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Exergaming interventions for older adults: The effect of game characteristics on gameplay

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ABSTRACT

Purpose: Exergames can be used to train physical and cognitive abilities and have been shown to be effective in reducing the risk of falls in older adults. However, there is limited evidence about how people play exergames and how gameplay is affected by game settings and, thus, the potential training effects. The aim of this study was to investigate the impact of repeated exergaming sessions over 4 weeks and two game settings (difficulty level and game speed) on gameplay (performance, physical activity and perceived exertion) in older adults over a four-week exergaming intervention.

Methods: 28 independently living older adults (mean age 74.47 years; 14 females) played two different exergames (Puzzle and Fox) at two difficulty levels 3× per week for 4 weeks. Physical activity measures from an accelerometer at the lower back, performance as game scores from the exergaming system, and self-reported measures of physical and cognitive exertion were collected at sessions 1,2,3,6,9 and 12.

Results: For the Puzzle game, performance and physical activity increased significantly across the 12 training sessions. For the Fox game, an increased game speed was associated with increased performance, physical activity, and exertion across the exergaming sessions. Across all exergaming sessions, increasing difficulty by adding cognitive elements decreased the performance and amount of physical activity.

Conclusion: Game characteristics significantly influence how the exergames are played during a 4-week exergaming intervention. Hence, individual tailoring of the difficulty level and game speed is important. This study highlights the importance of understanding the interplay between game characteristics and gameplay during an exergaming intervention, thereby adding critical information for interpreting intervention effects – or the lack thereof.

1. Introduction

The risk for loss of physical and cognitive function increases with age, which can lead to an increased risk of falls (Laurence and Michel, 2017). Approximately one in three healthy community living adults over the age of 65 falls once a year (Rubenstein, 2006), making falls the leading cause of injury in this age group (Sterling et al., 2001). Exercise programs are recommended for the prevention of falls and have a greater effect if they involve balance exercises (Sherrington et al., 2017). Furthermore, there is evidence that cognitive training can also reduce risk factors for falls (Montero-Odasso and Speechley, 2018).

One way of training both physical and cognitive function is by playing exergames. Although originally designed for entertainment purposes, these computer games open up for full-body interaction and have become popular as a means to improve various parameters that influence the risk of falling (Donath et al., 2016; Chen et al., 2021) and to prevent falls in community-dwelling older adults (Sturnieks et al., 2024). Other intervention studies have shown positive effects of

Abbreviations: CBMS, Community Balance and Mobility Scale; DF, Degree of Freedom; EEG, electroencephalography; FES-I, Falls Efficacy Scale International; HFEN, Highpass Filtered followed by Euclidian Norm; LMM, Linear Mixed Model; PASE, physical activity scale for the elderly; RPE, rate of perceived exertion; SE, standard error; VAS, visual analogue scale.

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exergaming on specific outcomes related to falls, including balance (Donath et al., 2016; Leal et al., 2023), mobility (Chao et al., 2015; Jung et al., 2015; Gomes et al., 2018), gait (Gomes et al., 2018; Swanenburg et al., 2018), global cognition (Yen and Chiu, 2021), and executive functions (Eggenberger et al., 2016; Jiang et al., 2022). However, most of these studies are conducted as randomized controlled trials which typically measures outcome parameters pre and post intervention, but rarely during the intervention. Additionally, detailed description of training characteristics during the intervention is seldom provided (Wollesen et al., 2020). Consequently, exergames have been used as interventions without enough knowledge of what players do during gameplay. It is essential to better understand the impact of game characteristics on gameplay during the intervention to maximize the training effect for each player.

There are many different exergames available, with a similarly large variation in movements needed to control the games, from just standing, leaning while standing, moving upper limbs, and rotating the head, to dual tasks while standing, or moving the body forwards, backwards, and sideways (Tahmosybayat et al., 2018). Even within games that are controlled by stepping, different games have shown to lead to different movement characteristics (Skjæret-Maroni et al., 2016). Furthermore, game settings, such as increasing the game speed level or the difficulty level by adding a cognitive element, influence participants' play in terms of performance and movement characteristics (Anders et al., 2020; Müller et al., 2023; Skjæret-Maroni and Bardal, 2018).

In addition, it is often individual whether, and how participants respond to a training intervention in exercise–cognition research (Herold et al., 2019). Various individuals may perceive a different training load during the same training protocol, leading to potentially large heterogeneity in outcome variables if all play the same games. The training protocol should therefore be adjusted based on the individual response to a prescribed load (Herold et al., 2019). Tailoring training interventions individually is important to achieve specific training objectives. Therefore, it is necessary to monitor individual responses to training sessions to optimize the effect of an intervention. However, previous studies rarely describe whether and if so, on what basis, they individualize or tailor exergames.

Studies that monitored the training load of exergaming training are scarce. One exception is the study of Bakker et al. (2020) who monitored the rate of perceived exertion (RPE) and the performance in older adults and reported it for each exergaming session, enabling them to describe the change in performance and RPE over the training intervention in detail. The group was divided into one group playing on a stable and one playing on an unstable surface. They found that the unstable group perceived their exertion as higher compared to the stable group, and that the perceived effort can change over time and was dependent on the game content (Bakker et al., 2020). Measuring the perceived effort seems suitable to monitor and tailor the challenges of an exergaming intervention. An appropriate training protocol that adapts to improved skills over the course of the training intervention has been shown to produce greater training effects than training with constant demands (Wollesen and Voelcker-Rehage, 2014). However, little is known about how changes in relevant game characteristics, such as the level of difficulty and the speed of the game, affect the playing itself like movement or exertion during an exergaming intervention, although this knowledge is crucial to be able to tailor exergaming interventions effectively.

Therefore, the primary aim of the current study was to investigate the impact of repeated exergaming sessions over 4 weeks and two game settings (difficulty level and game speed) on gameplay (performance, physical activity and perceived exertion) in older adults over a four-week exergaming intervention. Changes in physical activity, perceived exertion, and performance were described throughout a 4-week exergaming intervention comparing an exergame in which game speed was individually tailored with an exergame which is not individualized, both played at two difficulty levels. The secondary aim is to investigate whether there is a change in physical function and fear of falling after the exergaming intervention, assessing physical function and fear of falling at the first and last day of the exergaming intervention.

2. Methods

2.1. Design and setting

An intervention study was developed over four weeks with six points of measurement. Ethical approval was granted by the Ethics Committee of Paderborn University and the study was conducted in accordance with the Declaration of Helsinki. It was registered retrospectively at the German Clinical Trial Register (DRKS00034786, 30.07.2024). All testing was carried out at the laboratory of the Exercise Science and Neuroscience Unit at Paderborn University, Germany.

2.2. Participants

Initially, 42 participants were recruited via advertisements in local newspapers and word-of-mouth. In an information session, everyone that had shown an interest in participation was informed in detail about the study, screened for inclusion and exclusion criteria, and given the opportunity to familiarize themselves with the equipment and laboratory environment before the actual data collection. If found eligible, they provided written informed consent to participate in the study, and training sessions were scheduled. To be included, they had to be independently living older adults aged 70 years or older without previous experience with exergaming. They were excluded if they had a history of neurodegenerative and/or neurological diseases, acute physical or mental problems that prevented them from playing an exergame safely for four weeks, or had surgery or injury to the back or lower extremities that affected their ability to move pain-free during the study period. In total 28 older adults) participated in the study. All participants completed all training sessions.

2.3. Procedure

The study protocol included 12 training sessions over four weeks with three sessions scheduled per week (Fig. 1). All training sessions were conducted one-to-one with the participant and the first author.

Each training session lasted approximately 45 min and included two different exergames (Puzzle & Fox) played at two levels of difficulty (Easy & Hard). The order of the four conditions was counterbalanced across all participants and sessions. Rest periods of 10 to 30 s, or longer if required, were given between the games. The Puzzle game was played with seven different images at both the Easy and the Hard difficulty level. The seven images were the same for all participants in all sessions. Depending on the performance of the subjects, a Puzzle game was solved within approximately one to two minutes. The Fox game was played twice at both difficulty levels for four minutes each. Following each game, participants were requested to rate their perceived exertion, differentiating between physical and cognitive exertion, using a visual analogue scale (VAS). Additionally, they indicated if the game speed level of the Fox game was perceived as too slow, too fast or appropriate.

To be able to describe changes during the intervention, and especially during the first week of habituation to the intervention, 6 points of measurement were implemented in sessions 1,2,3,6,9, and 12. In those sessions participants' movements and brain activity were recorded while playing the games. Before starting the games, the participants were equipped with a heart rate belt, an accelerometer on the lower back and feet, and a 64-channel EEG system. The current paper focuses on the accelerometer data, data from EEG and heart rate are published elsewhere (Müller et al., 2023). In addition, physical function (CBMS), fear of falling (FES—I), and the level of physical activity during everyday life (PASE) were evaluated in the first and last sessions.

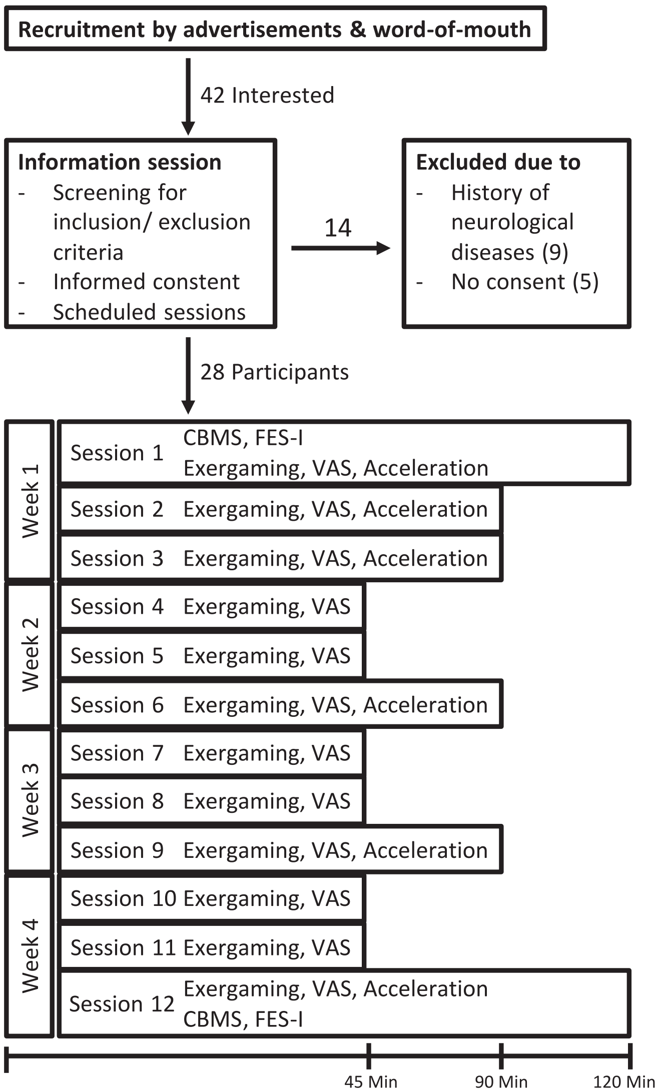

Fig. 1. Flowchart of the study design. Prior to the exergaming intervention, all participants were invited to accession for further information, familiarization with the laboratory and screening for inclusion criteria. 28 participants were included into the study. The intervention consisted of 12 training sessions with exergaming and recording of perceived exertion using virtual analogue scale (VAS). In session 1,2,3,6,9, and 12 additionally physical activity using accelerometer was measured during the exergaming. Additionally, at session 1 and 12, physical function (Community Balance and Mobility Scale – CBMS), and fear of falling (Falls Efficacy Scale - FES—I) were assessed. In this study, session 1,2,3,6,9, and 12 are analyzed.

2.4. *Exergaming system*

The exergames were chosen from the Silverfit System (SilverFit BV 3D, The Netherlands). The system uses a TV screen and a time-of-flight camera that records the body movements of the player in three dimensions within a 5 × 5 meter game area, corresponding to a 176 × 144 pixel array (Rademaker and Wiersinga, 2009).

The Puzzle game is controlled by leaning the upper body sideways without taking steps. The player's task is to solve a 5 × 5 pieces jigsaw puzzle. In the Easy condition, a puzzle piece appears on either the left or the right side and the player selects the puzzle pieces by leaning in the corresponding direction. In the Hard condition, two puzzle pieces appear on the left and the right side and the player selects the correct puzzle piece by leaning in the corresponding direction (see Fig. 2).

In the Fox game, the player controls a fox avatar on the screen by stepping left and right. In the simple Fox game, grapes fall from the top of the screen and the player's goal is to catch as many grapes as possible by placing the fox avatar underneath the falling grapes. In the Hard condition, additional branches are falling that must be avoided (see Fig. 2). All participants started playing the Fox game at the same game speed level (3 out of 10), after which the game speed level progressed individually from session to session. If a participant caught all grapes without hitting a branch or rated the game as too slow, the game speed level was increased at the next training session. Higher game speed levels lead to a higher number of grapes appearing on the screen, which were falling faster. In contrast, if the participant indicated that the game speed was too high during a session, the speed level was reduced at the next session. Table 1 shows the median speed levels across the intervention and whether the participants rated them as appropriate.

2.5. *Primary outcomes*

The game scores were directly exported from the Silverfit System and used as a performance measure. For the Puzzle game, the outcome parameter was the time needed to complete one image with lower scores indicating better performance. The times to complete the seven images were averaged within each difficulty level. In the Fox game, the game score represents the number of grapes caught. In the Hard condition, two points were deducted for each branch that hit the fox avatar. A higher score indicated a better performance. The Fox game scores for both times played at one session was averaged within each difficulty level. Due to technical problems during the recordings, 2.3 % of the game score data was missing.

Physical activity during games was measured using a triaxial accelerometer (AX3, Axivity, United Kingdom) placed on the lower back at the third lumbar vertebrae. The triaxial raw acceleration from the sensor was summarized to vector magnitude using the Highpass Filtered followed by Euclidian Norm (HFEN) method, with a 1-s window length (van Hees et al., 2013). For seven participants, >50 % of the accelerometer data were missing due to technical problems. These participants were excluded from further analysis of physical activity. Across the remaining participants, 15.7 % of the data were missing.

Rate of perceived exertion (RPE) was assessed using a virtual analogue scale (VAS). Following each exergame, the participants rated how physically and cognitively exhausting they perceived the games. The physical and cognitive exertion were rated independently on two scales for each game, but not separately for each level of difficulty. The VAS ranged from 1, “not exhausting at all”, to 10, “totally exhausting”. The VAS was transferred in 0.5 increments.

2.6. *Secondary outcomes and baseline measures*

Physical function and fear of falling were measured at sessions 1 and 12. The Community Balance and Mobility Scale (CBMS) evaluates higher level balance and mobility on 13 different tasks: “Unilateral Stance”, “Tandem Walking”, “180-degree Tandem Pivot”, “Lateral Foot Scooting”, “Hopping Forward”, “Crouch and Walk”, “Lateral Dodging”, “Walking & Looking”, “Running with Controlled Stop”, “Forward to Backward Walking”, “Walk, Look & Carry”, “Descending Stairs”, and “Step-Ups x1”. Each task is scored on a scale from 0 to 5. In the item “descending stairs”, an additional point is awarded for carrying a basket when descending the steps. The maximum score is 96 points, with higher scores reflecting better balance and mobility (Weber et al., 2018). Fear of falling was measured using the German version of the 16-item Falls Efficacy Scale–International (FES—I) questionnaire that measures the level of concern about falling on a 4-point scale (score 16–64) (Yardley et al., 2005), with higher scores indicating greater concern. The Physical Activity Scale for the Elderly (PASE) questionnaire assessed the level of physical activity of older people (Washburn et al., 1993) once after the intervention. Using the reported frequency, duration, and intensity level of activity for the previous week, a score ranging from 0 to 793 was

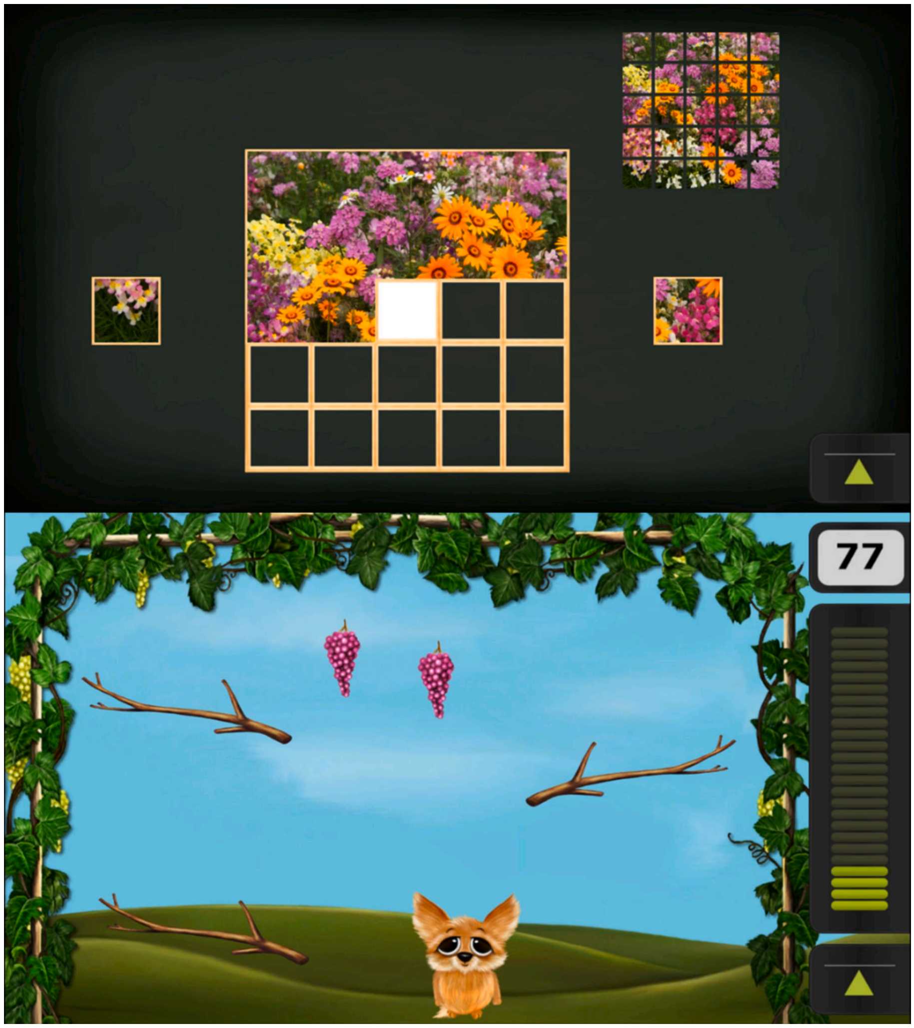

Fig. 2. Screenshot of the games. Top: Puzzle Hard: The game is controlled by leaning the upper body sideways to select the correct puzzle piece. In the Easy condition, one puzzle piece appears either left or right. Bottom: Fox Hard: The fox avatar is moved sideways by taking steps to the left or the right aiming to catch the grapes falling down the screen and avoiding the branches. In the Easy condition, no branches appear.

Table 1
Median with IQR and range for speed level in the Fox game across the exergaming intervention sessions and the number of participants rating whether they perceived the speed level as too slow, appropriate, or too fast. If they rated too fast or too slow, the game speed level was adapted accordingly at the next training session.

	Speed level Fox game		Rating of game speed level: The speed of the Fox game is		
	Median (IQR)	Min-Max	…too slow (n)	…appropriate (n)	…too fast (n)
Session 1	3 (0)	3–3	16	12	0
Session 2	4 (0)	3–4	7	21	0
Session 3	5 (1)	4–5	1	26	1
Session 6	5 (0)	4–7	3	25	0
Session 9	5 (0)	5–8	2	26	0
Session 12	5 (0)	5–8	0	28	0

calculated, with higher scores indicating higher levels of physical activity.

2.7. Statistical analysis

Descriptive statistics for all outcome measures are presented as means with standard error (± SE). Normal distribution of the data was evaluated with Shapiro-Wilk test, QQ plots, and histograms.

A linear mixed model (LMM) was applied to examine whether the mean game score, the mean physical activity score, or the mean physical and cognitive perceived exertion score changed during the 4-weeks intervention period, and/or across difficulty level of the game. In the LMM, subject was defined as random factor to account for the dependencies in the repeated measurements (random intercept model), whereas Difficulty Level (Easy, Hard) and Session (6 occasions) were defined as fixed effect factors. For the perceived exertion, only Session was defined as fixed effect factor since the RPE score did not distinguish between difficulty levels. To limit the number of parameters in the model, Session was treated as a continuous variable (range 1–12) and included as a second order polynomial function in the statistical model (2 terms only, linear and quadratic). To examine whether the change in game performance during the 4 weeks intervention period differed by difficulty level of the game, an interaction term between game level and session (modelled as a second order polynomial) was included in the statistical model (2 additional parameters added). To evaluate whether the change in game performance during the intervention period differed between the two games (Puzzle and Fox), a combined analyses of the two games were performed, and potential heterogeneity by game type was formally tested by inclusion of an interaction term between session and game type. To ease interpretations and limit the number of parameters in the model, these analyses were performed separately for each difficulty level of the game. *P*-values from likelihood ratio (LR) tests of overall effects of each single factor and their interaction effects are reported. The value of the LR statistics for the 3-way interaction is the change (absolute difference) in the value of the -2likelihood value from the model with all main effects +3 two-way interactions that is possible to construct from 3 grouping factors (game type, game level and session) to the final step when adding the 3-way interaction (a full factorial model). The degree of freedom (DF) is the additional number of regression parameters. The nominal significance level was set to 0.05 (p-values <0.05 regarded as statistically significant).

Distributions of the CBMS and FES-I data were skewed and potential changes between the pre- and post-measurement were assessed using the non-parametric Wilcoxon signed-rank test. All statistical analyses were performed using the IBM SPSS Statistics program package (version 29).

3. Results

3.1. Participants

28 older adults (14 female, mean age 74.57 ± 0.78 years, mean height 172.04 ± 1.86 cm, mean weight 76.85 ± 2.26 kg, mean PASE 170.08 ± 15.20) participated in the study and all completed all training sessions.

3.2. Progression of game speed level

All participants started at the game speed level 3 in the first session and increased their game speed level of the Fox game during the 4 weeks exergaming intervention. They ended up at a game speed level between 5 and 8 in session 12, which was perceived as appropriate by all participants (Table 1).

3.3. Performance

Participants improved their performance during the exergaming intervention (Fig. 3). The mixed effect model analysis revealed that the performance increased significantly for both games and Difficulty Levels over the 12 training sessions (Puzzle: LR-test statistics = 199.86, DF = 2, $p < 0.001$; Fox: LR-test statistics = 415.72, DF = 2, $p < 0.001$; Easy: LR-test statistics = 213.72, DF = 2, $p < 0.001$; Hard: LR-test statistics = 334.02, DF = 2, $p < 0.001$). For both games, the participants scored significantly higher in the Easy condition than in the Hard condition (Puzzle: LR-test statistics = 363.9, DF = 1, $p < 0.001$; Fox: LR-test statistics = 458.33, DF = 1, $p < 0.001$). Furthermore, the significant interaction effect between Difficulty Level and Session in the Puzzle game indicated that the participants decreased their time to solve a

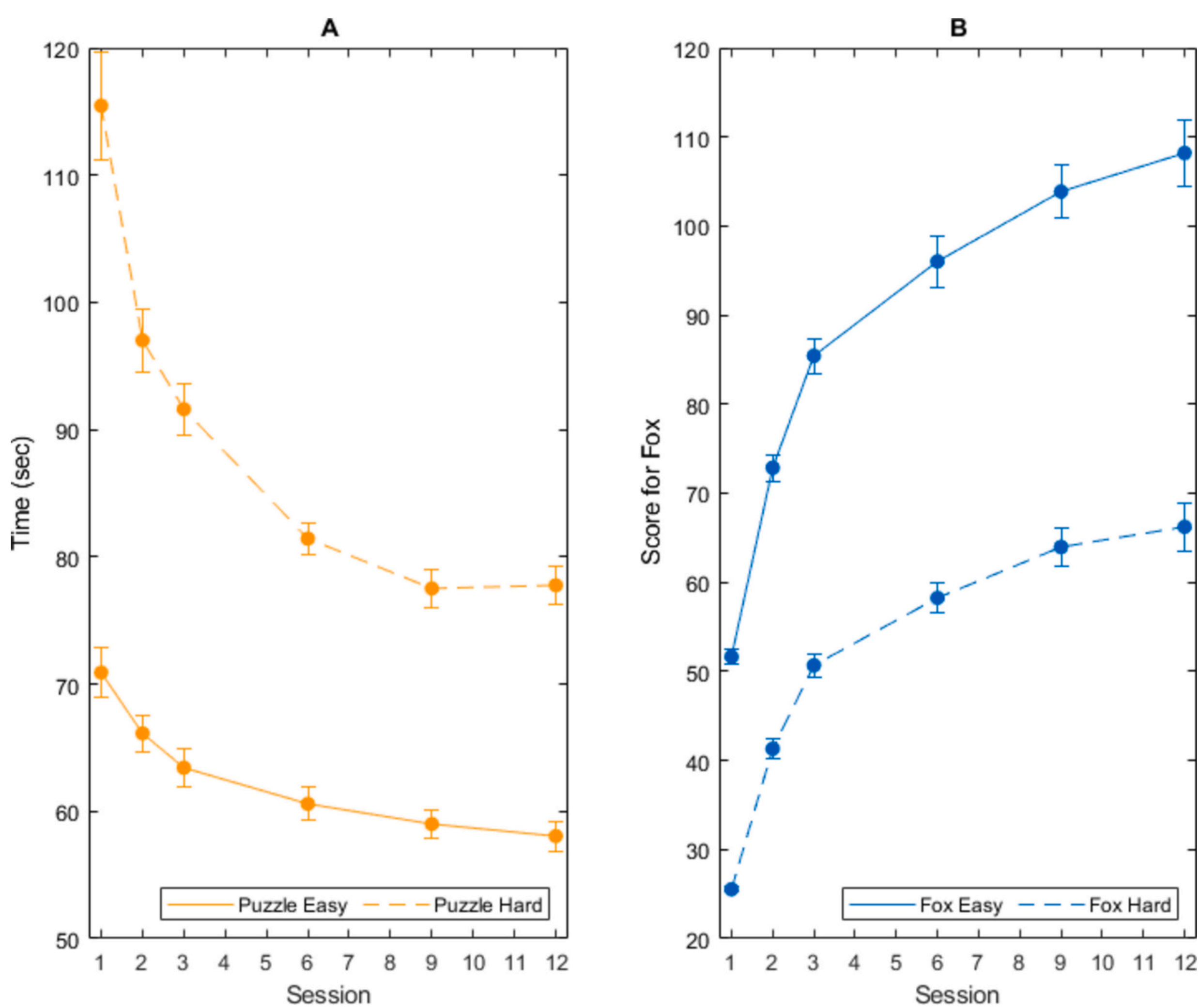

Fig. 3. Mean performance with SE across the 12 sessions. Panel A: Time needed to solve one Puzzle in the easy and hard condition. Better performance is indicated by a shorter playing time. Panel B: Game Score for the Fox game calculated from the number of grapes caught minus the branches that were hit. A higher score in the Fox game is associated with a better performance.

puzzle over the sessions and this decrease was greater in the Hard Puzzle game compared to the Easy Puzzle game (LR-test statistics = 80.20, DF = 2, $p < 0.001$). Opposite effects were found for the Fox game where the participants improved their performance over the sessions and this improvement in performance was higher in the Easy Fox game compared to the Hard game (LR-test statistics = 23.58, DF = 2, p < 0.001).

3.4. Physical activity

The participants increased their amount of movement across the training intervention (Fig. 4). Statistical analysis revealed a significant main effect of Session, indicating that participants increased their physical activity during gaming significantly across sessions for both Games and Difficulty Levels throughout the training intervention (Puzzle: LR-test statistics = 8.71, DF = 2, $p < 0.05$; Fox: LR-test statistics = 175.97, DF = 2, $p < 0.001$; Easy: LR-test statistics = 49.80, DF = 2, p < 0.001; Hard: LR-test statistics = 84.43, DF = 2, p < 0.001). The participants moved significantly more during the Fox game than the Puzzle game in both conditions (Easy: LR-test statistics = 182.8, DF = 1, $p < 0.001$; Hard: LR-test statistics = 98.76, DF = 1, $p < 0.001$). Furthermore, in both games, the amount of movement was significantly higher in the Easy condition compared to the Hard condition (Puzzle: LR-test statistics = 9.09, DF = 1, $p < 0.005$; Fox: LR-test statistics = 155.66, DF = 1, p < 0.001). The significant 2-way interaction Game*Difficulty Level (LR-test statistics = 76.80, DF = 1, $p < 0.001$) indicated that the difference between the Difficulty Levels was larger for the Fox game than the Puzzle game.

Additionally, a significant interaction was found between Game and Session for both Difficulty Levels (Easy: LR-test statistics = 67.66, DF = 2, p < 0.001; Hard: LR-test statistics = 41.25, DF = 2, p < 0.001), indicating that the physical activity increased more across sessions for the Fox game than for the Puzzle game. The significant interaction between Difficulty Level and Session (Puzzle: LR-test statistics = 8.8, DF = 2, $p < 0.05$; Fox: LR-test statistics = 8.08, DF = 2, $p = 0.05$) indicated that in the Puzzle game, physical activity increased more in the Hard condition compared to Easy across the exergaming sessions. For the Fox game, the effect was the opposite with a higher increase for Easy condition compared to Hard. In contrast, the increase in physical activity during the intervention period was more pronounced at the easiest level of the Fox game, possible reflecting that the most difficult level of the Fox game is more challenging for elderly people, both when it comes to cognitive and physical function. The contrast by game level on the effect of exergaming differed significantly between the Puzzle and the Fox game (LR-test statistics = 34.57, D.F. = 2, $p < 0.001$, test on 3-way interaction term).

3.5. Perceived exertion

After each training session, participants rated their physical and cognitive exertion for both games (Fig. 5). Perception of physical and cognitive exertion were significantly affected by Session indicating that the perceived exertion increased significantly throughout the exergaming intervention for the Fox game (LR-test statistics = 69.92, DF = 2, $p < 0.001$) but not for the Puzzle game (LR-test statistics = 4.84, DF = 2, $p = 0.089$). Overall, the participants' rating increased significantly across the exergaming interventions for both physical (LR-test statistics = 17.78, DF = 2, $p < 0.001$) and cognitive exertion (LR-test statistics = 35.69, DF = 2, p < 0.001). When comparing the two games, the Fox game was perceived as significantly more physically exhausting than the Puzzle game (LR-test statistics = 13.3, DF = 1, $p < 0.001$), but no significant differences were found for cognitive exhaustion (LR-test statistics = 1.3, DF = 1, $p = 0.254$).

Furthermore, a significant interaction effect between Game and

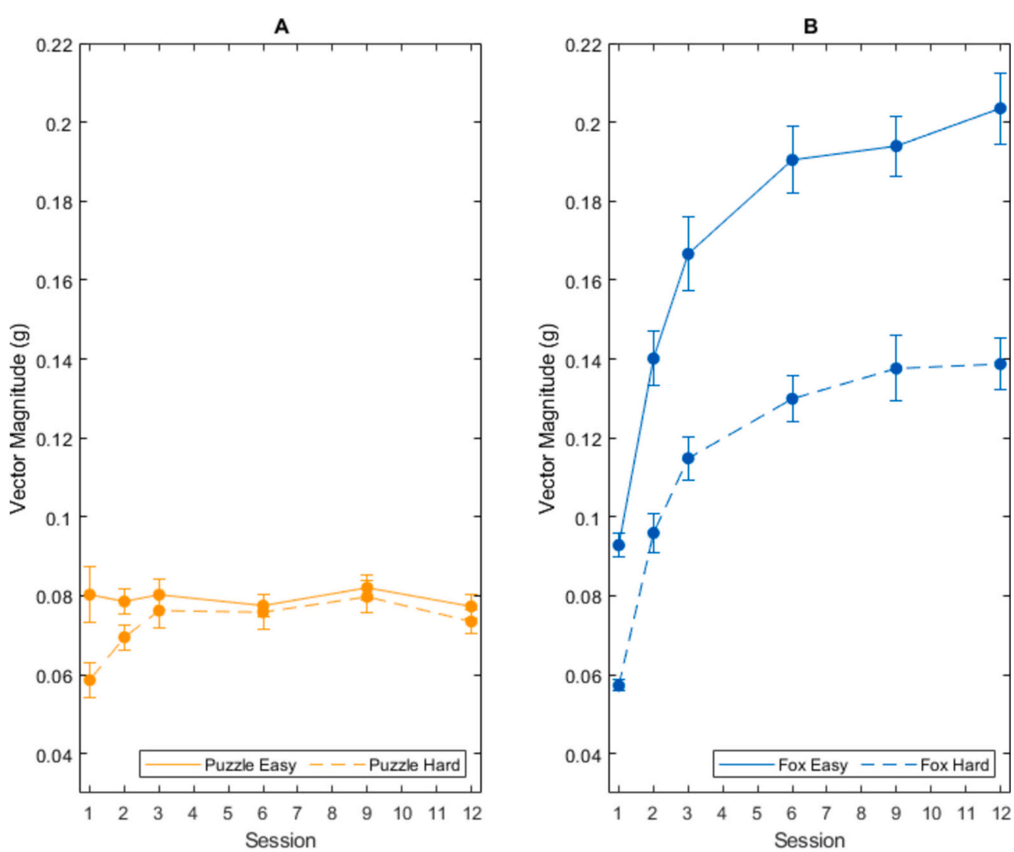

Fig. 4. Mean physical activity with SE across participants for each of the exergame sessions for the Puzzle game (A) and Fox game (B) in both easy and hard condition. An increased vector magnitude indicates a higher amount of physical activity during the game.

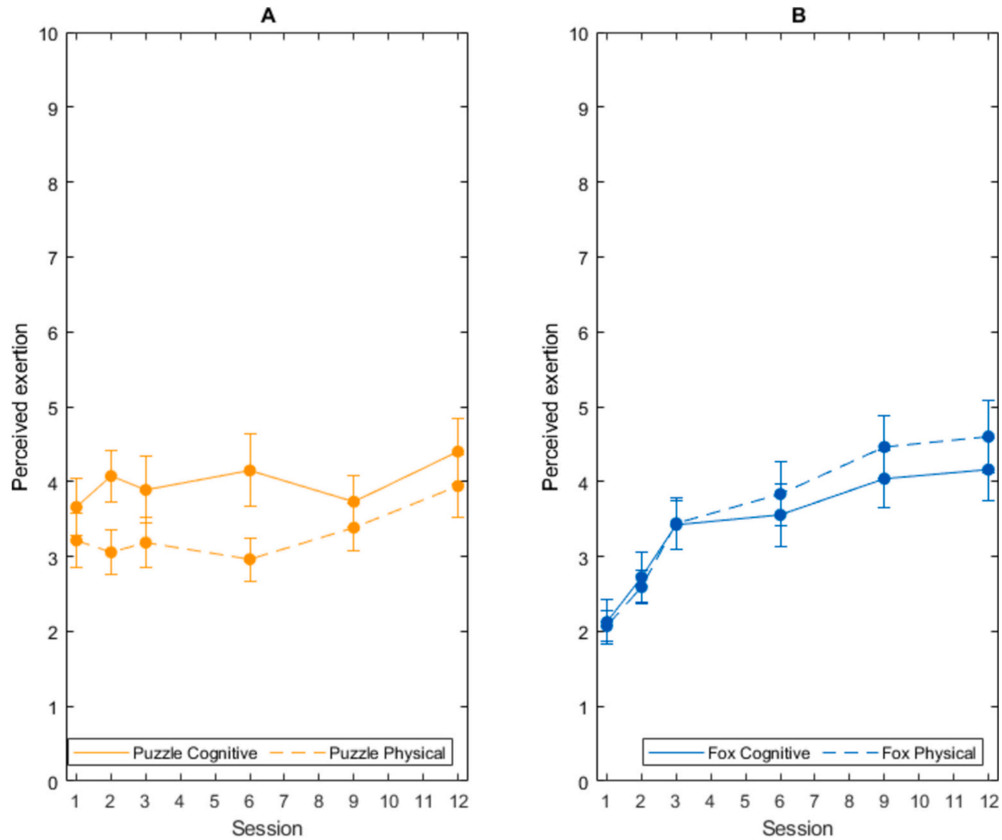

Fig. 5. Mean Rating of perceived exertion with SE across participants for the Puzzle game (A) and the Fox game (B), split into cognitive and physical exertion. The participants rated their exhaustion on a visual analogue scale from 1 (not exhausting at all) until 10 (totally exhausting).

Session was found for both physical and cognitive exhaustion (physical: LR-test statistics = 10.91, DF = 2, $p < 0.005$; cognitive: LR-test statistics = 21.60, DF = 2, $p < 0.001$) indicating that perceived exhaustion increased more across the exergaming sessions in the Fox game than in the Puzzle game.

3.6. Physical function and fear of falling

All 28 older adults had good physical abilities with high CBMS scores and low fear of falling scores at both the first and last sessions. For the CBMS, participants improved their score significantly across the exergaming intervention from 64.39 (±2.07) to 68.86 (±2.03) (Z = -3.49, $p < 0.001$). Participants' fear of falling was not significantly affected by the exergaming intervention (Z = -1.32, $p = 0.19$, pre: 18.09 ± 0.34, post: 17.68 ± 0.34).

4. Discussion

The results of this study showed that increased difficulty level by adding a cognitive element affected both the game performance and level of physical activity. During the 4-week intervention period, the participants showed improved performance. Furthermore, this study showed that tailoring game speed level based on individual performance and perception of game speed level was effective to realize an appropriate game speed for each participant. This resulted in a higher increase in performance, physical activity and RPE compared to the game with constant demands across the intervention. After the 4-week exergaming intervention, older adults increased their physical function, but their fear of falling was not affected.

4.1. Effect of difficulty level

In exergaming, increasing difficulty level often involves implementing an additional cognitive element to the game such as having to avoid an element or choosing between different options. As the results in this study showed, these elements affect older adults' gaming performance and the general amount of physical activity during gameplay.

Lower performances in the harder difficulty level indicate that additional cognitive elements indeed increase the demands, which is in line with previous studies (Anders et al., 2020; Müller et al., 2023). Furthermore, this effect persisted over the 4-week training intervention in both exergames, irrespective of whether the additional cognitive element expanded the number of options or needed to be avoided. Thus, changing the level of difficulty allows for increasing variation in exergaming interventions and adapting the demands of the games to the abilities of the participants.

However, additional cognitive elements also influenced physical activity and led to less overall movement in the more difficult levels of both games. This is consistent with previous cross-sectional studies that showed that an additional element can lead to shorter steps, reduced cadence, fewer arm lifts and reduced overall amount of movement in a stepping game (Anders et al., 2020; Müller et al., 2023; Skjæret-Maroni and Bardal, 2018). The present study confirms that this effect is maintained over a 4-week training intervention. One potential reason for reduced physical activity at more difficult levels might be the additional cognitive element in the form of the branches or a second puzzle piece, that complicated the game by requiring participants to focus on additional elements of the game in addition to their own movements. The ability to perform cognitive and motor tasks simultaneously generally declines with age and may lead to reduced movement performance when a dual task is made more cognitively demanding (Brustio et al., 2017). When using exergames as exercise in older adults, it is thus important to keep in mind that the addition of cognitive elements may have mixed effects. However, it cannot be ruled out that the design of the games is the reason for less physical activity (Anders et al., 2020). In the Fox game, the total number of grapes is lower in the Hard compared to the Easy difficulty level, meaning that less movement is required for the players to catch all the grapes. Additionally, when trying to avoid being hit by the branches, the older adults sometimes had to stop moving and wait for a branch to disappear when their fox avatar got "stuck" between the edge of the screen and the falling branches. This disruption to the gameplay also led to a decrease in older adults' total movement. When developing games, such waiting situations should optimally be avoided by allowing for instance solutions to move around the obstacle. On the one hand, additional elements may make the games more interesting and challenging cognitively, but on the other hand, they also make participants move less or in a different way. Thus, it is important to be aware that game settings determine whether the training stimulus should have a cognitive or physical effect. Hence, the game characteristics should be adjusted depending on the specific effects one aims to achieve.

4.2. Training effect

Participants significantly improved their performance on both games over the course of the exergaming intervention, reflecting a training effect. The shape of the performance curves showed that participants improved the most during the first three to six training sessions, and then reached a plateau. This is a typical finding in motor learning, as well as in previous exergaming studies (Swanenburg et al., 2018; Prasertsakul et al., 2018), and indicates that the participants reached the level of mastery for both games, which means that they are able to play the games (Hardon et al., 2021). To increase the performance further, the game characteristics need to be changed. In this study, the participants played the Fox game with a game speed tailored based on their perception if the game speed level was suitable or if they reached the maximum score it was increased automatically. To increase the performance further, a game speed level may needed that challenges the participants more.

Since the participants were not accustomed to playing exergames before the intervention, increasing performance may result from a mixture of understanding how to control the exergames efficiently in general (how far do I need to lean to select the puzzle piece) and how to play the two games in detail (I may rather miss one grape instead of being hit by a branch). In this study, the participants played always the same two games, and for the Puzzle the same images as well. The order of having to lean right or left was randomized during the Puzzle, nevertheless the participants may have gotten used to these images, and some reached a ceiling effect in the easy condition. To enable further improvement, modifying the game for instance by increasing the game speed level like in the Fox might be one option as well as a bigger variety in the chosen games.

4.3. Effect of game speed level

Although the Puzzle game was played at the same game speed throughout the intervention period, the level of game speed in the Fox game was adjusted during the 12 training sessions. In both games, the participants improved their game performance and increased their amount of movement during the 4 weeks of gameplay. However. the Fox game showed a larger increase in movement than the Puzzle game. This is in accordance with previous studies showing that training demands which adapt to changing skills over time achieve larger training effects than constant demands (Wollesen and Voelcker-Rehage, 2014). To achieve the largest training effects, exergames should neither be too easy nor too difficult. In the current study, the perceived challenge of the game speed level combined with the objective performance was used to individualize the game speed level for the Fox game. This approach seems to be effective, as all participants found a game speed level that they felt was appropriate. Furthermore, performance, physical activity, and rate of perceived exertion increased more for the Fox game than for the Puzzle game, which likely resulted from the adjustment of the game speed level in the Fox game. This may underscore that individualized progression is important in a training intervention, as it allows to challenge older adults with an appropriate training stimulus.

4.4. Physical function & fear of falling

Despite our training intervention being limited to only four weeks and the absence of a control group, our findings indicated that physical function improved without increasing fear of falling in older adults. Older adults who participated in the current study were living in the community with a high level of physical functioning already at baseline, as indicated by good balance and mobility scores (Knorr et al., 2010), high amount of physical activity in daily life (Washburn and Ficker, 1999), and low concerns about falling (Hauer et al., 2010; Delbaere et al., 2010). Nevertheless, we found that their balance and mobility was further improved after 12 sessions of exergaming within four weeks. This is in line with previous findings of positive effects of exergaming on physical function in older adults living in the community (Suleiman-Martos et al., 2022). Hence, this study supports the potential of exergaming interventions to improve physical functioning and thus improving fall risk factors in older adults. Furthermore, previous studies showed that exergames can reduce fear of falling in community dwelling older adults (Ge et al., 2022) and induce positive effects on fall prevention, especially if the games involve balance exercises (Sherrington et al., 2017). This study was not able to show any changes in the fear of falling since the group of healthy older adults already had low concerns of falling before the intervention. With a score of 18 pre intervention, on a scale ranging from 16 to 64, there was little room for improvement.

4.5. Critical remarks

The exergames introduced the participants to a new way of exercising, with new challenges in moving and dual tasking. Safety is an important factor when using exergames, both for the older adults and health care workers using it (Ringgenberg et al., 2022). Evidence indicates that exergames are safe for older adults, however most studies do not report whether any accidents occurred (Sattar et al., 2023). In the current study, no adverse events occurred while playing the exergames, indicating that exergaming in this group of participants can be safe to use. However, it is important to notice that all sessions were played in a lab environment with a researcher always present.

Physical activity during the game play was analyzed using the vector magnitude that describes the amount of movement per second, which is a function of time. In the Puzzle game, the participants always perform the same movement (25 times leaning to the side), but across the exergaming intervention they solve the puzzle faster so that the amount of movement per time increases. The total amount of movement during the game will however be approximately the same. In contrast, the playing time for the Fox game was always eight minutes divided into two games of four minutes per condition. To catch as many grapes as possible in this period, the participants had to take more and faster steps resulting in the total amount of movement during the game. When using exergames as an exercise tool, it is therefore important to be aware of the effect that the exercise load might decrease with increasing skills like it is the case in the Puzzle game in this study.

In this study, the physical and cognitive exertion were assessed for each game, but we did not distinguish between the difficulty levels. The Hard game condition included an additional cognitive element, which aimed to increase the cognitive demand. Future studies could ask for perceived exertion after each difficulty level to investigate whether this is affected by additional cognitive elements.

The intervention period of this study was rather short with four weeks only which is not enough to assess long-term training effects. Furthermore, the study protocol did not include a control group, hence changes in fear of falling and physical function should be interpreted with caution. The main aim of this study was to investigate how gameplay changes during an exergaming intervention depending on game settings. Therefore, we measured six times within the intervention period to describe those changes in detail, which is why the intervention period was limited to only four weeks. To make statements about long-term training effects and potential transfer effects, high-quality randomized controlled trials are needed as a next step.

5. Conclusion

This study monitored the effect of game characteristics on performance, physical activity, and perceived exertion during an exergaming intervention. Results showed that difficulty level, game speed level, and individualized tailoring influence gameplay in terms of physical activity and perceived exertion. Hence the choice of game settings influences potential effect that can be achieved from exergaming. To optimize targeted training outcomes, it is essential to consider the characteristics of the game. Alterations that yield positive impacts on certain aspects, such as enhanced cognitive demands, could potentially exert adverse effects on other parameters, such as the intensity of physical activity. In conclusion, our study highlights the importance of understanding how game characteristics and individual tailoring of exergaming interventions influence playing behavior. Moreover, the findings suggest that in order to interpret the effect of training studies, or lack thereof, it is essential to not only examine the outcomes before and after the intervention, but also monitor the participants load and performance during the intervention.

CRediT authorship contribution statement

Helen Müller: Writing – original draft, Methodology, Investigation, Formal analysis, Conceptualization. **Nina Skjæret-Maroni:** Writing – review & editing, Methodology, Conceptualization. **Ellen Marie Bardal:** Writing – review & editing, Formal analysis. **Beatrix Vereijken:** Writing – review & editing, Methodology, Conceptualization. **Jochen Baumeister:** Writing – review & editing, Methodology, Conceptualization.

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Declaration of competing interest

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