it engaged them emotionally and socially. It may remain a valid form of 'collaborative play'.

Similarly, while the CUE has been widely used to assess user experiences, it primarily focuses on the individual UX during use of the device (i.e. usability, emotional experience and aesthetics), while placing less emphasis on social influences and cultural context. Post-completion reflections on the qualitative data collected posit that the emotional experiences of the user and the subjective nature of aesthetics could arguably be affected by cultural influences and social norms, or even the personality/personal characteristics of the users, such as the older adult participants of this thesis preferring non-abstract music. Nevertheless, a detailed exploration of how culture and social preferences impact UX was beyond the scope of this thesis. By underrepresenting these factors, the CUE may provide an incomplete picture of user experience in settings where social participation or cultural symbolism significantly influence user engagement.

The design of the present research did not explicitly address these cultural influences, as the study's scope was focused on exploring the general user experience of older adults. However, this limitation highlights the need for future work to explore how cultural values, social dynamics, and contextual factors shape both opportunities for and expressions of participation. Extending research to include these dimensions could provide a more holistic understanding of participation both socially and culturally. Future researchers might consider whether better instruments are available to capture the social and cultural contexts of participation and user experience, or whether existing models such as the fPRC and CUE might be adapted to incorporate these broader influences. Doing so could enhance the ecological validity and cultural sensitivity of participation and user experience research, ensuring that interpretations extend beyond individual-level constructs to include the wider social and ecological conditions that shape engagement and participation.

One key limitation arose from the data collection process in the aged care facility (Study 3), where collection of quantitative data proved to be challenging. While both quantitative and qualitative data were successfully obtained from participants in the retirement village (Study 2), participants in the aged care facility struggled to complete the questionnaires within the allocated time. Specifically, it became evident that older adults required additional time to complete the questionnaires.

As for the participants in the retirement village, they had the flexibility in their daily schedules to offer slightly more time, where needed, to extend the period of data collection to complete the questionnaires, if they chose to do so. On average, participants from Study 2 took about ten to fifteen minutes to finish the questionnaire. The additional time needed by the older adults to complete the questionnaires was influenced partly by the need for additional reading time, but also by their desire to ponder the questions before answering. Additionally, they may also have been more physically, cognitively, and emotionally comfortable when they could pace themselves through the whole process.

In contrast, participants in the residential aged care facility (Study 3) had schedules that tended to be less flexible due to scheduling constraints commonly found in aged care environments, such as having scheduled medication rounds, health checks, or similar, which limited flexibility for extended engagement. Specifically, there was a fixed, assigned time for the study to take place, which went towards actual play time with EDNA Playboards and the semi-structured interview. The participants left for their regular, scheduled activities right after the assigned time as part of the aged-care facility's daily schedule. Having more time to do the data collection was not feasible, and the questionnaires were given to the participants to complete in their own time and submit later, but only one participant returned the filled in questionnaire. The differences in how quantitative data was collected in each study could have contributed to the lack of quantitative data received from Study 3.

As suggested in the extended methodology (Chapter 5), there does not appear to be a quantitative measure available that was designed specifically to examine the UX of older adult users. While successfully used in Study 2, the measures used in this program of research were lengthy and not well suited for all participants, leading to the methodological limitation for Study 3.

Another limitation concerns the small sample size in both studies. While this allowed for close researcher-participant interaction (discussed further in the next section), the limited number of participants limited the generalisability of the findings to the broader older adult population. Additionally, the demographic composition of the study sample in Study 3 consisted predominantly of older adults aged 85 and above, which presents a unique set of limitations and strengths. Notably, the youngest participant in Study 3 was 77 years old, while the rest were aged 85 and above. This demographic profile reflected the overall demographic profile of Australian aged care facility residents where more than half (58%) are aged 85 and over based on recent statistics (Australian Institute of Health and Welfare, 2024b). Hence, the results from Study 3 were collected from a cohort who were representative of a typical Australian population living in aged care and, therefore, are expected to provide good insight into the experiences of older adults living in these environments. Nevertheless, the older age range (range: 77 to 91 years of age) of the participants in Study 3 would likely limit the generalizability of the findings to younger cohorts of older adults, such as those involved in Study 2 who ranged from 69 to 88 years of age.

Study 2 and 3 adopted a cross-sectional, single-use design rather than a longitudinal approach. This limited this thesis' ability to infer causation between the use of EDNA Playboards and an increase in active participation of older adults. This also meant that the thesis was unable to assess changes over time.

8.4 Research strengths

Despite the limitations, this thesis also demonstrated several research strengths. The studies in this thesis had a small researcher-to-participant ratio. This enabled close interaction and hands-on observation of participants' engagement with the EDNA Playboards. As an exploratory study involving a novel MR device with a new user group, this level of engagement yielded deep insights into the older adults' experience with MR-based interactive experiences.

Additionally, the application of mixed methods and MR technology in Study 2 proved valuable for capturing a nuanced understanding of user experiences among older adults. The flexibility in adapting data collection methods, especially in the retirement village context, allowed older adults the time and space they needed to engage meaningfully with the questionnaires. This thesis provided insight into how research methodology may be tailored for the older adult population to improve the quality of the data.

When collecting qualitative data, interaction with the older adult participants across both studies indicated that semi-structured interviews may benefit from providing options for both group and individual interview formats to tailor this aspect to the preference of the participants. In this research, the same set of questions was used to guide each interview regardless of interview modality, ensuring that essential topics were discussed. From the experience of Study 3, group interviews appeared to foster a sense of comfort and camaraderie among the older adult participants. It was observed that the group dynamic encouraged richer and more in-depth responses, as participants often built on each other's comments, validated shared experiences, or debated differing opinions based on questions and discussions with their peers. The group dynamic also allowed for a smooth, conversational flow with less guidance required from the facilitators as the participants naturally covered follow-up questions that may have been asked by the facilitators. Furthermore, group-based interviews gave participants more confidence to identify any negative aspects of the EDNA Playboards system or their experience with using it, reducing the potential for positively biased responses. While these initial findings suggest that group interviews may be beneficial for future research involving older adults, the benefits may be contingent on the composition of the group (e.g., personalities, perceived or actual power imbalances). As such, this should be considered when settling on a methodological approach to ensure the collected data are representative of the chosen cohort. This approach is also resource-intensive and may have limited feasibility in larger scale studies due to practical constraints. Future research will need to weigh the benefits of richer individual data against improved generalizability and tailor this to best suit their research goals.

8.5 Future research

Based on the findings of this thesis, several directions for future studies are suggested. Future research could consider revising the methodology for collecting quantitative data. Possible adaptations could include:

i) Negotiating for a longer data collection session to allow for flexibility in time,

ii) Collecting both quantitative and qualitative data in person wherever possible so that there is opportunity to provide assistance when needed to ensure completion,

iii) Designing a more accessible questionnaire that can be completed in less time and that is tailored for older adults, such as using more pictures than words.

There is an opportunity for future research to investigate the development of a measure that is specifically meant for assessing the UX of older adults and other populations that may require a short and easy-to-understand questionnaire that explores their experience in using a digital application.

To enhance the generalisability of findings, future studies could consider replication of these studies with participants of a wider age range to understand the UX of older adults with MR applications more broadly within and outside of the aged care facility and retirement village context. It is also important to recognise that the younger adults of today are the older adults of tomorrow. Therefore, engaging adults at younger ages may help foster healthier, longer-term habits that support more effective and sustained use of MR technologies in later life. Future studies should also explore the UX of the older adults after allowing for multiple sessions of gameplay. Doing so would help test the reliability and transferability of this thesis' findings and help to identify context-specific factors that may influence outcomes for older adults in general.

8.6 Conclusion

Research findings have shown the importance of staying active in older age (Chapter 1), and one way of doing this is to encourage older adults to remain active in participation. Similarly, older adults are internally motivated to stay cognitively active and socially connected with their community. A device that addresses their needs and perceived benefits while also promoting physical movement and social interaction can effectively serve multiple objectives.

Taken together, the findings of this thesis contribute to a growing body of work seeking to understand how older adults engage with MR applications. It does so by addressing previously less covered areas in the research literature, such as the importance of non-instrumental qualities and social interaction during gameplay. This work expanded the conversation to consider other often underexplored dimensions of UX, including sensory needs, the importance of challenge, and the role of social interaction and connectedness.

The chosen mixed method design of this thesis, particularly the use of qualitative data, was effective in highlighting aspects of UX that are easily missed in standard usability testing used by studies in this research area which typically focused on the usability aspects of the MR applications. This thesis also surfaced several limitations, such as a small sample size and the difficulties experienced during collection of quantitative data from older adults. While the sample size and age group of the participants in this study may limit the research findings' generalisability, the in-depth qualitative insights provide a strong foundation for future studies to build upon. Continued research is needed to develop a measure that is specially meant for assessing the UX of older adults, and to replicate the study where older adult participants can have access to the EDNA Playboards across multiple sessions.

Finally, these insights affirm that older adults, including older-old adults above 85 years, were not only open to engaging with emerging technologies but were eager to contribute their thoughts and recommendations to improve the technology for their use. Guided by the experiences and preferences of these end users – older adults who desire to have fun and benefit from the perceived cognitive stimulation that comes from using an interesting technology – there is a need to design future MR-based interactive experiences that are accessible, tailored to their aesthetic preferences, and which provide a relaxed way of socially interacting with their peers. By prioritising UX and co-designed approaches, future MR-based interactive experiences can better support older adults' well-being in later life.

References

Adair, B., Ullenhag, A., Rosenbaum, P., Granlund, M., Keen, D., & Imms, C. (2018). Measures used to quantify participation in childhood disability and their alignment with the family of participation-related constructs: a systematic review. *Developmental Medicine & Child Neurology*, *60*(11), 1101-1116.

Adams, K. E., Tyler, J. M., Calogero, R., & Lee, J. (2017). Exploring the relationship between appearance-contingent self-worth and self-esteem: The roles of self-objectification and appearance anxiety. *Body image*, *23*, 176-182.

Agnew, H. C., Phillips, L. H., & Pilz, K. S. (2020). Visual attention, biological motion perception, and healthy ageing. *Psychological Research*, *84*(3), 625-642.

Alofs, T., Theune, M., & Swartjes, I. (2015). A tabletop interactive storytelling system: Designing for social interaction. *International journal of arts and technology*, *8*(3), 188-211.

Ambagtsheer, R., Beilby, J., Seiboth, C., & Dent, E. (2020). Prevalence and associations of frailty in residents of Australian aged care facilities: findings from a retrospective cohort study. *Aging clinical and experimental research*, *32*, 1849-1856.

Andersen, G. J. (2012). Aging and vision: changes in function and performance from optics to perception. *Wiley Interdisciplinary Reviews: Cognitive Science*, *3*(3), 403-410.

Ang, D., & Mitchell, A. (2017). *Comparing Effects of Dynamic Difficulty Adjustment Systems on Video Game Experience* Proceedings of the Annual Symposium on Computer-Human

Interaction in Play, Amsterdam, The Netherlands. https://doi.org/10.1145/3116595.3116623

Aronson, L. (2020). Healthy aging across the stages of old age. *Clinics in Geriatric Medicine*, *36*(4), 549-558.

Australian Institute of Health and Welfare. (2023, 28 June 2023). *Older Adults*. https://www.aihw.gov.au/reports/older-people/older-australians/contents/demographic-profile

Australian Institute of Health and Welfare. (2024a). *Older Australians*. https://www.aihw.gov.au/reports/older-people/older-australians

Australian Institute of Health and Welfare. (2024b, 30 April 2024). *People using aged care* https://www.gen-agedcaredata.gov.au/topics/people-using-aged-care#agedcareusebyageandsexovertime

Australian Institute of Health and Welfare. (2024c, 26/08/2024). *Physical Activity*. Retrieved 17/11/2024 from

Baker, Waycott, J., Robertson, E., Carrasco, R., Neves, B. B., Hampson, R., & Vetere, F. (2020). Evaluating the use of interactive virtual reality technology with older adults living in residential aged care [Article]. *Information Processing and Management*, *57*(3), Article 102105. https://doi.org/10.1016/j.ipm.2019.102105

Baker, L., & Gringart, E. (2009). Body image and self-esteem in older adulthood. *Ageing & Society*, *29*(6), 977-995.

Ball, K., Berch, D. B., Helmers, K. F., Jobe, J. B., Leveck, M. D., Marsiske, M., Morris, J. N., Rebok, G. W., Smith, D. M., & Tennstedt, S. L. (2002). Effects of cognitive training interventions with older adults: a randomized controlled trial. *Jama*, *288*(18), 2271-2281.

Barnard, Y., Bradley, M. D., Hodgson, F., & Lloyd, A. D. (2013). Learning to use new technologies by older adults: Perceived difficulties, experimentation behaviour and usability. *Computers in human behavior*, *29*(4), 1715-1724.

Baur, K., Wolf, P., Novak, V., Boering, D., Hörner, S., Dahlen, C., Berger, J., Riener, R., & Novak, V. H. V. (2023). Competitive versus cooperative forms of therapeutic gaming with subacute stroke patients. *IEEE Transactions on Medical Robotics and Bionics*, *5*(4), 956-965.

Beard, J. R., & Bloom, D. E. (2015). Towards a comprehensive public health response to population ageing. *The Lancet*, *385*(9968), 658-661.

Bertolazzi, A., Quaglia, V., & Bongelli, R. (2024). Barriers and facilitators to health technology adoption by older adults with chronic diseases: an integrative systematic review. *BMC Public Health*, *24*(1), 506.

Bethancourt, H. J., Rosenberg, D. E., Beatty, T., & Arterburn, D. E. (2014). Barriers to and facilitators of physical activity program use among older adults. *Clinical medicine & research*, *12*(1-2), 10-20.

Billino, J., & Pilz, K. S. (2019). Motion perception as a model for perceptual aging. *Journal of vision*, *19*(4), 3-3.

Bird, M.-L., Clark, B., Millar, J., Whetton, S., & Smith, S. (2015). Exposure to "exergames" increases older adults' perception of the usefulness of technology for improving health and physical activity: a pilot study. *JMIR Serious Games*, *3*(2), e4275.

Bloom, D. E., Canning, D., & Fink, G. (2010). Implications of population ageing for economic growth. *Oxford review of economic policy*, *26*(4), 583-612.

Boletsis, C., & McCallum, S. (2016). Augmented Reality Cubes for Cognitive Gaming: Preliminary Usability and Game Experience Testing. *International Journal of Serious Games*, *3*(1), 3-18.

Bonneville-Roussy, A., Rentfrow, P. J., Xu, M. K., & Potter, J. (2013). Music through the ages: Trends in musical engagement and preferences from adolescence through middle adulthood. *Journal of Personality and Social Psychology*, *105*(4), 703.

Bonneville-Roussy, A., Stillwell, D., Kosinski, M., & Rust, J. (2017). Age trends in musical preferences in adulthood: 1. Conceptualization and empirical investigation. *Musicae Scientiae*, *21*(4), 369-389.

Boulton, E. R., Horne, M., & Todd, C. (2018). Multiple influences on participating in physical activity in older age: Developing a social ecological approach. *Health Expectations*, *21*(1), 239-248.

Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative research in psychology*, *3*(2), 77-101.

Buyl, R., Beogo, I., Fobelets, M., Deletroz, C., Van Landuyt, P., Dequanter, S., Gorus, E., Bourbonnais, A., Giguère, A., Lechasseur, K., & Gagnon, M. P. (2020). E-Health interventions for healthy aging: A systematic review. *Systematic Reviews, 9*(1), Article 128. https://doi.org/10.1186/s13643-020-01385-8

Byrne, D. (2022). A worked example of Braun and Clarke's approach to reflexive thematic analysis. *Quality & Quantity*, *56*(3), 1391-1412. https://doi.org/10.1007/s11135-021-01182-y

Candy, L., & Ferguson, S. (2014). Interactive experience in the digital age. *Springer Series on Cultural Computing*.

Cantwell, D., Broin, D. O., Palmer, R., & Doyle, G. (2012). Motivating elderly people to exercise using a social collaborative exergame with adaptive difficulty. Proceedings of the 6th European Conference on Games Based Learning, Cork, Ireland.

Cassidy, A., Bannon, N., Wallen, M., Dimarco, A., Garrity, N., Hunter, O., Anaby, D., Fredrickson, E., Cowan, H., & Knudsen, D. (2024). A stakeholder-involved adaptation of pathways and resources for engagement and participation (PREP) material with young adults with complex disability in Australia: an implementation feasibility study. *Disability and Rehabilitation*, 1-13.

Cavalcanti, V. C., Santana, M. I. d., Da Gama, A. E., & Correia, W. F. (2018). Usability assessments for augmented reality motor rehabilitation solutions: A systematic review. *International Journal of Computer Games Technology*, *2018*.

Chan, J. Y. C., Chan, T. K., Wong, M. P. F., Cheung, R. S. M., Yiu, K. K. L., & Tsoi, K. K. F. (2020). Effects of virtual reality on moods in community older adults. A multicenter randomized controlled trial. *International Journal of Geriatric Psychiatry*, *35*(8), 926-933. https://doi.org/10.1002/gps.5314

Chen, C. K., Tsai, T. H., Lin, Y. C., Lin, C. C., Hsu, S. C., Chung, C. Y., Pei, Y. C., & Wong, A. M. K. (2018). Acceptance of different design exergames in elders. *Plos One*, *13*(7), Article e0200185. https://doi.org/10.1371/journal.pone.0200185

Chen, S., Shang, H. L., & Yang, Y. (2025). Is the age pension in Australia sustainable and fair? Evidence from forecasting the old-age dependency ratio using the Hamilton-Perry model. *Journal of Population Research*, *42*(1), 2.

Chihuri, S., Mielenz, T. J., DiMaggio, C. J., Betz, M. E., DiGuiseppi, C., Jones, V. C., & Li, G. (2016). Driving cessation and health outcomes in older adults. *Journal of the American Geriatrics Society*, *64*(2), 332-341.

Choi, M., Sempungu, J. K., Lee, E. H., & Lee, Y. H. (2024). Living longer but in poor health: healthcare system responses to ageing populations in industrialised countries based on the Findings from the Global Burden of Disease Study 2019. *BMC Public Health*, *24*(1), 576.

Ciemer, C., Kröper, L., Klotzbier, T. J., Ghellal, S., & Schott, N. (2025). Digital interactive experience-and game-based fall interventions for community-dwelling healthy older adults: a cross-disciplinary systematic review. *Frontiers in Public Health*, *12*, 1489258.

Cleland, J., Hutchinson, C., Khadka, J., Milte, R., & Ratcliffe, J. (2021). What defines quality of care for older people in aged care? A comprehensive literature review. *Geriatrics & Gerontology International*, *21*(9), 765-778.

Condino, S., Gesi, M., Viglialoro, R. M., Carbone, M., & Turini, G. (2022). Serious games and mixed reality applications for healthcare. *12*(7), 3644.

Coussens, M., Vitse, F., Desoete, A., Vanderstraeten, G., Van Waelvelde, H., & Van de Velde, D. (2021). Participation of young children with developmental disabilities: parental needs and strategies, a qualitative thematic analysis. *BMJ open*, *11*(4), e042732.

Crisp, D. A., Windsor, T. D., Anstey, K. J., & Butterworth, P. (2013). Considering relocation to a retirement village: Predictors from a community sample. *Australasian journal on ageing*, *32*(2), 97-102.

Czaja, S. J., Moxley, J. H., & Rogers, W. A. (2021). Social support, isolation, loneliness, and health among older adults in the PRISM randomized controlled trial. *Frontiers in Psychology*, *12*, 728658.

De Schutter, B., & Abeele, V. V. (2015). Towards a gerontoludic manifesto. *Anthropology & Aging*, *36*(2), 112. https://doi.org/10.5195/aa.2015.104

De Schutter, B., & Vanden Abeele, V. (2010). Designing meaningful play within the psycho-social context of older adults. Proceedings of the 3rd International Conference on Fun and Games,

De Schutter, B., & Vanden Abeele, V. (2015). Towards a gerontoludic manifesto. *Anthropology & Aging*, *36*(2), 112-120. https://doi.org/10.5195/AA.2015.104

De Vries, A. W., Van Dieën, J. H., Van Den Abeele, V., & Verschueren, S. M. (2018). Understanding motivations and player experiences of older adults in virtual reality training. *Games for Health Journal*, *7*(6), 369-376.

Dermody, G., Whitehead, L., Wilson, G., & Glass, C. (2020). The role of virtual reality in improving health outcomes for community-dwelling older adults: Systematic review. *Journal of Medical Internet Research*, *22*(6), N.PAG-N.PAG. https://doi.org/10.2196/17331

Donovan, N. J., & Blazer, D. (2020). Social isolation and loneliness in older adults: review and commentary of a national academies report. *The American journal of geriatric psychiatry*, *28*(12), 1233-1244.

Drazich, B. F., McPherson, R., Gorman, E. F., Chan, T., Teleb, J., Galik, E., & Resnick, B. (2023). In too deep? A systematic literature review of fully-immersive virtual reality and cybersickness among older adults. *Journal of the American Geriatrics Society*.

Duckworth, J., Mumford, N., Caeyenberghs, K., Eldridge, R., Mayson, S., Thomas, P. R., Shum, D., Williams, G., & Wilson, P. H. (2015, 2015//). Resonance: An Interactive Tabletop

Artwork for Co-located Group Rehabilitation and Play. Universal Access in Human-Computer Interaction. Access to Learning, Health and Well-Being, Cham.

Duplàa, E., Kaufman, D., Sauvé, L., & Renaud, L. (2017). A questionnaire-based study on the perceptions of canadian seniors about cognitive, social, and psychological benefits of digital games. *Games for Health Journal*, *6*(3), 171-178.

Fachko, M. J., Xiao, C., Bowles, K. H., Robinson, K. M., & Libonati, J. R. (2013). Cardiovascular effects and enjoyment of exercise gaming in older adults. *Journal of gerontological nursing*, *39*(12), 43-54.

Fleury, J., Sedikides, C., Wildschut, T., Coon, D. W., & Komnenich, P. (2022). Feeling safe and nostalgia in healthy aging. *Frontiers in Psychology, 13*, 973.

Fragala, M. S., Cadore, E. L., Dorgo, S., Izquierdo, M., Kraemer, W. J., Peterson, M. D., & Ryan, E. D. (2019). Resistance training for older adults: position statement from the national strength and conditioning association. *The Journal of Strength & Conditioning Research*, *33*(8).

Franco, M. R., Tong, A., Howard, K., Sherrington, C., Ferreira, P. H., Pinto, R. Z., & Ferreira, M. L. (2015). Older people's perspectives on participation in physical activity: a systematic review and thematic synthesis of qualitative literature. *British journal of sports medicine*, *49*(19), 1268-1276.

Gonçalves, A., Muñoz, J., Cameirão, M. S., Gouveia, É. R., Sousa, H., & Bermudez i Badia, S. (2021). The benefits of custom exergames for fitness, balance, and health-related quality of life: a randomized controlled trial with community-dwelling older adults. *Games for Health Journal*, *10*(4), 245-253.

Graham, V., & Tuffin, K. (2004). Retirement villages: Companionship, privacy and security. *Australasian journal on ageing*, *23*(4), 184-188.

Guell, C., Shefer, G., Griffin, S., & Ogilvie, D. (2016). ‘Keeping your body and mind active’: an ethnographic study of aspirations for healthy ageing. *BMJ open*, *6*(1), e009973.

Hagani, N., Clare, P. J., Luo, M., Merom, D., Smith, B. J., & Ding, D. (2024). Effect of retirement on loneliness: a longitudinal comparative analysis across Australia, China and the USA. *J Epidemiol Community Health*.

Hajek, A., & König, H.-H. (2020). Which factors contribute to loneliness among older Europeans? Findings from the survey of health, ageing and retirement in Europe: determinants of loneliness. *Archives of gerontology and geriatrics*, *89*, 104080.

Hamari, J., Shernoff, D. J., Rowe, E., Coller, B., Asbell-Clarke, J., & Edwards, T. (2016). Challenging games help students learn: An empirical study on engagement, flow and immersion in game-based learning. *Computers in human behavior*, *54*, 170-179.

Haslam, C., Cruwys, T., & Haslam, S. A. (2014). “The we's have it”: Evidence for the distinctive benefits of group engagement in enhancing cognitive health in aging. *Social Science & Medicine*, *120*, 57-66.

Hassenzahl, M., & Tractinsky, N. (2006). User experience - a research agenda. *Behaviour & information technology*, *25*(2), 91-97.

Havukainen, M., Laine, T. H., Martikainen, T., & Sutinen, E. (2020). A case study on co-designing digital games with older adults and children: Game elements, assets, and challenges. *The Computer Games Journal*, *9*(2), 163-188.

Healy, D., Flynn, A., Conlan, O., McSharry, J., & Walsh, J. (2022). Older Adults' Experiences and Perceptions of Immersive Virtual Reality: Systematic Review and Thematic Synthesis. *JMIR Serious Games, 10*(4), e35802.

Hosseini, M., Thomas, R., Pilutti, L., Fallavollita, P., & Jutai, J. W. (2023). Acceptance of physical activity virtual reality games by residents of long-term care facilities: a scoping review. *Disability and Rehabilitation: Assistive Technology*, 1-9.

Hung, L., Mann, J., Wallsworth, C., Upreti, M., Kan, W., Temirova, A., Wong, K. L. Y., Ren, H., To-Miles, F., & Wong, J. (2023). Facilitators and barriers to using virtual reality and its impact on social engagement in aged care settings: a scoping review. *Gerontology and Geriatric Medicine, 9*, 23337214231166355.

Hwang, M.-Y., Hong, J.-C., Hao, Y.-w., & Jong, J.-T. (2011). Elders' usability, dependability, and flow experiences on embodied interactive video games. *Educational Gerontology*, *37*(8), 715-731.

Ijsselsteijn, W., Nap, H. H., de Kort, Y., & Poels, K. (2007). Digital game design for elderly users. Proceedings of the 2007 conference on Future Play,

IJsselsteijn, W. A., De Kort, Y. A., & Poels, K. (2013). The game experience questionnaire.

IJsselsteijn, W. A., Freeman, J., & De Ridder, H. (2001). Presence: Where are we? In (Vol. 4, pp. 179-182): Mary Ann Liebert, Inc.

Imms, C., Adair, B., Keen, D., Ullenhag, A., Rosenbaum, P., & Granlund, M. (2016). 'Participation': a systematic review of language, definitions, and constructs used in intervention research with children with disabilities. *Developmental Medicine & Child Neurology*, *58*(1), 29-38.

Imms, C., Granlund, M., Wilson, P. H., Steenbergen, B., Rosenbaum, P. L., & Gordon, A. M. (2017). Participation, both a means and an end: a conceptual analysis of processes and outcomes in childhood disability. *Developmental Medicine & Child Neurology*, *59*(1), 16-25.

Izquierdo, M., Merchant, R., Morley, J. E., Anker, S., Aprahamian, I., Arai, H., Aubertin-Leheudre, M., Bernabei, R., Cadore, E. L., & Cesari, M. (2021). International exercise recommendations in older adults (ICFSR): expert consensus guidelines. *The journal of nutrition, health & aging*, *25*(7), 824-853.

Jayakody, D. M., Friedland, P. L., Martins, R. N., & Sohrabi, H. R. (2018). Impact of aging on the auditory system and related cognitive functions: a narrative review. *Frontiers in neuroscience*, *12*, 125.

Jeremic, J., Zhang, F., & Kaufman, D. (2019). Older adults' perceptions about commercially available xbox kinect exergames. Human Aspects of IT for the Aged Population. Design for the Elderly and Technology Acceptance: 5th International Conference, ITAP 2019, Held as Part of the 21st HCI International Conference, HCII 2019, Orlando, FL, USA, July 26-31, 2019, Proceedings, Part I 21,

Johnson, D., Gardner, M. J., & Perry, R. (2018). Validation of two game experience scales: the player experience of need satisfaction (PENS) and game experience questionnaire (GEQ). *International Journal of human-computer studies, 118*, 38-46.

Jonas, J. L. (1991). Preferences of elderly music listeners residing in nursing homes for art music, traditional jazz, popular music of today, and country music. *Journal of Music Therapy*, *28*(3), 149-160.

Jones, C. H., & Dolsten, M. (2024). Healthcare on the brink: navigating the challenges of an aging society in the United States. *npj Aging*, *10*(1), 22.

Kaufman, D., Sauvé, L., & Ireland, A. (2020). Playful aging: digital games for older adults. *Age Well*, *4*.

Kaufman, D., Sauvé, L., Renaud, L., Sixsmith, A., & Mortenson, B. (2016). Older adults' digital gameplay: Patterns, benefits, and challenges. *Simulation & Gaming*, *47*(4), 465-489.

Kell, K. P., & Rula, E. Y. (2019). Increasing exercise frequency is associated with health and quality-of-life benefits for older adults. *Quality of Life Research*, *28*, 3267-3272.

Kemperman, A., van den Berg, P., Weijs-Perrée, M., & Uijtdewillegen, K. (2019). Loneliness of older adults: Social network and the living environment. *International journal of environmental research and public health*, *16*(3), 406.

Kim, E., Park, Y.-K., Byun, Y.-H., Park, M.-S., Kim, H., Kim, E., Park, Y.-K., Byun, Y.-H., Park, M.-S., & Kim, H. (2014). Influence of aging on visual perception and visual motor integration in Korean adults. *Journal of exercise rehabilitation*, *10*(4), 245-250.

Krueger, K. R., Wilson, R. S., Kamenetsky, J. M., Barnes, L. L., Bienias, J. L., & Bennett, D. A. (2009). Social Engagement and Cognitive Function in Old Age. *Experimental Aging Research*, *35*(1), 45-60. https://doi.org/10.1080/03610730802545028

Laurienti, P. J., Burdette, J. H., Maldjian, J. A., & Wallace, M. T. (2006). Enhanced multisensory integration in older adults. *Neurobiology of aging*, *27*(8), 1155-1163.

Lee, H., Park, H. Y., & Lim, Y.-M. (2022). Facilitators and Barriers of Social Participation of Older Adults: Systematic Review of Qualitative Studies. *The Journal of the Korea Contents Association*, *22*(10), 475-487.

Lee, L. N., Kim, M. J., & Hwang, W. J. (2019). Potential of augmented reality and virtual reality technologies to promote wellbeing in older adults. *Applied sciences*, *9*(17), 3556.

Lee, N., Choi, W., & Lee, S. (2021). Development of an 360-degree virtual reality video-based immersive cycle training system for physical enhancement in older adults: a feasibility study. *BMC Geriatrics*, *21*(1). https://doi.org/10.1186/s12877-021-02263-1

Lees, F. D., Clark, P. G., Nigg, C. R., & Newman, P. (2005). Barriers to exercise behavior among older adults: a focus-group study. *Journal of Aging and Physical Activity*, *13*(1), 23-33.

Li, F., Fisher, K. J., Harmer, P., McAuley, E., & Wilson, N. L. (2003). Fear of falling in elderly persons: association with falls, functional ability, and quality of life. *The Journals of Gerontology Series B: Psychological Sciences and Social Sciences*, *58*(5), P283-P290.

Li, J., Xu, X., Pham, T. P., Theng, Y.-L., Katajapuu, N., & Luimula, M. (2017). Exergames designed for older adults: a pilot evaluation on psychosocial well-being. *Games for Health Journal*, *6*(6), 371-378.

Li, X., Niksirat, K. S., Chen, S., Weng, D., Sarcar, S., & Ren, X. (2020). The impact of a multitasking-based virtual reality motion video game on the cognitive and physical abilities of older adults. *Sustainability*, *12*(21), 9106.

Lim, K. J., McGuckian, T. B., Cole, M. H., Duckworth, J., & Wilson, P. H. (2023). User experience of mixed reality applications for healthy ageing: A systematic review. *Cyberpsychology: Journal of Psychosocial Research on Cyberspace*, *17*(4), Article 5. https://doi.org/10.5817/CP2023-4-5

Liukkonen, T. N., Ahtosalo, H., Heinonen, T., Raitoharju, R., Pitkakangas, P., & Makila, T. (2015). Motion Tracking Exergames For Elderly Users. *IADIS International Journal on Computer Science and Information Systems, 10*(2), 52-64.

Luther, L., Tiberius, V., & Brem, A. (2020). User Experience (UX) in business, management, and psychology: A bibliometric mapping of the current state of research. *Multimodal Technologies and Interaction*, *4*(2), 18.

Mackenzie, C. S., & Abdulrazaq, S. (2021). Social engagement mediates the relationship between participation in social activities and psychological distress among older adults. *Aging & mental health*, *25*(2), 299-305.

Maestas, N., Mullen, K. J., & Powell, D. (2023). The effect of population aging on economic growth, the labor force, and productivity. *American Economic Journal: Macroeconomics*, *15*(2), 306-332.

Malhotra, R., Tareque, M. I., Saito, Y., Ma, S., Chiu, C. T., & Chan, A. (2021). Loneliness and health expectancy among older adults: A longitudinal population-based study. *Journal of the American Geriatrics Society, 69*(11), 3092-3102.

Mannheim, I., Schwartz, E., Xi, W., Buttigieg, S. C., McDonnell-Naughton, M., Wouters, E. J., & Van Zaalen, Y. (2019). Inclusion of older adults in the research and design of digital technology. *International journal of environmental research and public health, 16*(19), 3718.

McAuley, E., Blissmer, B., Katula, J., Duncan, T. E., & Mihalko, S. L. (2000). Physical activity, self-esteem, and self-efficacy relationships in older adults: A randomized controlled trial. *Annals of Behavioral Medicine*, *22*(2), 131-139.

McAuley, E., Elavsky, S., Motl, R. W., Konopack, J. F., Hu, L., & Marquez, D. X. (2005). Physical activity, self-efficacy, and self-esteem: Longitudinal relationships in older adults. *The Journals of Gerontology Series B: Psychological Sciences and Social Sciences*, *60*(5), P268-P275.

McCosker, A., Critchley, C., Walshe, J., Tucker, J., & Suchowerska, R. (2023). Accounting for diversity in older adults' digital inclusion and literacy: the impact of a national intervention. *Ageing & Society*, *43*(11), 2629-2649.

McKenzie, G., Shields, N., & Willis, C. (2023). 'Finding what works for me'–a qualitative study of factors influencing community gym participation for young adults with cerebral palsy. *Disability and Rehabilitation*, *45*(12), 1984-1991.

McPhee, J. S., French, D. P., Jackson, D., Nazroo, J., Pendleton, N., & Degens, H. (2016). Physical activity in older age: perspectives for healthy ageing and frailty. *Biogerontology*, *17*, 567-580.

Melillo, K. D., Williamson, E., Houde, S. C., Futrell, M., Read, C. Y., & Campasano, M. (2001). Perceptions of older Latino adults regarding physical fitness, physical activity, and exercise. *Journal of gerontological nursing*, *27*(9), 38-46.

Meredith, S. J., Cox, N. J., Ibrahim, K., Higson, J., McNiff, J., Mitchell, S., Rutherford, M., Wijayendran, A., Shenkin, S. D., & Kilgour, A. H. (2023). Factors that influence older adults' participation in physical activity: a systematic review of qualitative studies. *Age and Ageing*, *52*(8), afad145.

Meza-Kubo, V., Moran, A. L., & Rodriguez, M. D. (2014). Bridging the gap between illiterate older adults and cognitive stimulation technologies through pervasive computing.

Universal Access in the Information Society, *13*(1), 33-44. https://doi.org/10.1007/s10209-013-0294-3

Mezuk, B., & Rebok, G. W. (2008). Social integration and social support among older adults following driving cessation. *The Journals of Gerontology Series B: Psychological Sciences and Social Sciences*, *63*(5), S298-S303.

Milgram, P., & Kishino, F. (1994). A taxonomy of mixed reality visual displays. *IEICE Transactions on Information and Systems*, *77*(12), 1321-1329.

Miller, K. J., Adair, B. S., Pearce, A. J., Said, C. M., Ozanne, E., & Morris, M. M. (2014). Effectiveness and feasibility of virtual reality and gaming system use at home by older adults for enabling physical activity to improve health-related domains: A systematic review [Article]. *Age and Ageing*, *43*(2), 188-195. https://doi.org/10.1093/ageing/aft194

Minge, M., Thüring, M., Wagner, I., & Kuhr, C. V. (2017). The meCUE questionnaire: a modular tool for measuring user experience. In *Advances in Ergonomics Modeling, Usability & Special Populations* (pp. 115-128). Springer.

Moschny, A., Platen, P., Klaaßen-Mielke, R., Trampisch, U., & Hinrichs, T. (2011). Barriers to physical activity in older adults in Germany: a cross-sectional study. *International Journal of Behavioral Nutrition and Physical Activity*, *8*, 1-10.

Mumford, N., Duckworth, J., Thomas, P. R., Shum, D., Williams, G., & Wilson, P. H. (2010). Upper limb virtual rehabilitation for traumatic brain injury: initial evaluation of the elements system. *Brain injury*, *24*(5), 780-791.

Mumford, N., Duckworth, J., Thomas, P. R., Shum, D., Williams, G., & Wilson, P. H. (2012). Upper-limb virtual rehabilitation for traumatic brain injury: A preliminary within-group evaluation of the elements system. *Brain injury*, *26*(2), 166-176. https://doi.org/10.3109/02699052.2011.648706

Nilsson, N. C., Nordahl, R., & Serafin, S. (2016). Immersion revisited: A review of existing definitions of immersion and their relation to different theories of presence. *Human technology*, *12*(2), 108-134.

Norman, D. (2013). *The design of everyday things: Revised and expanded edition*. Basic books.

Ong, A. D., Uchino, B. N., & Wethington, E. (2016). Loneliness and health in older adults: A mini-review and synthesis. *Gerontology*, *62*(4), 443-449.

Penedo, F. J., & Dahn, J. R. (2005). Exercise and well-being: a review of mental and physical health benefits associated with physical activity. *Current opinion in psychiatry*, *18*(2), 189-193.

Pereira, F., Bermúdez i Badia, S., Jorge, C., & Cameirão, M. S. (2021). The use of game modes to promote engagement and social involvement in multi-user serious games: a within-person randomized trial with stroke survivors. *Journal of NeuroEngineering and Rehabilitation*, *18*(1), 62.

Pereira, F., Bermúdez i Badia, S., Ornelas, R., & S. Cameirão, M. (2019). Impact of game mode in multi-user serious games for upper limb rehabilitation: a within-person randomized trial on engagement and social involvement. *Journal of NeuroEngineering and Rehabilitation*, *16*(1), 109.

Pezzera, M., & Borghese, N. A. (2020). Dynamic difficulty adjustment in exer-games for rehabilitation: A mixed approach. 2020 IEEE 8th International Conference on Serious Games and Applications for Health, Vancouver, Canada.

Postal, M. R. B., & Rieder, R. (2019). A Usability Evaluation Experiment of 3D User Interfaces for Elderly: a pilot study. *Revista Brasileira De Computacao Aplicada*, *11*(3), 28-38. https://doi.org/10.5335/rbca.v11i3.9477

Prinsloo, P., Dada, S., Bastable, K., Raghavendra, P., & Granlund, M. (2024). The application of the family of participation-related constructs (fPRC) framework to AAC intervention outcomes in children with complex communication needs: a scoping review. *Augmentative and Alternative Communication*, *40*(3), 182-195.

Profant, O., Jilek, M., Bures, Z., Vencovsky, V., Kucharova, D., Svobodova, V., Korynta, J., & Syka, J. (2019). Functional age-related changes within the human auditory system studied by audiometric examination. *Frontiers in aging neuroscience*, *11*, 26.

Pyae, A., Joelsson, T. N., Saarenpaa, T., Mika, L., Kattimeri, C., Pitkakangas, P., Granholm, P., & Smed, J. (2017). Lessons Learned from Two Usability Studies of Digital Skiing Game with Elderly People in Finland and Japan. *International Journal of Serious Games*, *4*(4), 37-52. https://doi.org/10.17083/ijsg.v4i4.183

Pyae, A., Liukkonen, T. N., Saarenpaa, T., Luimula, M., Granholm, P., & Smed, J. (2016). When Japanese elderly people play a Finnish physical exercise game: A usability study. *Journal of Usability Studies*, *11*(4), 131-152.

Quartermaine, J. R., Rose, T. A., Auld, M. L., & Johnston, L. M. (2024). Factors impacting positive and negative participation of young people with cerebral palsy: a Delphi study of consumers and health professionals. *Disability and Rehabilitation*, *46*(7), 1330-1338.

Rebsamen, S., Knols, R. H., Pfister, P. B., & de Bruin, E. D. (2019). Exergame-driven high-intensity interval training in untrained community dwelling older adults: A formative one group quasi-experimental feasibility trial. *Frontiers in Physiology, 10*(8). https://doi.org/10.3389/fphys.2019.01019

Riggins, F. J., & Dewan, S. (2005). The digital divide: Current and future research directions. *Journal of the Association for information systems*, *6*(12), 4.

Rogers, J. M., Duckworth, J., Middleton, S., Steenbergen, B., & Wilson, P. H. (2019). Elements virtual rehabilitation improves motor, cognitive, and functional outcomes in adult stroke: evidence from a randomized controlled pilot study. *Journal of NeuroEngineering and Rehabilitation*, *16*(1), 56. https://doi.org/10.1186/s12984-019-0531-y

Rogers, J. M., Mumford, N., Caeyenberghs, K., Richards, H., Nuijen, N., Steenbergen, B., Williams, G., Shum, D. H. K., Duckworth, J., Amos, N., & Wilson, P. H. (2021). Co-located (multi-user) virtual rehabilitation of acquired brain injury: feasibility of the Resonance system for upper-limb training. *Virtual Reality*, *25*(3), 719-730. https://doi.org/10.1007/s10055-020-00486-y

Rudnicka, E., Napierała, P., Podfigurna, A., Męczekalski, B., Smolarczyk, R., & Grymowicz, M. (2020). The World Health Organization (WHO) approach to healthy ageing. *Maturitas*, *139*, 6-11.

Saariluoma, P., & Jokinen, J. P. (2014). Emotional dimensions of user experience: A user psychological analysis. *International Journal of Human-Computer Interaction*, *30*(4), 303-320.

Salmon, J. P., Dolan, S. M., Drake, R. S., Wilson, G. C., Klein, R. M., & Eskes, G. A. (2017). A survey of video game preferences in adults: Building better games for older adults. *Entertainment Computing*, *21*, 45-64. https://doi.org/10.1016/j.entcom.2017.04.006

Sander, M., Oxlund, B., Jespersen, A., Krasnik, A., Mortensen, E. L., Westendorp, R. G. J., & Rasmussen, L. J. (2015). The challenges of human population ageing. *Age and Ageing*, *44*(2), 185-187.

Sanford, A. M., Orrell, M., Tolson, D., Abbatecola, A. M., Arai, H., Bauer, J. M., Cruz-Jentoft, A. J., Dong, B., Ga, H., & Goel, A. (2015). An international definition for “nursing home”. *Journal of the American Medical Directors Association*, *16*(3), 181-184.

Santos, L. H. O., Okamoto, K., Hiragi, S., Yamamoto, G., Sugiyama, O., Aoyama, T., & Kuroda, T. (2019). Pervasive game design to evaluate social interaction effects on levels of physical activity among older adults. *Journal of Rehabilitation and Assistive Technologies Engineering*, *6*. https://doi.org/10.1177/2055668319844443

Sauvé, L., & Kaufman, D. (2019). Learning with Educational Games: Adapting to Older Adult's Needs. CSEDU (1),

Sauvé, L., Kaufman, D., & Plante, P. (2019). *Designing a User-Friendly Educational Game for Older Adults* [Conference Paper]. Advances in Web-Based Learning – ICWL 2019, https://www.scopus.com/inward/record.uri?eid=2-s2.0-85076771862&doi=10.1007%2f978-3-030-35758-0_4&partnerID=40&md5=f987a2401fb3e220f950f80869adf772

Schell, R., Hausknecht, S., Zhang, F., & Kaufman, D. (2016). Social benefits of playing Wii Bowling for older adults. *Games and Culture*, *11*(1-2), 81-103.

Seaborn, K., & Fels, D. I. (2015). Gamification in theory and action: A survey. *International Journal of human-computer studies*, *74*, 14-31.

Seah, E. T. W., Kaufman, D., Sauvé, L., & Zhang, F. (2018). Play, Learn, Connect: older adults' experience with a multiplayer, educational, digital Bingo game. *Journal of Educational Computing Research*, *56*(5), 675-700.

Shin, O., Park, S., Amano, T., Kwon, E., & Kim, B. (2020). Nature of retirement and loneliness: The moderating roles of social support. *Journal of Applied Gerontology*, *39*(12), 1292-1302.

Simmonds, B. A., Hannam, K., Fox, K. R., & Tobias, J. H. (2016). An exploration of barriers and facilitators to older adults' participation in higher impact physical activity and bone health: a qualitative study. *Osteoporosis International*, *27*, 979-987.

Skarbez, R., Smith, M., & Whitton, M. C. (2021). Revisiting milgram and kishino's reality-virtuality continuum. *Frontiers in Virtual Reality*, *2*, 27.

Slater, M. (2003). A note on presence terminology. *Presence connect*, *3*(3), 1-5.

Slater, M., & Wilbur, S. (1997). A framework for immersive virtual environments (FIVE): Speculations on the role of presence in virtual environments. *Presence: Teleoperators & Virtual Environments*, *6*(6), 603-616.

Sluggett, J. K., Ilomäki, J., Seaman, K. L., Corlis, M., & Bell, J. S. (2017). Medication management policy, practice and research in Australian residential aged care: current and future directions. *Pharmacological research*, *116*, 20-28.

Smeddinck, J. D., Siegel, S., & Herrlich, M. (2013). Adaptive difficulty in exergames for Parkinson's disease patients. Graphics Interface, Saskatchewan, Canada.

Soares, B. C., Bacha, J. M. R., Mello, D. D., Moretto, E. G., Fonseca, T., Vieira, K. S., de Lima, A. F., Lange, B., Torriani-Pasin, C., de Deus Lopes, R., & Pompeu, J. E. (2021). Immersive virtual tasks with motor and cognitive components: A feasibility study with young and older adults. *Journal of Aging and Physical Activity*, *29*(3), 400-411. https://doi.org/10.1123/JAPA.2019-0491

Speicher, M., Hall, B. D., & Nebeling, M. (2019). What is mixed reality? Proceedings of the 2019 CHI conference on human factors in computing systems,

Spiteri, K., Broom, D., Bekhet, A. H., De Caro, J. X., Laventure, B., & Grafton, K. (2019). Barriers and motivators of physical activity participation in middle-aged and older adults—a systematic review. *Journal of Aging and Physical Activity*, *27*(6), 929-944.

Steinsbekk, S., Wichstrøm, L., Stenseng, F., Nesi, J., Hygen, B. W., & Skalická, V. (2021). The impact of social media use on appearance self-esteem from childhood to adolescence–A 3-wave community study. *Computers in human behavior*, *114*, 106528.

Strain, T., Flaxman, S., Guthold, R., Semenova, E., Cowan, M., Riley, L. M., Bull, F. C., & Stevens, G. A. (2024). National, regional, and global trends in insufficient physical activity among adults from 2000 to 2022: a pooled analysis of 507 population-based surveys with 5· 7 million participants. *The Lancet Global Health*, *12*(8), e1232-e1243.

Stroobach, A., Wilson, A. C., Lam, J., Hall, G. L., Withers, A., & Downs, J. (2023). Factors influencing participation in home, school, and community settings by children and adolescents with neuromuscular disorders: A qualitative descriptive study. *Developmental Medicine & Child Neurology*, *65*(5), 664-673.

Subramanian, S., Dahl, Y., Skjæret Maroni, N., Vereijken, B., & Svanæs, D. (2020). Assessing motivational differences between young and older adults when playing an exergame. *Games for Health Journal*, *9*(1), 24-30.

Syed-Abdul, S., Malwade, S., Nursetyo, A. A., Sood, M., Bhatia, M., Barsasella, D., Liu, M. F., Chang, C. C., Srinivasan, K., Raja, M., & Li, Y. C. J. (2019). Virtual reality among the elderly: a usefulness and acceptance study from Taiwan. *BMC Geriatrics*, *19*(1), Article 223. https://doi.org/10.1186/s12877-019-1218-8

Taitelbaum-Swead, R., & Fostick, L. (2016). The effect of age and type of noise on speech perception under conditions of changing context and noise levels. *Folia Phoniatrica et Logopaedica*, *68*(1), 16-21.

Thach, K. S., Lederman, R., & Waycott, J. (2020). How older adults respond to the use of Virtual Reality for enrichment: A systematic review. 32nd Australian Conference on Human-Computer Interaction, Sydney, Australia.

Thach, K. S., Lederman, R., & Waycott, J. (2020). Virtual Reality in Residential Aged Care: a study of adoption and system complexity.

Theou, O., Tan, E. C., Bell, J. S., Emery, T., Robson, L., Morley, J. E., Rockwood, K., & Visvanathan, R. (2016). Frailty levels in residential aged care facilities measured using the frailty index and FRAIL-NH scale. *Journal of the American Geriatrics Society*, *64*(11), e207-e212.

Thüring, M., & Mahlke, S. (2007). Usability, aesthetics and emotions in human–technology interaction. *International journal of psychology*, *42*(4), 253-264.

Tieland, M., Trouwborst, I., & Clark, B. C. (2018). Skeletal muscle performance and ageing. *Journal of Cachexia, Sarcopenia and Muscle*, *9*(1), 3-19. https://doi.org/https://doi.org/10.1002/jcsm.12238

Townsend, B. G., Chen, J. T., & Wuthrich, V. M. (2021). Barriers and facilitators to social participation in older adults: a systematic literature review. *Clinical gerontologist*, *44*(4), 359-380.

Tyler, M., De George-Walker, L., & Simic, V. (2020). Motivation matters: Older adults and information communication technologies. *Studies in the Education of Adults*, *52*(2), 175-194.

Ullmer, B., & Ishii, H. (2000). Emerging frameworks for tangible user interfaces. *IBM systems journal*, *39*(3.4), 915-931.

Valiani, V., Lauzé, M., Martel, D., Pahor, M., Manini, T. M., Anton, S., & Aubertin-Leheudre, M. (2017). A new adaptive home-based exercise technology among older adults living in nursing home: A pilot study on feasibility, acceptability and physical performance [Article]. *Journal of Nutrition, Health and Aging*, *21*(7), 819-824. https://doi.org/10.1007/s12603-016-0820-0

Vaughan, M., LaValley, M. P., AlHeresh, R., & Keysor, J. J. (2016). Which features of the environment impact community participation of older adults? A systematic review and meta-analysis. *Journal of aging and health*, *28*(6), 957-978.

Vozikaki, M., Linardakis, M., Micheli, K., & Philalithis, A. (2017). Activity participation and well-being among European adults aged 65 years and older. *Social Indicators Research*, *131*, 769-795.

Wais, P. E., Arioli, M., Anguera-Singla, R., & Gazzaley, A. (2021). Virtual reality video game improves high-fidelity memory in older adults. *Scientific reports*, *11*(1), 2552.

Wang, C. M., Tseng, S. M., & Huang, C. S. (2020). Design of an Interactive Nostalgic Amusement Device with User-Friendly Tangible Interfaces for Improving the Health of Older Adults. *Healthcare*, *8*(2), Article 179. https://doi.org/10.3390/healthcare8020179

Waycott, J., Kelly, R. M., Baker, S., Barbosa Neves, B., Thach, K. S., & Lederman, R. (2022). The role of staff in facilitating immersive virtual reality for enrichment in aged care: an ethic of care perspective. Proceedings of the 2022 CHI Conference on Human Factors in Computing Systems,

Waycott, J., & Vines, J. (2019). Designing technologies with older adults: Ethical tensions and opportunities. *Ageing and digital technology: Designing and evaluating emerging technologies for older adults*, 173-187.

Weiss, C. O. (2011). Frailty and chronic diseases in older adults. *Clinics in Geriatric Medicine*, *27*(1), 39-52.

Williams, D., Alam, M. A. U., Ahamed, S. I., & Chu, W. (2013). Considerations in designing human-computer interfaces for elderly people. 2013 13th International Conference on Quality Software,

Williams, K. N., & Kemper, S. (2010). Interventions to Reduce Cognitive Decline in Aging. *Journal of Psychosocial Nursing and Mental Health Services*, *48*(5), 42-51. https://doi.org/doi:10.3928/02793695-20100331-03

Wilson, C. K., Thomas, J., & Barraket, J. (2019). Measuring digital inequality in Australia: The Australian digital inclusion index. *Journal of Telecommunications and the Digital Economy*, *7*(2), 102-120.

Wilson, R. S., De Leon, C. F. M., Barnes, L. L., Schneider, J. A., Bienias, J. L., Evans, D. A., & Bennett, D. A. (2002). Participation in cognitively stimulating activities and risk of incident Alzheimer disease. *Jama*, *287*(6), 742-748.

Witmer, B. G., Jerome, C. J., & Singer, M. J. (2005). The Factor Structure of the Presence Questionnaire. *Presence: Teleoperators and Virtual Environments*, *14*(3), 298-312. https://doi.org/10.1162/105474605323384654

Witmer, B. G., & Singer, M. J. (1998). Measuring presence in virtual environments: A presence questionnaire. *Presence*, *7*(3), 225-240.

Wollersheim, D., Merkes, M., Shields, N., Liamputtong, P., Wallis, L., Reynolds, F., & Koh, L. (2010). Physical and psychosocial effects of Wii video game use among older women. *International journal of emerging technologies and society*, *8*(2), 85-98.

World Health Organization. (2007). *International Classification of Functioning, Disability, and Health: Children & Youth Version: ICF-CY*. World Health Organization.

World Health Organization. (2016). *Health workforce for ageing populations*. Retrieved 26/11/2024 from https://cdn.who.int/media/docs/default-source/mca-documents/ageing/health-workforce-ageing-populations.pdf?sfvrsn=da6b8877_1

World Health Organization. (2024, 1/10/2024). *Ageing and health*. Retrieved 25/11/2024 from https://www.who.int/news-room/fact-sheets/detail/ageing-and-health

Yen, H. Y., Chi, M. J., & Huang, H. Y. (2022). Social engagement for mental health: An international survey of older populations. *International Nursing Review*, *69*(3), 359-368.

Yoon, J., Oishi, J., Nawyn, J., Kobayashi, K., & Gupta, N. (2004). FishPong: Encouraging human-to-human interaction in informal social environments. Proceedings of the 2004 ACM conference on Computer supported cooperative work,

Zhang, H., Miao, C., Wu, Q., Tao, X., & Shen, Z. (2019). The effect of familiarity on older adults' engagement in exergames. 21st Human-Computer Interaction International Conference, Florida, USA.

Zhang, H., Shen, Z. Q., Liu, S. Y., Yuan, D. Z., & Miao, C. Y. (2021). Ping Pong: An Exergame for Cognitive Inhibition Training. *International Journal of Human-Computer Interaction*, *37*(12), 1104-1115. https://doi.org/10.1080/10447318.2020.1870826

Zhang, W., & Wang, A.-p. (2023). Functional ability of older adults based on the World Health Organization framework of healthy ageing: a scoping review. *Journal of Public Health*, 1-19.

Zhou, C., Yuan, F., Huang, T., Zhang, Y., & Kaner, J. (2022). The impact of interface design element features on task performance in older adults: evidence from eye-tracking and EEG signals. *International journal of environmental research and public health*, *19*(15), 9251.

Appendices

Appendix A: Statement of the contribution of authors

I hereby declare that my contribution to the published manuscript within this thesis, as outlined below, to be accurate and true. Manuscript title: User experience of mixed reality applications for healthy ageing: A systematic review.

Name	Signature	Date
I, Joyce Lim, acknowledge that my contribution to the above paper is at 60%		07/03/2025
I, Thomas B. McGuckian, acknowledge that my contribution to the above paper is at 10%		07/03/2025
I, Michael H. Cole, acknowledge that my contribution to the above paper is at 10%		07/03/2025
I, Jonathan Duckworth, acknowledge that my contribution to the above paper is at 10%		07/03/2025
I, Peter H. Wilson, acknowledge that my contribution to the above paper is at 10%		07/03/2025

Appendix B: Ethics Approval

25582 EDNA PlayBoards: Understanding the design and usability of interactive surfaces to increase social participation and activity of older adults. - Approved

donotreply@infonetica.net <donotreply@infonetica.net>
Fri 2/09/2022 3:50 PM
To: Jonathan Duckworth <jonathan.duckworth@rmit.edu.au>
Cc: Jonathan Duckworth <jonathan.duckworth@rmit.edu.au>

Dear Associate Professor Duckworth

Please be advised that the DSC CHEAN has approved your ethics application for 25582 EDNA PlayBoards: Understanding the design and usability of interactive surfaces to increase social participation and activity of older adults.

[2022-2863R] - Registration of external Ethics approved!

Tanya Quesnel <Tanya.Quesnel@acu.edu.au>
on behalf of
Res Ethics <Res.Ethics@acu.edu.au>
Mon 9/19/2022 2:04 PM
To:PeterH Wilson <PeterH.Wilson@acu.edu.au>
Cc:Res Ethics <Res.Ethics@acu.edu.au>;jonathan.duckworth <jonathan.duckworth@rmit.edu.au>;Kianying Joyce Lim <kianyingjoyce.lim@myacu.edu.au>

Dear Applicant,

Chief Investigator: Professor Peter Wilson & Jonathan Duckworth
Student Researcher: Kian Ying Lim
Ethics Register Number: 2022-2863R
Project Title: EDNA PlayBoards: Understanding the design and usability of interactive surfaces to increase social participation and activity of older adults
Date Approved: 19/09/2022
End Date: 17/12/2022

Appendix C: Supplementary Material for Systematic Review (Chapter 4)

Chapter 4: PRISMA Checklist for Systematic Review

Section and Topic	Item #	Checklist item	Location where item is reported
TITLE			
Title	1	Identify the report as a systematic review.	1
ABSTRACT			
Abstract	2	See the PRISMA 2020 for Abstracts checklist.	2
INTRODUCTION			
Rationale	3	Describe the rationale for the review in the context of existing knowledge.	3-6
Objectives	4	Provide an explicit statement of the objective(s) or question(s) the review addresses.	6-7
METHODS			
Eligibility criteria	5	Specify the inclusion and exclusion criteria for the review and how studies were grouped for the syntheses.	8-9
Information sources	6	Specify all databases, registers, websites, organisations, reference lists and other sources searched or consulted to identify studies. Specify the date when each source was last searched or consulted.	7-8
Search strategy	7	Present the full search strategies for all databases, registers and websites, including any filters and limits used.	7-8
Selection process	8	Specify the methods used to decide whether a study met the inclusion criteria of the review, including how many reviewers screened each record and each report retrieved, whether they worked independently, and if applicable, details of automation tools used in the process.	9-10
Data collection process	9	Specify the methods used to collect data from reports, including how many reviewers collected data from each report, whether they worked independently, any processes for obtaining or confirming data from study investigators, and if applicable, details of automation tools used in the process.	10-12
Data items	10a	List and define all outcomes for which data were sought. Specify whether all results that were compatible with each outcome domain in each study were sought (e.g. for all measures, time points, analyses), and if not, the methods	10-12

Section and Topic	Item #	Checklist item	Location where item is reported
		used to decide which results to collect.	
	10b	List and define all other variables for which data were sought (e.g. participant and intervention characteristics, funding sources). Describe any assumptions made about any missing or unclear information.	10
Study risk of bias assessment	11	Specify the methods used to assess risk of bias in the included studies, including details of the tool(s) used, how many reviewers assessed each study and whether they worked independently, and if applicable, details of automation tools used in the process.	12
Effect measures	12	Specify for each outcome the effect measure(s) (e.g. risk ratio, mean difference) used in the synthesis or presentation of results.	NA
Synthesis methods	13a	Describe the processes used to decide which studies were eligible for each synthesis (e.g. tabulating the study intervention characteristics and comparing against the planned groups for each synthesis (item #5)).	11-12
	13b	Describe any methods required to prepare the data for presentation or synthesis, such as handling of missing summary statistics, or data conversions.	11-12
	13c	Describe any methods used to tabulate or visually display results of individual studies and syntheses.	11-12
	13d	Describe any methods used to synthesize results and provide a rationale for the choice(s). If meta-analysis was performed, describe the model(s), method(s) to identify the presence and extent of statistical heterogeneity, and software package(s) used.	11-12
	13e	Describe any methods used to explore possible causes of heterogeneity among study results (e.g. subgroup analysis, meta-regression).	NA
	13f	Describe any sensitivity analyses conducted to assess robustness of the synthesized results.	NA
Reporting bias assessment	14	Describe any methods used to assess risk of bias due to missing results in a synthesis (arising from reporting biases).	NA
Certainty assessment	15	Describe any methods used to assess certainty (or confidence) in the body of evidence for an outcome.	NA

Section and Topic	Item #	Checklist item	Location where item is reported
RESULTS			
Study selection	16a	Describe the results of the search and selection process, from the number of records identified in the search to the number of studies included in the review, ideally using a flow diagram.	12
	16b	Cite studies that might appear to meet the inclusion criteria, but which were excluded, and explain why they were excluded.	12-13
Study characteristics	17	Cite each included study and present its characteristics.	17-24
Risk of bias in studies	18	Present assessments of risk of bias for each included study.	S2
Results of individual studies	19	For all outcomes, present, for each study: (a) summary statistics for each group (where appropriate) and (b) an effect estimate and its precision (e.g. confidence/credible interval), ideally using structured tables or plots.	NA
Results of syntheses	20a	For each synthesis, briefly summarise the characteristics and risk of bias among contributing studies.	NA
	20b	Present results of all statistical syntheses conducted. If meta-analysis was done, present for each the summary estimate and its precision (e.g. confidence/credible interval) and measures of statistical heterogeneity. If comparing groups, describe the direction of the effect.	NA
	20c	Present results of all investigations of possible causes of heterogeneity among study results.	NA
	20d	Present results of all sensitivity analyses conducted to assess the robustness of the synthesized results.	NA
Reporting biases	21	Present assessments of risk of bias due to missing results (arising from reporting biases) for each synthesis assessed.	NA
Certainty of evidence	22	Present assessments of certainty (or confidence) in the body of evidence for each outcome assessed.	NA

Section and Topic	Item #	Checklist item	Location where item is reported
DISCUSSION			
Discussion	23a	Provide a general interpretation of the results in the context of other evidence.	25-29
	23b	Discuss any limitations of the evidence included in the review.	30
	23c	Discuss any limitations of the review processes used.	30
	23d	Discuss implications of the results for practice, policy, and future research.	30-31
OTHER INFORMATION			
Registration and protocol	24a	Provide registration information for the review, including register name and registration number, or state that the review was not registered.	7
	24b	Indicate where the review protocol can be accessed, or state that a protocol was not prepared.	7
	24c	Describe and explain any amendments to information provided at registration or in the protocol.	NA
Support	25	Describe sources of financial or non-financial support for the review, and the role of the funders or sponsors in the review.	1
Competing interests	26	Declare any competing interests of review authors.	1
Availability of data, code and other materials	27	Report which of the following are publicly available and where they can be found: template data collection forms; data extracted from included studies; data used for all analyses; analytic code; any other materials used in the review.	NA

From: Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ 2021;372:n71. doi: 10.1136/bmj.n71

Chapter 4: Quality Analysis Using Adapted Downs and Black checklist by Wronikowska et al. (2021)

	Questions	Give 1 point if:
1	Is the hypothesis and aim/objective of the study clearly described?	Hypothesis and aim/objectives all clearly described
2	Are the main usability evaluation methods described in the Introduction or Methods section?	Usability evaluation methods clearly described in Introduction or Methods section
3	Are all the usability evaluation methods referenced?	Referenced the method if the method is not novel or described the method clearly if the method is novel.
4	Are the characteristics of the participants participating in the usability evaluation method/s clearly described?	The number of participants, age, gender, inclusion & exclusion criteria are all clearly described
5	Are the participants participating in the usability evaluation method/s representative of the intended eventual users?	The participant profile should fit intended end users stated in the introduction (e.g. does it fit the demographics intended to be examined?)
6	Is the time period described over which the study was carried out?	Time period described (including intervention period if applicable and duration of sessions)
7	Do the results accurately reflect the methods described?	The authors do exactly what they said they would do

8	Are all the studied usability evaluation method results described (numerically or graphically)?	Usability evaluation method results clearly described
9	Are the usability evaluation methods measured using standardised measurement tools?	A standardised measurement was used and described (e.g. the use of standardized set of questionnaire or semi-structured interview questions across all participants)
10	Do the authors apply appropriate qualitative/quantitative statistics (specific to usability/user experience evaluation methods)?	Application and sufficient reporting of statistics in case of quantitative methods (e.g. reporting of central tendency and variation), narrative analysis for qualitative methods

Chapter 4: Results of Quality Analysis

Paper/Criteria	1	2	3	4	5	6	7	8	9	10	TOTAL	Quality Category
Meza-kubo et al., 2014	0	0	1	0	0	1	1	1	1	1	6	Moderate
Santos et al., 2019	1	0	1	0	1	1	1	1	1	0	7	Moderate
Valiani et al., 2017	1	1	0	1	1	1	1	1	0	0	7	Moderate
Postal et al., 2019	1	1	1	1	1	1	1	1	0	0	8	High
Boletsis and McCallum, 2016	1	1	1	0	0	1	1	1	1	1	8	High
Chen et al., 2018	1	1	1	1	1	0	1	1	1	1	9	High
Wang et al., 2020	1	1	1	0	1	1	1	1	1	1	9	High
Pyae et al., 2017 Pyae et al., 2016	1	1	1	1	1	0	1	1	1	1	9	High
Chan et al., 2020	1	1	1	1	1	0	1	1	1	1	9	High
Liukkonen et al., 2015	1	1	1	1	1	0	1	1	1	1	9	High
Soares et al., 2021	1	1	1	1	1	0	1	1	1	1	9	High
Lee et al., 2021	1	1	1	1	1	1	1	1	1	1	10	High
Syed-Abdul et al., 2019	1	1	1	1	1	1	1	1	1	1	10	High
Rebsamen et al., 2019	1	1	1	1	1	1	1	1	1	1	10	High
Zhang et al., 2021	1	1	1	1	1	1	1	1	1	1	10	High
TOTAL	**14**	**13**	**14**	**11**	**13**	**10**	**15**	**15**	**13**	**12**		

Appendix D: Publication

Lim, K. J., McGuckian, T. B., Cole, M. H., Duckworth, J., & Wilson, P. H. (2023). User experience of mixed reality applications for healthy ageing: A systematic review. *Cyberpsychology: Journal of Psychosocial Research on Cyberspace*, *17*(4), Article 5. https://doi.org/10.5817/CP2023-4-5

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User experience of mixed reality applications for healthy ageing: A systematic review

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