Digital Health Games for Older Adults: Development, Implementation, and Programmatic Implications of Health Game Use in Senior Centers

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Abstract

By 2030, an estimated 21.6% of the U.S. population will exceed 65 years old. Within this demographic, ongoing broad efforts are needed to address modifiable factors related to common chronic conditions of aging. Digital, or "serious," health games offer one innovative approach to reach and engage older adults, with documented positive impacts on physical, mental/cognitive, and social health. Informed by healthy aging theory and community-engaged, user-centered design methods, our multidisciplinary team has developed a prototype multicomponent educational exergame designed to educate about and promote healthy lifestyle behaviors (i.e., healthy eating, physical activity), stimulate cognitive functioning, engage movement, and promote social connection. Additionally, we included functional near infrared spectroscopy (fNIRS) in our pilot work to measure real time brain activation during gameplay. Our objectives are to: 1) describe the formative development and testing process of an example multi-component educational exergame, including multidisciplinary team science collaboration, application of aging theory, and use of community-engaged and user-centered approaches; and 2) present a pilot study examining implementation and multiple aspects of an innovative educational exergame, including usability, acceptability, preliminary impact, and cognitive function measurement using brain imaging technology (fNIRS) to measure changes in cognitive load during gameplay. The results provide initial support for acceptability, usability, and positive perceived impact, as well as the preliminary encouraging pre to post improvements in behavioral intention, content knowledge, and relative neural efficiency. This paper also explores the potential of implementing serious health games in senior centers as part of their regular programming.

***Keywords*:** exergame, health promotion, older adults, behavior, cognition

Juegos digitales de salud para adultos mayores: desarrollo, implementación e implicaciones programáticas del uso de juegos de salud en centros para personas mayores

Resumen

Para 2030, se estima que el 21,6 % de la población de EE. UU. superará los 65 años. Dentro de este grupo demográfico, se necesitan amplios esfuerzos continuos para abordar los factores modificables relacionados con las condiciones crónicas comunes del envejecimiento. Los juegos de salud digitales o "serios" ofrecen un enfoque innovador para llegar e involucrar a los adultos mayores, con impactos positivos documentados en la salud física, mental/cognitiva y social. Informado por la teoría del envejecimiento saludable y métodos de diseño centrados en el usuario y comprometidos con la comunidad, nuestro equipo multidisciplinario ha desarrollado un prototipo de juego educativo multicomponente diseñado para educar y promover comportamientos de estilo de vida saludable (es decir, alimentación saludable, actividad física), estimular el funcionamiento cognitivo, involucrar el movimiento y promover la conexión social. Además, incluimos espectroscopía de infrarrojo cercano funcional (fNIRS) en nuestro trabajo piloto para medir la activación cerebral en tiempo real durante el juego. Nuestros objetivos son: 1) describir el desarrollo formativo y el proceso de prueba de un ejemplo de exergame educativo de múltiples componentes, incluida la colaboración científica de equipos multidisciplinarios, la aplicación de la teoría del envejecimiento y el uso de enfoques centrados en el usuario y comprometidos con la comunidad; y 2) presentar un estudio piloto que examina la implementación y múltiples aspectos de un exergame educativo innovador, incluida la usabilidad, la aceptabilidad, el impacto preliminar y la medición de la función cognitiva utilizando tecnología de imágenes cerebrales (fNIRS) para medir los cambios en la carga cognitiva durante el juego. Los resultados brindan un apoyo inicial para la aceptabilidad, la usabilidad y el impacto positivo percibido, así como las mejoras preliminares alentadoras previas y posteriores en la intención de comportamiento, el conocimiento del contenido y la eficiencia neuronal relativa. Este documento también explora el potencial de implementar juegos de salud serios en centros para personas mayores como parte de su programación regular.

Palabras clave: exergame, promoción de la salud, adultos mayores, conducta, cognición

老年人数字健康游戏：老年中心的健康游戏开发、实施以及计划启示

摘要

到2030年，预计21.6%的美国人口将超过65岁。在这一人群中，需要持续的广泛举措来应对一系列与常见慢性衰老疾病相关的可改变因素。数字（或“重要的”）健康游戏提供了一种接触老年人并使其参与的创新方法，这种方法对身体、心理/认知以及社会健康产生了可证实的积极影响。基于健康老龄化理论和一系列关于社区参与、以用户为中心的设计方法，我们的多学科团队开发了一款原型多组件教育运动游戏，旨在教育和促进健康生活方式行为（即健康饮食、体育活动）、刺激认知功能、参与运动、以及促进社会联系。此外，我们还在试点研究中使用了功能性近红外光谱学(fNIRS)，以衡量游戏过程中的实时大脑激活情况。我们的目标是：1)描述示例多组件教育运动游戏的形成开发与测试过程，包括多学科团队的科学协作、老龄化理论的应用、以及关于社区参与和以用户为中心的方法的使用；2)提出一项试点研究，分析创新教育运动游戏的实施和多个方面，包括可用性、可接受性、初步影响、以及认知功能测量——使用大脑成像技术(fNIRS)测量游戏过程中认知负荷的变化。研究结果为可接受性、可用性以及积极的感知影响提供了初步支持，并为行为意图、内容知识和相对神经效率的前后改进提供了初步鼓励。本文还探究了一种可能性，即在老年中心实施重要的健康游戏，以作为其常规计划的一部分。

关键词：运动游戏，健康促进，老年人，行为，认知

Background

Recent estimates indicate that by 2050, 22% of the total global population—including the United States—will be people 60 years or older (World Health Organization [WHO], 2017; Administration on Aging [AOA], 2020). Many older adults manage one or more chronic conditions such as diabetes and cardiovascular disease, emphasizing the need for healthy lifestyle promotion (Kochanek et al., 2017). There are many evidence-based health promotion interventions in older adults targeting multiple behaviors, such as healthy eating and physical activity. National groups, such as the National Council on Aging (NCOA) and the Centers for Disease Control and Prevention (CDC), have recognized the importance of using evidence-based interventions to address multiple areas of healthy aging.

To that end, "serious health games" may offer an innovative tool to support healthy aging. Serious health games are defined as digital games that focus on impacting health (Adams, 2010), and have been used in a variety of ways to affect health, such as educating about health topics, promoting lifestyle change, supporting self-management of chronic diseases, and rehabilitation. Mounting evidence supports a positive impact across diverse populations (Li, Theng, & Foo, 2014; Sanchez et al., 2019; Staiano & Flynn, 2014; Zhang et al., 2022). In addition to potential health-related benefits, serious health games may have benefits based on their focus on fun, engagement, and social interaction (Li et al., 2018). Exergames, a specific type of health game, are designed to incorporate movement into gameplay. Exergames have been widely studied and research has shown the promising impacts of exergames in many health areas with diverse populations (Calafiore et al., 2021; Cugusi, Prosperini, & Mura; 2021; Street, Lacey, & Langdon, 2017; Wu et al., 2022). Exploring the use of serious health games in general and specifically exergames as a health promotion approach may pave the way for their consideration among evidence-based interventions incorporated into programs and policies that support healthy aging in older adults.

Serious Health Games in Older Adults

Multiple systematic reviews of serious health games and exergames have been published summarizing outcomes in older adults. Since the focus of our research is on independently living older adults, we will summarize relevant work on their impact with this population overall rather than in specific health issues or clinical populations. In general, research supports the efficacy of serious health games on different aspects of health. One early systematic review (Hall et al., 2012) (N = 13 studies) of use of digital video games in older adults concluded that such games showed positive impacts in physical (e.g., balance, mobility), mental (e.g., working memory, depression), and social outcomes. A recent systematic review (Xu et al., 2020) examined the use of video game interventions in older adults (N= 23 studies) and found a positive impact of such games on mental (e.g., executive functions, processing speed) and physical (e.g., balance, mobility, walking performance/gait parameters) health of older adults. The authors recommended the use of exergames, especially those with a cognitive component, to simultaneously affect physical and cognitive health. For example, one systematic review (N=18 RCTs) examined the impact of exergames on physical performance measures and found a positive impact of exergames on mobility and balance (Taylor et al., 2018). A recent meta-analysis (N=48 studies) examined the specific effect of exergame training on various aspects of physical functioning in healthy older adults (Hai et al., 2022). This meta-analysis found that exergame training demonstrated a small effect on overall physical functioning with differential impacts in specific areas (moderate benefits specifically in balance, lower body strength, aerobic endurance; small benefit in gait; negligible effects on upper body flexibility and lower body flexibility). Another recent meta-analysis focused on the use of the Nintendo Wii-Fit exergame (N= 10 studies) found positive improvement in functional, static, and dynamic balance in older adults but no significant impact on lower limb muscle strength (Liu et al., 2022). In sum, the research to date highlights the promising impact of serious health games, especially exergames, for older adults.

Cognition in Older Adults and Impact of Health Games

One area of health of particular concern in older adults is cognition. Cognition is the ability to coordinate thoughts and actions for completing a goal (Lennox-Smith et al., 2018). As individuals age, cognitive decline (trouble remembering, recalling, learning new things, concentrating, or making decisions) becomes more prevalent (CDC, 2019; Hegde & Ellajosyula, 2016) and often begins to worsen between the ages of 50 and 70 years (Xu et al., 2020). Due to the projected increase in the older adult population, there is high demand for programs and interventions aimed at decreasing the progression of cognitive decline. While memory can worsen with age, its severity can be offset by behavioral interventions targeting cognitive stimulation (Martin et al., 2011). Programs aimed at slowing cognitive decline among older adults have been previously implemented and have included components such as education, socialization, and physical activity in a variety of settings (Causse et al., 2017; Eggenberger et al., 2016; Fishburn et al., 2014). Exergames that incorporate these components and are used in combination with other approaches may add one innovative approach to our toolbox to help minimize cognitive decline.

Researchers performing systematic reviews have found that exergames provide improvement in cognitive and dual task function (Ogawa et al., 2016) in older adults and training with video games improved several cognitive functions (Toril et al., 2014). For example, Howes concluded that active computer games can significantly affect balance and cognition in older adults (Howes et al., 2017). In another study, Moreira et al. (2021) found that exergaming improved cognitive status in older adults similar to the effects associated with traditional exercise training. A recent review of cognition and exergames (Stojan & Voelcker-Rehage, 2019) found executive functions were most examined in these studies. However, only four studies included physiological measures of cortical activity such as using modalities such as EEG or functional near infrared spectroscopy to assess executive function levels. The extant literature also suggests exergames may improve cognitive functioning in older adults (LeRouge & Wickramasinghe, 2013; Stojan & Voelcker-Rehage, 2019), although the underlying neural mechanisms that may give rise to potential cognitive and motor benefits of exergames are not well understood (Yeung & Chan, 2021). Therefore, more research is needed to examine changes in neural activity that may demonstrate the impact of exergame use in older adults.

One emerging technology holds promise when studying physiological measures of cognitive function during movement activities. fNIRS is a non-invasive way to examine the allocation of cognitive resources and intervention efficacy by providing measures of brain oxygenation and hemodynamic change (a proxy for neural activity) occurring within the prefrontal cortex (Shewokis et al., 2015, Vassena et al., 2019). fNIRS can provide information about cognitive load changes, such as improvements in working memory, neural efficiency, and involvement (Mellecker et al., 2013). A benefit of fNIRS use is that it is relatively motion tolerant and can provide information about cognitive load changes (i.e., improvements in working memory and neural efficiency) when combined with behavioral performance data, such as game play scores (Shewokis et al., 2015; Stojan & Voelcker-Rehage, 2019). Previous research (Causse et al., 2017, Fishburn et al., 2014; Vassena et al., 2019) has shown strong agreement between executive function and average oxygenation measure changes.

Aging has been linked with higher reliance on cognitive resources (Mirelman et al., 2017), thereby further supporting the value of fNIRS measurement in our game research. Moreover, aging has been linked with a gradual increase in the activity of prefrontal cortex; and a comparison between age groups has shown that this compensatory mechanism may reach a resource ceiling effect beginning at 70-years-old, resulting in reduced executive function efficiency and subsequent motor impairments (Nóbrega-Sousa et al., 2020). Therefore, we believe including oxygenation measures from fNIRS, in combination with behavioral measures from game play, in our research paradigm will provide an innovative way to document changes in executive function. In addition, this current research may garner preliminary support to include in consideration of policy and procedures for implementation of exergaming protocols with independently living older adults.

In summary, the literature to date supports the positive impact of serious health game interventions and, specifically exergames, on important dimensions of healthy aging, especially including physical and mental/cognitive health. These serious health games, particularly exergames, show promise in impacting independently living older adults as a form of training for both physical health and cognitive function. Furthermore, there are few studies that examine the impact that serious health games and exergames may have on social health or social engagement. Inclusion of exergames to supplement health-related programs in sites where large numbers of independently living older adults (e.g., senior centers, community centers) congregate may offer one approach to support the overall effort to enhance healthy aging.

Objectives of Paper

As described in the background section, research indicates that positive outcomes of serious health games exist in multiple health areas important to successful aging (Hall et al., 2012, Kovisto & Malik, 2020). At the same time, Hall and colleagues (2012) have noted some limitations in game development for older adults. Furthermore, few studies of exergames have investigated theory-guided outcome domains, described specific development/tailoring for older adults, or included older adults in the development process (Koivisto & Malik, 2020, Lee et al., 2021). Finally, limited research has used fNIRS to measure prefrontal cortex changes that result from exergaming in older adults. We hope to address these knowledge gaps with our work. Therefore, the two aims of this paper are to: 1) describe the formative development and testing process of an example multi-component educational exergame, including multidisciplinary team science collaboration (Bennett & Gadlin, 2012), application of aging theory, and use of community-engaged and user-centered approaches (Brox et al., 2017; LeRouge & Wickramasinghe, 2013); and 2) present a pilot study examining implementation and evaluation of multiple aspects of an innovative educational exergame, including usability, acceptability, preliminary impact, and cognitive function measurement using brain imaging technology (fNIRS) to measure changes in cognitive load during gameplay; and conclude by discussing the programmatic and policy implications of the use of exergames in older adults attending senior centers.

Aim 1: Version Formative Development and Testing Process

Given the prior literature highlighting the emerging interest and potential impact of health games in older adults, our team's prior work developing, tailoring, and/or examining the impact of exergames or gamification in youth and older adults (Orsega-Smith et al., 2012; Orsega-Smith et al., 2020; Ruggiero et al., 2014; Ruggiero et al., 2020; Ruggiero, et al., 2023), we sought to expand this work in a variety of ways. Building on our prior work, we organized a multidisciplinary team, guided by Successful Aging theory (Rowe & Kahn, 1997) and user-centered approaches (Lee et al., 2021), and employed community-engaged methods (Brox et al., 2017; CDC, 2011) to develop and examine a new multi-component educational exergame.

Multidisciplinary Development and Research Team

Our team uses a multidisciplinary team science approach (Bennett and Gadlin, 2012) with collaborators from computer science, psychology/behavioral science, and kinesiology, along with specific expertise in aging and motor learning. The team also brings experience in the development and implementation of tailored technology-based health promotion interventions; community-engaged mixed-methods research; and embodied interactive games. The development work expanded upon team members' prior work with health game development (Ruggiero et al., 2020; Ruggiero et al., 2023), research in senior centers using commercial exergames (Orsega-Smith et al., 2012; Orsega-Smith et al., 2020), use of fNIRS in adults participating in cognitively stimulating computer-based tasks (Bakhshipour et al., 2020; Koiler et al., 2022; Liang et al., 2016; Milla et al., 2019), and designing embodied interactive systems and games using Microsoft Kinect for healthcare education and rehabilitation (Barmaki & Hughes, 2018a; Barmaki & Hughes, 2018b; Barmaki et al., 2019; Bork et al., 2017; Yu et al., 2018).

The game development phase leveraged our team member's prior experience with health games (Barmaki & Hughes, 2018; Barmaki et al., 2019; Orsega-Smith et al., 2012; Orsega-Smith et al., 2020; Ruggiero et al., 2020; Ruggiero et al., 2023; Yu et al., 2018) to develop an educational exergame targeting multiple areas emphasized in aging theory (see next section). Our prior game development/tailoring work with older adults was based on a review of limited literature at the time on game design for older adults (e.g., Gerling et al., 2012) that influenced the specific game design elements such as quiz-like game, points, and features such as font size, game pace, audio, team play option, easy instructions; simple game interface. Multidisciplinary researchers, students, and programmers worked together to iteratively design the game, develop the content, and conduct the formative examination of the game. The team regularly interacted with a programmer to discuss initial and ongoing design ideas and share feedback for ongoing iterative adaptation of the game.

Informed by Aging Theory

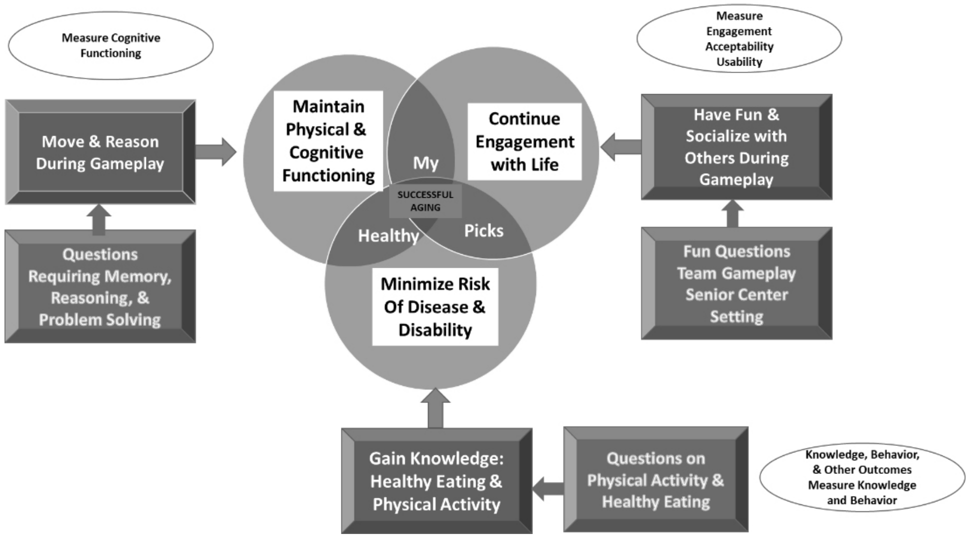

Figure 1. Successful aging theory informs game development, implementation and measurement.

Note: The circles represent the theory components, boxes represent game goals and game question types, and ovals describe measurement areas (Rowe and Kahn, 1997).

Our work is informed by Rowe and Kahn's (1997) mode of successful aging (see Figure 1) which posits that successful aging occurs at the intersection of engagement with life, avoidance of disease, and maintenance of cognitive and physical functioning. In the development of MHP, the overall goals for these three areas during gameplay were to encourage movement and stimulate cognitive reasoning; have fun and socialize; and gain knowledge to promote healthy lifestyles. In a paper highlighting Rowe and Kahn's framework, they mention that engagement with life includes being part of a social group or engaging in leisure activities with friends and family (Liffiton et al., 2012). In turn, this theoretical/conceptual framework informed the specific content, game features, and gameplay implementation approach, including physical activity and healthy eating educational content; cognitively challenging items; and questions with tailored difficulty levels, minigames, and other strategies for example team gameplay and scores designed to be fun/engaging. Our development work focused on using content and strategies to address each of these areas (See Table 1). For example, minimizing risk of disease and disability was addressed by including educational questions, educational messages, and mini-games related to healthy eating and physical activity. Maintaining physical and cognitive functioning was addressed by including cognitive challenge or educational questions, educational messages, mini-games, and through movement during gameplay. Continued engagement with life was addressed through inclusion of trivia questions and competition to make it fun and team gameplay to promote social engagement with others (Liffiton et al., 2012).

Table 1: Healthy Aging Goals/Topics, Game Methods, and Samples Used Across the Game

Healthy Aging Goal/Area	Method	Sample Items
Minimize Risk of Disease and Disability – Educate about lifestyle change		
Healthy eating	Educational questions	1)Vegetables are a good source of: (a) fiber, (b) vitamins, (c) minerals, (d) all of these choices 2)You should try to avoid food and drink containing too many: (a) minerals, (b) nutrients, (c) added sugars, (d) electrolytes
Healthy eating	Educational messages	MyPlate recommends that half the plate be made up of fruits and vegetables.
Healthy eating	Mini game	Virtually catch dropping fruits and vegetables while avoiding catching less healthy items
Physical activity	Educational questions	1)Physical activity can lower the risk of: (a) type 2 diabetes, (b) depression, (c) cancer, (d) all of these choices 2) What regular activity can help bone strength? (a) walking around the room several times, (b) reading a book while on a stationary bike, (c) lifting soup cans while watching television, (d) all of these choices
Physical activity	Educational messages	Getting at least 150 minutes a week of moderate-level activity, such as brisk walking, is recommended for older adults.
Physical activity	Mini game	Complete the swimming breaststroke with arms while virtually swimming
Maintain physical and cognitive functioning – Educate about and activate cognitive functioning		
Cognitive functioning	Cognitive challenge questions	1)Which does not belong? (a) team, (b) sport, (c) cat, (d) goal 2)A soccer game has 45-minute halves, how long is the full game? (a) 12 minutes, (b) 45 minutes, (c) 90 minutes, (d) 100 minutes

Cognitive functioning	Educational messages	Finding a new hobby, like learning a new instrument or language can keep your mind active!
Cognitive functioning	Mini games	Virtually move shapes that appear in the center of a circle to their matching shapes around the circle (See Figure 2 for picture)
Physical functioning	Movement during question responding gameplay	Stretching arms to virtually answer questions
Physical functioning	Movement during mini games	Stretching arms or incorporating other movements to complete mini-game activities
Maintain engagement with life – Promote fun, engagement, socialization		
Social connection	Team gameplay	Game implementation involved forming and playing in teams with encouragement to cheer on and support team members their gameplay
Engagement/fun	Competition	Scores for correct answers are provided for each round of gameplay. Game implementation involved tracking team scores across gameplays and teams were encouraged to compete for the highest score.
Fun	Trivia questions	1) Which famous band released the album "Abbey Road"? (a) the Beatles, (b) Aerosmith, (c) Oasis, (d) the Rolling Stones 2) Which city is known as the "City of Love"? (a) Paris, (b) Chicago, (c) Hong Kong, (d) Los Angeles

Note: This table is separated into the three components of the "Successful Aging Theory" (gray shading used for section headings).

Community-Engaged User-Centered Game Adaptation

User-centered design (UCD) principles, including literature review, surveys on user preferences for game questions/preferences; observing gameplay, focus groups, guided the development of the game prototype with feedback loops between design and implementation (Brox et al., 2017; LeRouge & Wickramasinghe, 2013). We used UCD for iteratively adapting the game (Lee et al., 2021) for independently living older adults and senior center implementation. End users' (older adults) needs, wants (for instance, movement/content difficulty levels), and suggested modifications were considered at each stage of the adaptation process (Baranowski et al., 2014). This method incorporated multiple prototype demonstrations with gameplay iterations. Our integrated community-engaged approach (CDC/ATSDR, 2011 involved gathering input from both senior center staff/leadership and its members. Overall, we obtained the following from our community members over the course of our formative work: input for game development/tailoring (e.g., instructions, question/movement difficulty levels; educational content) (Koivisto & Malik, 2020); general feedback on our overall research approach, especially including recruitment planning (e.g., strategies; anticipated barriers/solutions); and input on senior center implementation approach to support feasibility and enhance engagement/fun (e.g., gameplay approach: timing, frequency, team approach). These user-centered approaches will be more specifically described in the descriptions of the adaptation and examination of each game version.

"MyHealthy Picks" (MHP) Version 1 Description

MHP Version 1 used a Unity game engine (Unity Technologies, San Francisco, CA) and Kinect One sensor (Microsoft Corporation, Seattle, WA) allowing for a robust physical activity component. In this embodied interactive game, users' body movements and gestures are tracked by the Kinect sensor to control the game interface. Users' images are captured by the computer camera and projected, so users see themselves along with questions and response choices, on a large monitor in front of them. The game is played by virtually selecting question responses by stretching and hovering their hands over their answer choice (See photos in Figure 2) or engaging in various movements during the mini-game activities. Version 1 focused on the areas of avoidance of disease and disability and maintaining physical functioning

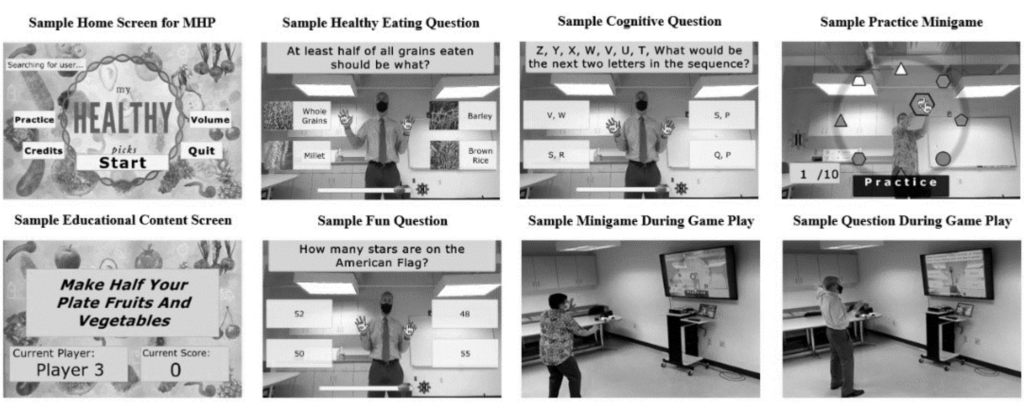

Figure 2. Version 2 game, including home screen, sample questions, educational message screen, cognitive mini-game, and gameplay.

based on healthy aging theory. Specifically, content included questions and educational messages in the areas of healthy eating and physical activity and activities were developed to promote movement (See Table 1 overview).

Version 1 Formative Testing

This pilot was designed to get preliminary feedback on acceptability and usability of the game from older adults. A convenience sample of older adults (N=14) was recruited from a senior center using flyers and word of mouth recruitment approaches. Interested individuals observed a game demonstration and played MyHealthy Picks Version 1 at a senior center. After gameplay, the 14 participants (13 females, 1 male) completed an anonymous survey that assessed aspects of acceptability and usability of the game. Participants ranged in age from 65–81 years (mean age = 73.07 years) and ten identified as white and four as African American/Black. All 14 participants also took part in a semi-structured focus group to gather qualitative feedback on the game. The structured focus group questions focused on the general game appearance and experience, what they liked about the game, background graphics, text size and color, and feedback on types of game questions (healthy eating, physical activity), planned (cognitive), or considered (trivia questions). In addition, recommendations were obtained for specific types of trivia questions to add, audio, feedback on educational messages, and general recommendations for how to make the game most appealing to older adults (e.g., Gerling et al., 2012).

The results generally indicated favorable feedback on the game with greater than 90% of participants agreeing or strongly agreeing that it had clear instructions (93%), appealing audio (92%), readable text (93%), was comfortable and enjoyable to play (93%), and they would play it again if asked to do so (93%). More than 80% of participants agreed or strongly agreed that the sound quality is appropriate (84.6%), they got excited to get the answers correct (86%), and the game increased their enthusiasm for learning more about healthy eating (84%). In addition, about 78.6% agreed or strongly agreed (21.4% neutral) that feedback related to their correct/incorrect responses was motivating, and 62% agreed or strongly agreed (15% neutral; 23% disagree/strongly disagree) that they were paying attention to their score. These survey results support the acceptability and usability of Version 1 of the game.

The focus group input was transcribed and then reviewed by two investigators to identify the main themes regarding game aspects participants liked or felt needed improvement. When asked about their overall game experience, there was a balance of positive (e.g., "it was fun"), negative (e.g., "hand tracking wasn't precise"), and neutral (e.g., "it wasn't too hard") comments. Participants provided positive feedback on multiple features, such as getting feedback on answers (e.g., "I liked when you got a correct answer and the confetti on the screen"), getting a score (e.g., "Getting a score was kind of neat"), and types of questions (e.g., "good variety"). The participants provided constructive feedback for further adaptation of instructions (e.g., more clear), adding more trivia question types (e.g., history, movies, sports), adding levels of content (e.g., easy, medium, hard), adding options for movement, improving the graphics and colors, and improving the hand tracker sensitivity.

Version 2 Game Adaptation

Based on the participant feedback and observations by our team, the following adaptations were made to create MyHealthy Picks Version 2: 1) improved color contrast and graphics overall; 2) added new categories of questions (i.e., cognitive stimulation activities, trivia) and developed additional questions in the areas of physical activity and healthy eating to create different levels of difficulty 3) refined the hand tracking for gameplay (i.e., Kinect sensor sensitivity); and 4) developed minigames to add other opportunities for movement. Cognitively stimulating questions to target areas of attention, perception, comprehension, executive control, and calculation were developed by our multidisciplinary team. It has been suggested that gamification of these types of cognitive training questions may be enjoyable for older adults (Lumsden et al., 2016). A variety of trivia questions, such as history, movies, and music, were added to the game based on senior center member input to make the game more fun and engaging. Content was expanded for physical activity and healthy eating and, in general, content was obtained from reliable information sources, such as USDA MyPlate.gov, National Institute on Aging, Dietary Guidelines for Americans, U.S. Department of Health and Human Services Physical Activity Guidelines for Americans, and the Centers for Disease Control and Prevention (CDC). Various levels of questions (easy and moderate) and use of a team gameplay implementation approach was added to encourage social engagement. This adaptation process also included regular meetings with the programmer to exchange ideas for adapting the game based on user input and researcher observations to work towards developing the next version.

Version 2 Formative Testing

Following initial development, the new educational, trivia, and cognitive questions were reviewed by a convenience sample of six older adults who were in the target age range of 65–85 years of age including senior center members and general population. Participants were given the new and expanded list of questions to review and were asked to provide feedback on perceived difficulty level, interest, and perceived relevance of the trivia questions. Based on the user feedback, the questions were refined and categorized by level of difficulty. This process led to the final set of questions incorporated into Version 2 to be tested in the formative pilot on this game version.

A new MyHealthy Picks Version 2 was demonstrated to and/or played by a small sample of members from a local senior center (N = 4; 3 females, 1 male). Over a 30-minute demonstration period, participants either directly played the game or observed others play the game. The gameplay was followed by a focus group (N = 4) in which additional feedback was garnered on overall impression of game, aspects liked, areas for improvement, anticipated use, and feedback on specific game features (for example, questions, mini-games, sensor use, movement). Two investigators independently reviewed the transcript for overall themes and suggested areas for game refinement. Most comments (about 20%) on overall impression of the game (i.e., "what did you think of MyHealthy Picks?"; "How would you describe the game in a few words?") were positive, such as "engaging," "encouraging," "fun," "informative," "colorful," and "fun and different…way of learning." Examples of aspects of the game they liked included "learning," "move your body," and "exercising your brain." General suggestions offered for enhancing the game focused on adding levels or more instructions/practice before gameplay, and using rewards. Feedback for improving specific game features focused on improvement in mini-game functioning. Responses to the questions of "would you play the game again?" and "would you recommend it to a friend?" were all positive.

Version 3 Game Adaptation

Based on feedback using game Version 2, the following adaptations were made to the game to develop MyHealthy Picks Version 3: 1) adding a practice round for participants; 2) providing instructions (text and audio) within the game to explain how to play; and 3) improving the functioning of the three minigames. For piloting purposes, this game version focused on inclusion of 20 easy questions in each of four categories: healthy eating, physical activity, cognition, and trivia; and three mini-games focused on the three healthy aging areas (See Table 1).

Aim 2: Implementation Pilot (Version 3) Participant Eligibility, Criteria, Recruitment, and Incentives

Participants were recruited from a senior center via distribution of study information in fliers, social media, informational sessions, and word of mouth. Interested senior center members signed up during an informational session at the local senior center. Inclusion criteria were age 65–95 years, community dwelling and independently living, and a member of our partner senior center. Participants were excluded if they had health conditions that precluded participation in physical activity and were non-English speaking. Prior to participation and guided by the consent form, interested/eligible individuals were fully informed of the study purpose, procedures, risks, and benefits, and given the opportunity to have their questions addressed; if interested, they completed the consent form for participation. Upon completion of participation, each participant received a ten-dollar gift certificate as an incentive. All procedures were approved by the University of Delaware's Institutional Review Board.

Procedure

Participants completed an informed consent process, completed a pre-questionnaire, had the fNIR sensor placed on their foreheads, played the game for 15 minutes as a pretest, and subsequently were assigned to a team. The team gameplay occurred in four sessions over a two-week period. Participants worked together in teams of two to three members to answer knowledge, trivia, and cognitive challenge questions and competed for the highest score across the teams. Following the four sessions of team game play, individuals completed a post-questionnaire and had a post session of individual gameplay for 15 minutes with the fNIRS measures being taken.

Questionnaires were conducted electronically on an IPAD using Qualtrics or on paper, as preferred by the participant. The pre-questionnaire collected demographics, health status, and stages of change/intention to change. The post-questionnaire included stages of change/intention to change, acceptability (e.g., satisfaction), and usability (e.g., perceived ease of use, usefulness of game).

Measures

Demographics

Questions assessed the following: gender, race, age, education, marital status, employment status, annual salary, living situation, and health conditions.

Behavioral stages of change

Adapted from Nigg and colleagues (1999) five stages of change questions, participant's intentions or engagement in a health behavior were assessed. Questions were used for the following behaviors: eating five or more fruits and vegetables per day, eating whole grains, avoiding high fat proteins, avoiding high fat dairy, avoiding sugary drinks, and engaging in 30 minutes of physical activity per day. Participants were asked to select one of the following statements related to intention or engagement in each behavior: No, and I do not intend to start in the next six months (i.e., precontemplation stage); No, but I intend to start sometime in the next six months (i.e., contemplation stage); No, but I intend to start in the next month (i.e., preparation stage); Yes, I have been but for less than 6 months (i.e., action stage); and Yes, I have been for 6 months or more (i.e., maintenance stage).

Usability

The System Usability Scale (SUS; Brooke, 1996) was adapted to focus specifically on health games. Example items include "I think that I would need technical support to be able to use this game," "I found the various features in this game were well integrated," and "I thought there was too much inconsistency/repetition in this game." The standard scoring approach was used to create the final usability score [range = 0-100; Brooke, 1996] and a benchmark of 68 was used for comparison (Hyzy et al., 2022).

Acceptability, Perceived Impact, and Anticipated Use

The researchers developed a survey to gather information on acceptability (content, game features, mini-games, team play), perceived impact, anticipated frequency of use, and recommendation to others (See Table 3 for survey items). In addition, one survey item addressed recommending the game to other adults. These questions used a four item Likert scale with response choices of "strongly disagree," "disagree," "agree," or "strongly agree." One additional item asked: "How often would you play the game if you could play it at home?" with response choices of "never," "less than once a week," "once a week," and "more than once a week."

Cognition

The Saint Louis University Mental Status Exam (SLUMS) was used to screen for detecting mild cognitive impairment (Tariq et al., 2006). It uses small cognition tasks such as recalling simple words, reciting numbers backwards, and answering verbatim questions after a small passage.

Pre and Post-test Content Knowledge

Ten questions each on healthy living, physical activity, and cognitive challenge assessed each of these areas. These questions were items included in the game during 15 minutes of gameplay as part of the pre and post-test during fNIRS data collection. Sample game questions included: "What are the benefits of physical activity?" and "What should half of your plate include?" This measure was scored by summing correct answers across the 30 items (range = 0-30) and creating a percentage correct (0-100%).

Brain Oxygenation and Relative Neural Efficiency

fNIRS was used to measure prefrontal neural correlates of cognitive aspects of the exergame. Our fNIRS system (fNIR Devices, Model 200s) requires participants to wear a headband-like sensor pad on the forehead and provides images of the surface of the brain (Figure 3). Placement of the fNIRS sensor band aligns the center of both the horizontal and vertical axes of the head with those of the band. This fNIRS system involves a series of four light sources and 10 light detectors. The light sources introduce near-infrared light introduced to the scalp, and the light detectors collect the light that travels through the brain and back to the surface. Part of the light will be absorbed by hemoglobin in the blood stream when it travels through the tissue. Based on the amount of absorbed light (the difference between emission and detection), the concentration of oxygen can then be calculated (oxyhemoglobin or Δ HbO). The greater the concentration of Δ HbO, the

Figure 3. In the top picture, the fNIRS sensor pad includes light sources (in orange) and detectors (in red). Infrared light is absorbed by hemoglobin in the blood screen. Oxygenation is calculated from the difference between emitted and detected light. The bottom picture shows a participant with the sensor pad placed on the forehead, where it will capture oxygenation of the prefrontal cortex.

more neural activity is occurring in that section of the brain. To examine changes in cognitive load that occur as a result of exergame practice, we calculated an estimate of relative neural efficiency (RNE), which is a measure that places brain oxygenation measures within the context of participant performance as a means to quantify the relationship between these two measures. In our case, a high scoring SLUMS performance coupled with low oxygenation values indicates high relative neural efficiency, whereas a low SLUMS performance with high oxygenation values indicates low relative neural efficiency (Koiler et al., 2022; Paas et al., 2003; Paas et al., 2005). This allows us to interpret changes in brain oxygenation within the context of changes in exergame performance following the principles of Cognitive Load Theory (Sweller, 1988).

Results

Participant Descriptives

The participants in this study were independently living members of a local community center. There were thirteen total participants, all females and white with a mean age of 78.3 years of age (range 67–94 years). All participants were retired and had a high school education or greater with a majority living alone (69%). The three most common health conditions reported were arthritis, hypertension, and thyroid disorder.

Acceptability, Perceived Impact and Anticipated Use

Greater than 90% of participants responded either "agree" or "strongly agree" to all but one acceptability and perceived impact question. For one content acceptability item (i.e., educational content was easy to understand), 85% of participants responded with either "agree" or "strongly agree." All participants (100%) agreed or strongly agreed that they would recommend the game to other adults. Regarding anticipated frequency of use of the game at home, the majority (92%) indicated they would play the game again. These results indicate overall favorable acceptability and strong perceived impact of the game.

Table 3: Version 3 Pilot Survey Results

Content Area **Question**	**Strongly Disagree**		**Disagree**		**Agree**		**Strongly Agree**	
	n	%	*N*	%	*n*	%	*N*	%
Content Acceptability								
It was easy for me to understand the educational content.	2	15.38	0	0.00	7	53.87	4	30.77
I was satisfied with the healthy eating and physical activity educational questions.	1	7.69	0	0.00	9	69.23	3	23.08
I was satisfied with the trivia questions.	1	7.69	0	0.00	8	61.54	4	30.77
I was satisfied with the brain teaser and puzzle questions.	1	7.69	0	0.00	8	61.54	4	30.77
Game Features Acceptability								
It was easy for me to understand the instructions.	1	7.69	0	0.00	8	61.54	4	30.77
I was satisfied with the game audio.	1	7.69	0	0.00	6	46.15	6	46.15
I was satisfied with the graphics.	1	7.69	0	0.00	6	46.15	6	46.15
I was satisfied with the music.	0	0.00	0	0.00	9	69.23	4	30.77
I was satisfied with the pace of the game.	0	0.00	0	0.00	9	69.23	4	30.77

Mini-Game Acceptability								
I was satisfied with the shape matching activity.	0	0.00	0	0.00	9	75.00	3	25.00
I was satisfied with the activity where you catch fruits and vegetables.	0	0.00	0	0.00	7	77.78	2	22.22
I was satisfied with the swimming activity.	0	0.00	0	0.00	7	87.50	1	12.50
The shape matching activity was fun.	0	0.00	0	0.00	10	83.33	2	16.67
The activity where you catch fruits and vegetables was fun.	0	0.00	1	10.00	6	60.00	3	30.00
The swimming activity was fun.	0	0.00	0	0.00	6	66.67	3	33.33
Acceptability with Social Aspects of Game								
Playing the game with a team was fun.	0	0.00	0	0.00	5	38.46	8	61.54
I found it enjoyable playing the game	1	7.69	0	0.00	9	69.23	3	23.08
I enjoyed the social part of the playing the game.	1	7.69	0	0.00	7	53.85	5	38.46
Perceived Impact of Game								
The game was helpful in improving my physical activity knowledge.	0	0.00	0	0.00	11	84.62	3	15.38
The game was helpful in increasing my motivation to do physical activity.	0	0.00	1	7.69	9	69.23	3	23.08
The game was helpful in improving my knowledge of a healthy diet.	0	0.00	0	0.00	11	84.62	2	15.38
The game was helpful in increasing my motivation to eat a healthy diet.	0	0.00	0	0.00	11	84.62	2	15.38
Recommend Game								
I would recommend this game to other adults.	0	0.00	0	0.00	8	61.54	5	38.46
Frequency of Gameplay								
If you could play this game at home, how often would you play it?	1	7.69	3	23.08	4	30.77	5	38.46

System Usability Survey

The average SUS score was 77.5 (out of 100; sample range = 45-100; SD = 15.94). Since the benchmark for satisfactory usability is 68 (Hyzy et al., 2022), this suggests usability of this health game with older adults is promising.

Stage of Behavior Change

There was little or no change in stage of change for grain intake, fruit and vegetable consumption, and avoiding sugar sweetened beverages. For avoiding high fat protein intake at baseline, five individuals were in pre-contemplation/contemplation stages and after two weeks of gameplay, three of those individuals moved into the action stage. Similarly, for avoiding high fat dairy intake there were six individuals in pre-contemplation/contemplation stages at baseline and after two weeks of gameplay, four of those individuals moved into the action stage. Additionally, there was no reported movement in intention to get 30 minutes of physical activity per day.

Knowledge

Following two weeks of MyHealthy Picks game play, individual participant overall knowledge scores significantly changed from pre to post-test (t=2.8, p= .008; n= 13). The overall number of correct answers was converted to a percentage correct (i.e., 27/30 is 90%). At pre-test individuals on average scored 81.6 (SD=15.4) and post-test was 91.8 (SD=6.9). Looking at the individual scores, 85% of participants had increases in their knowledge scores, one (8%) stayed at the same level (at 100%) and one (8%) participant's score slightly decreased. In terms of specific components, examination of pre-post physical activity knowledge approached significance (t=1.6, p= 0.07). Examination of healthy eating questions revealed a significant difference (t=2.67, p=.013) in knowledge of healthy eating between pre-test (67.04, SD=31.99) and post-test (88.89, SD=10.99). In summary, participants showed improvements in their knowledge of healthy eating and physical activity from pre-test to post-test.

Relative Neural Efficiency

We were able to collect fNIRS data from all participants during pre- and post-tests; because data reduction and analysis are complex, time consuming, and ongoing, we are reporting the results from the first participant for whom we were able to process both tests (Figure 4). The results suggest improvement in estimated RNE from pre-test to post-test for one participant. During the pretest, the participant expended a significant amount of cognitive effort during the exergame while performing relatively poorly (i.e., obtaining a low score) when answering the MHP questions during exergaming. After two weeks of practice (4 gameplays), this participant improved in RNE; that is, the participant answered more questions correctly using fewer neural resources. The participant moves from the low efficiency quadrant (high effort/low score) to the high efficiency quadrant (low effort, high score) after 2 weeks of practice (4 sessions). This pattern of change from low to high RNE is often associated with learning (Shewokis et al., 2015; Shewokis et al., 2017). While the results only represent one participant, they do indicate that, for at least this participant, the two-week educational exergame training appeared to enhance learning on the performance task. These results show promise that practice with the exergame may help to reduce cognitive load over time and underscore the importance of further research incorporating fNIRS measurement in health game research with older adults.

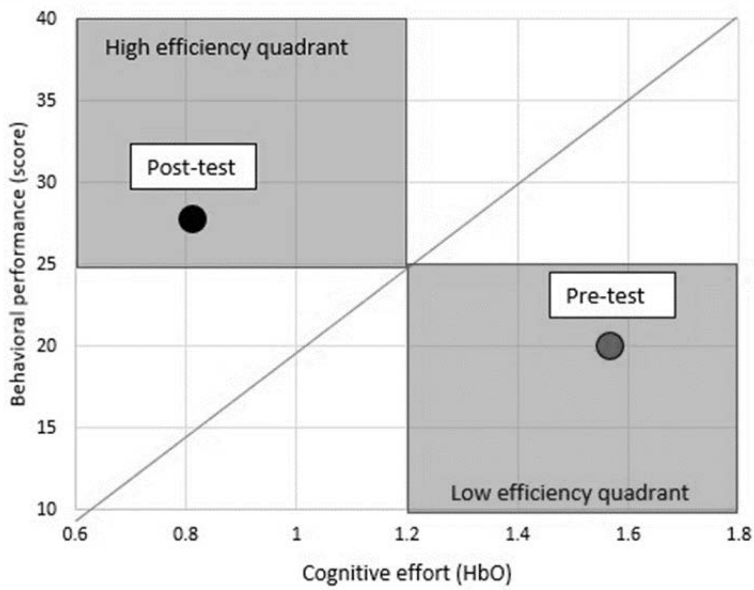

Figure 4. Changes from pre-test to post-test in an estimate of relative neural efficiency for one participant.

Discussion

This paper described the development process of an example multicomponent educational exergame, including multidisciplinary team science collaboration, application of aging theory, and use of community-engaged and user-centered approaches. Additionally, we presented our ongoing formative pilot work examining implementation and multiple aspects of an innovative educational exergame, including usability, acceptability, preliminary impact; and measurement of cognitive function. In this discussion section, we will discuss the programmatic implications of the use of this example exergame and health games in general within health promotion programs/activities for older adults attending senior centers.

Summary of Game Development Process

We highlighted our multidisciplinary team science approach and iterative user-centered, community engaged approach in the development of a multi-component educational exergame for older adults. The development of the game was informed by focus groups and iterative input from older adults in senior centers, along with senior center staff. Game development and implementation was conducted in the context of regular interactions with our multidisciplinary research and development team (including programmers) to share ideas and determine needed or desired adaptations. The game iterations evolved to include additional features to promote enhanced engagement, support cognitive functioning, and facilitate socialization among participants. The development of the game benefitted from the diverse perspectives and experiences of the team and the formative input from the older adults attending senior centers.

Summary of Formative Research

Iterative formative pilot studies were described focusing on different versions of the game. The results of the formative implementation pilot studies suggest that participants found the innovative educational exergame, MyHealthy Picks, to be acceptable on multiple levels, including the content, game features, mini-games, and social aspects of gameplay. The qualitative input helped to confirm the game aspects that were liked by participants, such as physical activity and healthy eating content; and areas that needed continued adaptation and refinement, such as instructions for gameplay. Following the 2-week implementation of the pilot game, senior center members indicated that they felt the game would have an impact on their knowledge and motivation related to healthy eating and physical activity. Participants also demonstrated pre-post improvements in their knowledge related to healthy eating and physical activity and with performance in cognitive challenges. Preliminary behavioral data suggested positive movement in their stages of change for avoidance of high-fat protein and avoidance of high-fat dairy intake. Further, the cognitive load results, while limited to a single case example, suggests that practice with the exergame may improve relative neural efficiency and reduce cognitive load in as little as two weeks (four gameplay sessions). The findings of our formative work on MyHealthy Picks are promising and align with the overall literature demonstrating the positive impact of health games along multiple dimensions of healthy aging in older adults. This exergame, and other such serious health games for older adults, should continue to be examined in large-scale studies to investigate effectiveness in diverse populations and settings. Future studies are also needed to further explore fNIRS assessment within game implementation. Larger scale implementation studies are planned and, if effective, this game may provide another in innovative tool to incorporate into senior center programming to be used in combination with other evidence-based health promotion programming to support healthy aging.

Program and Policy Implications

The literature on the positive impact of health games in various populations, specifically with older adults, supports their potential value. The accumulating literature, including reviews and meta-analyses suggests that such games should be taken seriously as a potential tool to support healthy aging (Hai et al., 2022; Stojan & Voelcker-Rehage, 2019; Xu et al., 2020).

Serious health games have multiple benefits as potential strategies to complement and combine with other health promotion programing. For example, they can be easily implemented in a variety of settings for independently living older adults, including in their homes and community centers where groups gather.

Senior centers represent one community setting that is generally accessible to a large portion of older adults and are influenced by policy and programmatic approaches to provide educational, nutritional, and food services for assisting older adults independent living (Schneider et al., 2014). The literature supports the notion that social engagement is a common reason for attending a senior center (Chang-Gusko et al.,2022; Pardasani & Thompson, 2012; Taylor-Harris & Zhan, 2011) as is participating in health and wellness related classes, such as health education, exercise classes, cognitive strengthening-related classes (Pardasani, 2019). A recent review of senior centers in Canada and in the United States (Kadowaki & Mahmood, 2018) note that a key focus on programming is health and wellness, with the most common reported programs related to nutrition, exercise, and blood pressure monitoring. Incorporating educational exergames in senior centers in combination with other evidence- based health promotion programs have the potential to enhance engagement and impact multiple aspects of healthy aging. Furthermore, these games may also promote social interaction while participating in fun, educational activities. Our findings provide preliminary support for acceptability, feasibility, and usability of MyHealthy Picks for potential use in a senior center setting.

As evidence is accumulated for the potential positive impact of health games, in general, on older adults, these games could be considered by organizations that evaluate and promote evidence-based senior center programs/interventions as an additional potential approach that may support healthy aging. The establishment of a substantial body of evidence on the positive impact could help inform policy relating to the use of exergames as part of the calculations used to determine state funding for senior centers. In the state of Delaware, exergames may fall under one of the program areas (physical fitness) used to assess service levels among the state's Grant- in-Aid eligible senior centers. Service and participation level information, in addition to demographic and geographic analyses, is used to determine public funding appropriations for these centers (https://www.bidenschool.udel.edu/ipa/content-sub-site/

Pages/Senior-Center-Grant-in-Aid-Funding-Formula-Program.aspx). This idea of federal funding and policies for health promoting activities may be further explored under the Title III-B Older American Act Funding (National Council on Aging, 2022b). This policy suggests that senior centers may be funded based on programs that promote aging in place which includes health promotion type programs.

Some senior centers already utilize some form of exergame, such as Nintendo Wii bowling, as a form of regular activity programming. Agencies that oversee senior centers could consider a policy to set aside time/space at centers to allow members to participate in exergames. For example, in the state of Delaware, there are over 100 senior centers with members who independently play Wii bowling on teams. They have established a league where senior center members compete against each other virtually and weekly submit their scores. This then serves as a way for individuals to interact socially as a team, be physically active, and have some fun competition on a regular basis. This is one specific example of how a region has successfully incorporated the use of an exergame in a population of older adults attending senior or community centers. The regular use of these exergames has continued and been sustained for ten years in this region and suggests that this type of exergame use can be easily implemented and sustained in community /senior centers.

Lessons learned through our pilot work on MyHealthy Picks provides guidance for programmatic senior center health game implementation. Senior center member interviews and focus group, and staff feedback suggest it is important to consider participant comfort (e.g., sitting/standing; difficulty level) in gameplay, involve a trained facilitator to provide a brief demonstration and instructions prior to game play, encourage social interaction through team play, and incorporate incentives for participating in the game play. Additionally, participants suggested that this game could incorporate opportunities for intergenerational game play by encouraging interaction between grandparents and grandchildren. Intergenerational exergame play may promote social engagement and education about health promotion, while being physically active.

Conclusion

Implementation of exergames, in general, and MyHealthy Picks as an example, may represent an innovative approach to engage, educate, facilitate socialization, and impact healthy aging in older adults attending senior centers or community centers. Accumulating evidence found in systematic reviews and meta-analyses, as well as our preliminary findings, support the impact of health games and underscore the importance of considering such evidence-based approaches, especially in combination with other health-promotion programs, for use in senior centers. Furthermore, the initial fNIRS research suggests that playing these types of exergames with an educational component may enhance learning on a performance task as indicated with brain activation. These initial results suggest the need for future studies of health game implementation incorporating fNIRS assessment to further understand the mechanisms by which cognitive load may be reduced. Larger scale implementation studies are planned and if effective, this game may be added as another innovative complementary educational option to healthy aging programming to consider for older adults at senior or community centers.

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