Designing for Movement Quality in Exergames: Lessons Learned from Observing Senior Citizens Playing Stepping Games

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Designing for Movement Quality in Exergames: Lessons Learned from Observing Senior Citizens Playing Stepping Games

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Key Words
Elderly · Exergames · Movement characteristics · Stepping · Falls

Abstract
Background: Exergames are increasingly used as an exercise intervention to reduce fall risk in elderly. However, few exergames have been designed specifically for elderly, and we lack knowledge about the characteristics of the movements elicited by exergames and thereby about their potential to train functions important for fall risk reduction. ***Objective:*** This study investigates game elements and older players' movement characteristics during stepping exergames in order to inform exergame design for movement quality in the context of fall preventive exercise. ***Methods:*** Fourteen senior citizens (mean age 73 years ± 5.7, range 65 – 85) played 3 stepping exergames in a laboratory. Each of the exergames was described with respect to 7 game elements (physical space, sensing hardware technology, game graphics and sound, model of user, avatar/mapping of movements, game mechanism and game narrative). Five movement characteristics (weight shift; variation in step length, speed, and movement direction; visual independency) were scored on a 5-point Likert scale based on video observations of each player and each game. Disagreement between raters was resolved by agreement. Differences in scores for the 3 exergames were analyzed with a multivariate one-way ANOVA. ***Results:*** The Mole received the highest sum score and the best score on each of the 5 movement characteristics (all p values <0.0005). LightRace scored the lowest of the 3 exergames on weight shift and variation in movement direction (both p values <0.0005), while DanceDanceRevolution scored lowest on step length variation and visual independency ($p < 0.03$ and $p < 0.0005$, respectively), and lower than The Mole on speed variation ($p < 0.05$). The physical space players used when exergaming and the on-screen representation of the player, affected movement quality positively as indexed by multiple weight shifts and variation in stepping size, direction, and speed. Furthermore, players' movements improved when playing speed-affected game progression and when the game narrative was related to a natural context. ***Conclusion:*** Comparing differences in game elements with associated differences in game movement requirements provides valuable insights about how to design for movement quality in exergames. This provided important lessons for the design of exergames for fall-preventive exercise in senior citizens and illustrates the value of including analyses of movement characteristics when designing such exergames.

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Introduction

The elderly population constitutes the single largest group of people requiring health care in modern-day society and their numbers will only increase further in the years to come [1, 2]. Long-term care costs for elderly continue to grow and are expected to double within the coming decades [3, 4]. To provide adequate health care to the growing population of elderly, we need to postpone dependence on health care by keeping elderly healthy and living independently as long as possible. The leading cause for institutionalization and loss of independence amongst senior citizens is falls and fall-related injuries [5, 6]. There is good evidence that fall risk and fall rate can be reduced by exercise programs that combine balance training with additional forms of exercise such as muscle strengthening and coordination, either delivered as group or as individual intervention [7].

Recently, attention has turned towards the use of serious videogames, so-called 'exergames', as a means to increase physical activity in different populations [8]. Games consoles such as Nintendo®Wii, Playstation®Move, and Microsoft®Kinect open up for rich, full-body interactive possibilities with computer games. Exergames are increasingly used in senior centers and retirement homes [9], as home-based exercise [10], and in research on exercise in the elderly [11]. However, one of the less explored aspects related to the utility of exergames is the extent to which they can provide effective training of specific physical functions such as balance, strength, or coordination. In order to serve as effective tools for fall prevention and rehabilitation, then, exergames need to be designed to elicit specific movement characteristics that are relevant for the function being trained.

Previous research has identified several relevant characteristics that should be part of exercise in order to be effective in fall prevention. As balance is the ability to anticipate and react to changes when moving around, balance exercises should include weight shifting such as occurring during stepping and walking [12]. Furthermore, stepping allows us to avoid obstacles and counter potentially destabilizing events such as slips, trips, and missteps. Impaired stepping responses in older persons have been associated with falls and when exposed to an external perturbation, previous fallers are more likely to take a step that is too short, too slow, or in the wrong direction, to collide one leg against the other during lateral compensatory stepping, and to be distracted when stepping under dual task conditions [13, 14]. In addition, for daily life stepping and walking to be adaptive, these functions must possess richness in both the temporal and spatial domains, consisting of the ability to make steps of different sizes at different speeds in different directions, dependent on the task at hand [15]. Finally, visual independency has been highlighted as an important quality of adaptive behavior [16]. Vision provides important information for prospective control of movements, and it is important to preserve the ability to take one's eyes off the feet or support surface without becoming disoriented or falling down [16]. In sum, for an exergame to elicit the movement characteristics deemed necessary in fall preventive exercise, it needs to induce weight shift, variation in step length, speed and movement direction, as well as promote visual independency from the feet and/or support surface. However, to what extent existing exergames succeed in eliciting these characteristic is an open question.

When playing exergames, the player's movements are affected by the game's sensor technology and game settings such as game task, intensity, and representation of the player's movements in the virtual world of the game [17–20]. The concept of exergaming and other applications of movement-based computer interaction have gained considerable attention in recent years, and several guidelines for exergame design have been constructed [21, 22]. However, how the exergames' hardware and software affect movement characteristics – and thereby movement quality – has not yet been a focus of study. This knowledge is urgently required if we are to design exergames that can be effective as part of fall prevention programs for senior citizens.

This paper aims to arrive at guidelines for designing exergames that can prompt fall-preventive exercise by investigating game elements, relevant aspects of stepping behavior during gameplay, and how these are related.

Methods

Participants

A convenience sample of 14 community-dwelling older adults (9 female, 5 male) participated in the study. To be included, participants had to be over the age of 65 years and able to walk safely without a walking aid. All subjects provided informed, written consent. The study was approved by the Norwegian Social Science Data Services, and conducted in accordance with the Declaration of Helsinki.

Apparatus

Three step-based exergames were chosen to be evaluated with respect to game elements and movement characteristics. These games were the open-source game DanceDanceRevolution (DDR; www.stepmania.com) modified by Schoene et al. [10], The Mole from SilverFit (SilverFit BV, Woerden, The Netherlands), and LightRace in YourShape: Fitness Evolved (Ubi Soft Divertissement

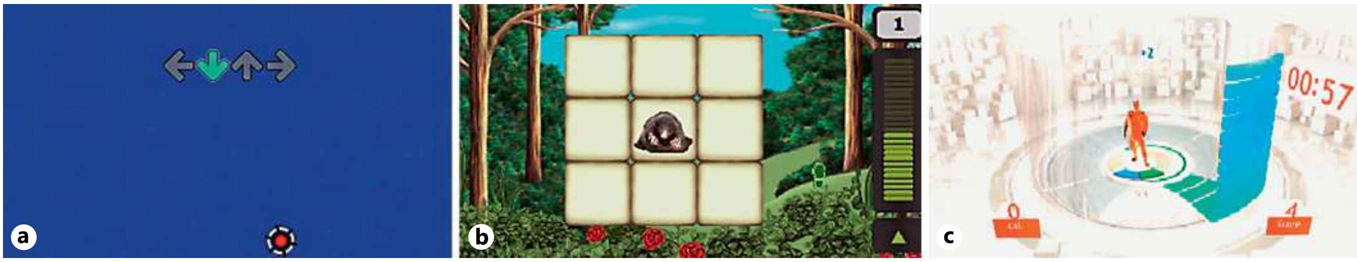

Fig. 1. The interfaces of the modified DDR (**a**), The Mole from SilverFit (**b**), and LightRace in YourShape: Fitness Evolved (**c**).

Inc., Montréal, Canada; see fig. 1). All games required the player to take steps in order to play the game and score points.

When playing the DDR, the player stands in the center of a pressure-sensitive panel (step pad) and controls the game by stepping left, right, forward, and backward. On a screen in front of the player, arrows drift from the bottom up to the target arrows on top of the screen, and participants need to time each step response to correspond with the drifting arrow passing over the target (see fig. 1a). After each step response, participants should return to the central panel. Feedback is given on each step in form of a word on the screen, Perfect, Good, or Miss. An additional cognitive load is included in the form of a pictured bomb rather than an arrow, in which case the step response should be inhibited. If participants fail to inhibit a step response, the bomb explodes on the screen to indicate the error. Playing is accompanied by music selected from a list.

SilverFit is a virtual reality rehabilitation system with several mini games specifically designed for senior citizens in exercise or rehabilitation settings [23]. The system uses a 3-D motion-sensing camera to detect the player's movements. In the current study, the mini game The Mole was played in 2 versions for 1 min each, Basic and Precision Control. In Basic, a mole appears at different areas on the screen that the player should step on to make the mole disappear and receive points (see fig. 1b). In Precision Control, an additional cognitive element is added in the form of a mouse that moves between the areas and should be stepped on before disappearing, and a ladybug that should be avoided. Stepping on a mole or mouse yields 1 point each, stepping on a ladybug reduces the game score by 2 points. All animals appear randomly on the screen, prompting the player to move in all directions.

LightRace in YourShape: Fitness Evolved uses a Kinect motion-sense camera to detect the player's movements and visualize these on the screen in the form of a full-body avatar. The player stands in front of the screen and has to step on the area that lights up around the avatar on the screen (see fig. 1c). At the easy level, 4 different areas can light up, 2 areas in the front, one to the left, and one to the right. Stepping on the correct area turns the specified area on the screen green, an affirmative sound is presented, a blue path shoots up, and the score increases. When stepping on the wrong area, it turns red without further penalty.

Procedure

The study was conducted in a usability laboratory at the Norwegian Research Centre for Electronic Patient Records (NSEP) at the Norwegian University of Science and Technology (NTNU), Norway. The main test area was set up with gaming equipment and offered enough space for participants to engage with the exergames. All sessions were monitored from an observation room and recorded using ceiling-mounted cameras. One researcher always stood behind the participants to ensure safety while playing the exergames. Each participant filled out a consent form and a questionnaire with background information regarding age, experience with technology, and physical activity. The 3 exergames were demonstrated to the participants before playing. All participants played all exergames in a counter-balanced order. All participants played DDR for one song ('That old black magic', lasting 3 min) at the easy level, The Mole from SilverFit for 1 min at Basic and 1 min at Precision Control, and LightRace in YourShape for 1 min at the easy level.

Game Elements

The game elements were described with respect to the external environment, that is, the physical space used for playing exergames, the internal functions of the game itself, and how each of the exergame technologies works compared to each other. In order to describe the game elements of the 3 exergames, 3 experts within the field of human computer interaction and usability evaluation played all the exergames, focusing on how the games differed.

Seven game elements were described: (1) physical space, (2) sensing hardware, (3) game graphics and sound, (4) model of player, (5) avatar, (6) game mechanism, and (7) game narrative. The physical space refers to the area in front of the screen that the players use to play each game. The sensing hardware technology refers to the hardware and sensor technologies used in each game. The game graphics and sound address the graphics that are used and the feedback mode. The model of the player describes how the game technology senses the person in order to give input to the game. An avatar refers to the representation of the player on the screen. The game mechanism refers to the rules of the exergame and how they adapt to the player. Finally, the game narrative is the representation of targets and the storyline that is followed in each of the exergames, i.e. the context of the game.

Movement Characteristics

Based on which movement characteristics should be present in stepping exercises in the context of fall prevention, the following 5 movement characteristics were chosen as important when exergaming for fall prevention: (1) weight shift, (2) temporal variation, (3) step length variation, (4) variation in movement direction, and (5) visual independency. Each of the 5 movement characteristics was scored on a 5-point Likert scale by 3 human movement scientists/physiotherapists. The scales ranged from 1 (bad) to 5 (very good). For weight shift, a score of 1 reflected virtually no change in center of mass, and a score of 5 a change in center of mass with vir-

Table 1. Description of the exergames with respect to game elements

	DDR	The Mole	Light Race
Physical space	Static – step pad Small: 90×80 cm	Static – detectable Large: 125×125 cm	Dynamic – detectable Small: 100×100 cm
Sensing hardware technology	Press-and-release step pad	Time-of-flight camera	Kinect camera
Game graphics and sound	2-D – simple Music Audio feedback Visual feedback	2-D – simple cartoon No music Audio feedback Visual feedback	3-D – advanced animation Music Audio feedback Large visual feedback
Model of user	No sense of bodily element	Position of feet	Centre of player
Avatar/mapping of movements	No avatar No mapping	Simplified avatar Mapping of feet	Avatar Mapping of player's body
Game mechanism	Constant time interval Hit target Avoid object	Player-dependent time interval Hit targets Avoid object	Player-dependent time interval Credit for speed Hit target
Game narrative	Target presented as arrow Object to be avoided presented as a bomb	Target presented as mole and mouse Object to be avoided presented as ladybug	Target indicated by light

tually every step. For temporal variation, a score of 1 indicated no variation in speed, while high variation in speed across steps gave a very good score of 5. For step length variation, same size steps during gameplay yielded a score of 1, while a combination of smaller and larger steps yielded a very good score. For variation in direction, a score of 1 was given when participants moved in one direction only, while movement in all directions gave a score of 5. Finally, looking down before each step gave a score of 1 on visual independency, while mostly looking at the screen yielded a score of 5.

To ensure common understanding of how to apply the scores, the 3 raters made a protocol on how to score each characteristic on the Likert Scale that was piloted on several videos. Videos were subsequently scored in the same order as the participants played the games. For each gameplay per participant, the raters watched that video section 5 consecutive times in order to score each of the 5 movement characteristics. After each viewing, the rates from all 3 raters on that particular movement characteristic were compared. Intraclass correlation coefficients across raters were ≥0.840 (range 0.840–1.0) for all characteristics for all 3 games. In case of disagreement, the raters explained why they arrived at that score, viewed the video section together once more, and decided by agreement upon the final score for that movement characteristic before moving on to the next gameplay.

Data Analysis

Mean and standard deviation for each of the 5 movement characteristics was calculated for each of the 3 games, as well as a total sum score of the 5 movement characteristics. The movement characteristics were analyzed using a multivariate one-way ANOVA (MANOVA) on the 5 movement characteristics and the total sum score, with Game as within-subject factor. All variables were within a normal distribution with no outliers as indicated by histograms, Q-Q plots, and descriptive statistics. The homogeneity of variance assumption was tested for all 6 variables, and was considered satisfied with nonsignificant Levene's F tests and Box's *M* test (p values >0.05). Post hoc tests were corrected for multiple comparisons using Bonferroni. Significance level was set at $p < 0.05$. All statistical processing was done in PASW (Predictive Analytics SoftWare) Statistics version 21.0.

Results

Participants' mean age was 73 years (SD = 5.7, range 65–85). All participants were independently living elderly in good health for their age. On average, they were physically active 2–3 h a week (range from never to nearly every day). All of the participants had previous experience with Internet and mobile phones, but only one participant had previous experience with game consoles.

As can be seen in table 1, the exergames differed with respect to the 7 game elements (see table 1). Regarding physical space and sensing technology, DDR uses a static press-and-release step pad which severely constrains the playing area and hence restricts possibilities to modify stepping movements. In contrast, both LightRace and The Mole use a motion-sensing camera that detects where the players are, allowing them to move freely in a larger area. Furthermore, LightRace uses a so-called dynamic playing area, meaning that the player's center of mass defines the game's center point. With respect to model of the user and mapping of the movements, both LightRace and The Mole use an avatar to map the players' movements on the screen. Whereas LightRace has an advanced 3-D avatar that maps

Table 2. Means ± SD (95% CI) of movement characteristics on a 5-point Likert Scale (with 5 as the best score) and of the sum score for the three games, with F values and p values from a MANOVA on Game

		DDR	The Mole	LightRace	F values	p value
Weight shift	(1–5)	3.29±0.61[a, b] (2.93–3.64)	4.43±0.94[a, c] (3.89–4.87)	2.43±0.65[b, c] (2.06–2.80)	3.38	0.050
Step length variation	(1–5)	3.00±0.00[a, b] (3.00–3.00)	3.93±0.62[a] (3.57–4.28)	3.50±0.52[b] (3.20–3.80)	49.40	<0.0005
Variation in direction	(1–5)	3.93±0.27[a, b] (3.77–4.08)	4.79±0.43[a, c] (4.54–5.03)	3.21±0.43[b, c] (2.97–3.46)	54.15	<0.0005
Temporal variation	(1–5)	2.86±0.53[a] (2.55–3.17)	3.43±0.76[a] (2.99–3.87)	3.00±0.88 (2.49–3.51)	17.02	<0.0005
Visual independency	(1–5)	3.29±0.83[a, b] (2.81–3.76)	5.00±0.00[a] (5.00–5.00)	4.86±0.36[b] (4.65–5.07)	84.50	<0.0005
Sum score	(5–25)	16.36±1.28[a] (15.62–17.10)	21.57±1.87[a, c] (20.49–22.65)	17.00±1.57[c] (16.09–17.91)	37.36	<0.0005

[a] Significant difference between DDR and The Mole. [b] Significant difference between DDR and LightRace. [c] Significant difference between The Mole and LightRace.

the entire body of the player, The Mole only displays the position of the feet on the screen. For DDR, there is no mapping of the player on the screen. Regarding game mechanism, the arrows in DDR drift over the screen in a constant time interval while the other 2 exergames have a player-dependent time interval; the faster the player hits the targets, the faster new targets appear on the screen. For LightRace, playing faster also results in exponentially increasing scores. Lastly, the storyline or game narrative differs between all 3 exergames. While the required action, stepping on targets, is the same in all 3 exergames, The Mole provides a context that more closely resembles a natural environment, a garden with different animals. The context of both LightRace and DDR is more abstract, with targets indicated by light or arrows.

Table 2 presents the scores on the 5 individual movement characteristics and the sum score. The Mole from SilverFit received the best sum score as well as the best score on each of the 5 movement characteristics. DDR and LightRace had approximately the same sum score, with DDR scoring lowest on variation in step length, variation in step speed, and visual independency, while LightRace scored lowest on weight shift and variation in direction. A MANOVA on the 5 movement characteristics and the sum score indicated that there was a significant Wilk's statistic, $\Lambda = 0.039$, $F(10, 4) = 9.81$, $p = 0.021$, and that the exergames differed significantly on the sum score and each of the 5 characteristics. See table 2 for F and p values for the main effect of Game. Post hoc tests indicated that the sum score for The Mole was significantly higher than for the other 2 games (both p values <0.0005). With respect to the individual movement characteristics, weight shift and variation in movement direction were significantly different in all 3 games, with The Mole scoring significantly better and LightRace significantly worse than DDR (both p values <0.0005). On step length variation and visual independency, DDR scored significantly worse than the other 2 games ($p < 0.03$ and $p < 0.0005$, respectively). Speed variation was significantly worse for DDR than for The Mole ($p < 0.05$).

Discussion

The aim of this study was to compare game elements and associated movement characteristics across 3 stepping exergames in order to arrive at guidelines for designing exergames that can prompt fall-preventive exercise. Movement characteristics of the players were shown to vary across the 3 stepping games. Playing The Mole from SilverFit resulted in the best overall movement quality as indicated by the highest sum score, weight shift, speed variation, and variation in movement direction. DDR scored lowest on step length variation, visual independency, and temporal variation, while LightRace in YourShape scored lowest on weight shift and variation in movement direction. The 3 exergames also differed in their game elements, most notably the physical space used during gameplay, type of avatar to represent the player, the game narrative, and whether the game sped up or slowed down depending on how fast or slow the player played the exergame. Relating these differences in movement characteristics to game elements can inform about how specific game elements may have affected specific movement characteristics elicited by the exergames. This will be discussed next.

Effects of Game Elements on Movement Quality

The rating of the movement quality of the players indicated that The Mole from SilverFit was the best exergame on each of the 5 movement characteristics. It is also

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the only exergame in this study that was specifically designed with the requirements of senior citizens in mind. It is tempting to conclude that this is due to the game elements of this exergame, and that we can use The Mole as an example of best practice when designing such exergames. However, by looking also at which exergames scored the lowest on different movement characteristics, we can arrive at a more detailed picture that provides additional information about exergame design.

LightRace Scored Lowest on Weight Shift

There might be several reasons why LightRace scored lowest on weight shift. Most importantly, the areas that the player should step on as they light up are aligned in a circle relative to the player's center of mass. If the latter changes, so does the position of the circle. This discourages players from taking (multiple) steps, while awarding them for tapping one foot on the lit up area while keeping the center of mass above the other foot. This latter strategy does not result in a complete weight shift and thus not in a good score. In The Mole, players achieve a more complete weight shift as they are enticed to move around a larger area in an attempt to chase moles and mice away from a garden. This latter aspect, the narrative of the game, addresses to what extent the required movements take place in a context that resembles a natural environment. In LightRace the goal is to step on an area that lights up around the player on the screen. This is not a natural context for daily life activity, and may be a second reason why LightRace scored the lowest on weight shift. Previous studies indicated that having 'real' physical objects that trigger known gestures that are related to everyday life is an important factor in designing full-body interactive games for elderly [e.g. 21, 24]. However, Lewis and Rose [25] also suggested that an exergame should be able to offer a variety of game environments that do not attempt to precisely mimic real life.

DDR Scored Lowest on Temporal Variation

The fact that DDR scored lowest on temporal variation may be due to several reasons. The most essential might be that in the modified DDR version used in the current experiment, the arrows that the players were to step on as they passed over the target, appeared at a constant time interval and moved at a constant speed across the screen. In other words, there was no progression or adaptive change in the game speed when a player was performing better or faster. This led to reduced temporal variation in players' movements. In contrast, the 2 other games provided new targets as soon as the user had stepped on the current target. Such adaptive changes in the game speed provide opportunities for more dynamic and complex movements, and offer the senior citizens increased possibilities to achieve higher game scores. Providing game diversity and progression of complexity are important factors to maintain the player's engagement [25]. As indicated in earlier research, providing a difficult enough challenge, the possibility for progression with increasing speed, and the ability to achieve high playing scores are important aspects for seniors [26]. Conversely, too high game speed may prevent elderly to continue to the next level of the game, which in turn may lead to lower adherence and uptake of the exergames [26]. Furthermore, high game speed might also induce 'cutting corners' behavior in the players, possibly resulting in reduced movement quality. Ideally, exergames should be designed in such a way that players cannot 'cheat' themselves to a high score through inappropriate movements [25].

DDR Scored Lowest on Step Length Variation

Not surprisingly, DDR scored lowest on step length variation. As the players are forced to step on predefined areas on the press-and-release step pad, their possibilities for varying step length are severely limited. This resulted in the same size step for all players throughout DDR gameplay, limiting the movement quality the player was able to achieve on this aspect. In contrast, the other 2 games provided larger floor space and more flexibility in where players could step, resulting in more variation in step length. Gerling et al. [21] recommended that full-body games for elderly should be adaptive to individual differences in movement area and calibrated according to individual player abilities instead of being predefined, to ensure that playing exergames becomes an accessible and enjoyable activity.

LightRace Scored Lowest on Variation in Movement Direction

Although LightRace enables stepping movements in all directions, the game level in the current study required stepping in sideways and forward directions only. This resulted in the lowest score on variation in movement direction. Being able to step in all directions from different starting points is important in everyday life in order to avoid stumbling and falling. Furthermore, previous research indicated that multidirectional stepping increases leg muscle activation as well and hence may play an additional role in fall prevention by improving lower extremity strength [27].

DDR Scored Lowest on Visual Independency

DDR was the only exergame in which players directed a significant part of their visual attention to the floor. It was also the only exergame that did not use an avatar to represent the player on the screen. This suggests that having real-time visual feedback of motion is important, and may contribute to game effectiveness by improving accuracy of movement prediction as well as postural stability [cf. 28, 29]. The Mole and LightRace represented the feet or the entire body, respectively, on the screen, thereby allowing players to disengage their visual attention from their feet and the floor and focus on the screen and environment instead. This improved movement quality with respect to visual independency. This illustrates the importance of representing the player as an avatar on the screen. However, the use of advanced 3-D animation, such as in LightRace, did not result in a higher score on visual independency (or any of the movement characteristics) compared to the representation of just the feet in The Mole. This suggests that information richness in terms of advanced graphics or use of a whole-body avatar may be less relevant for movement quality. Furthermore, the fact that the avatar in LightRace is mirrored might also have had a negative influence on the different movement characteristics, particularly with respect to forward/backward movements.

Limitations of the Study

There are several potential limitations of the current study. First of all, data were not collected in a controlled laboratory experiment, and movement characteristics were not objectively assessed using a motion capture system. However, the qualitative scores on the movement characteristics were highly correlated across the 3 movement experts. Secondly, we did not systematically collect data on participants' fall risk or fear of falling. Rather, the study's main focus was to which degree the different exergames elicited movement qualities of relevance for fall prevention exercise. Finally, exposure to the different exergames was short and not consistent across the 3 exergames. The latter was necessarily so because we used existing exergames that had different playing times. In order to avoid that the scoring of the movement characteristics would be affected by differences in playing time, overall scores on the Likert scale were given. Furthermore, our goal was not to investigate how game play may change with accumulated experience, but to provide the first informed reflections on how successful different exergames are in eliciting movement characteristics that are considered important elements in fall-preventive exercise and how this subsequently informs exergame design, two themes that so far have received little or no attention in the literature.

Design Guidelines

Drawing on the discussion above, we propose guidelines to successfully elicit each of the desired movement characteristics when designing exergames for fall prevention. Each guideline provides examples of how relevant movement characteristics in fall preventive exercise can be ensured when playing exergames.

Guideline 1: Weight Shift

Elicit weight shift in players by motivating them to move around a larger physical area and displace their center of mass. The narrative of the game can play a central role in eliciting weight shift by creating associations between the exergame task and real-life activities in players. One way to achieve this is to employ stepping targets that the player intuitively will attempt to press down rather than just touch or tap. For example, players may be more enticed to step on a mole or mouse to make these disappear from the garden as they can relate this to other real-life activities of stepping on physical objects. As movements resulting in complete weight shift are different from those involved in tapping (see fig. 2b, c), sensor technology capable of capturing full-body movements (e.g. Kinect) may also be utilized to distinguish between ideal and less ideal movements. One way to promote movement quality in players can be by offering more awards, points, or positive feedback when complete weight shifts are recognized during gameplay.

Guideline 2: Temporal Variation

Provide temporal variation in movements by offering adaptive changes in the game speed. One way to generate temporal variation is by dynamically changing the speed of the game, e.g. to match how fast the player performs the exergame tasks. Multiple variations in the game speed entice the players to adjust the speed of their movements as well. The temporal variation in the game can also be adaptive to the accuracy of the player's performance. If a player is not performing well, game speed could be reduced accordingly to allow the player to achieve more accurate movements.

Guideline 3: Step Length Variation

Promote step length variation by offering variation in exergame tasks. A fixed exergame task easily results in same-sized step lengths over a period of time. Providing

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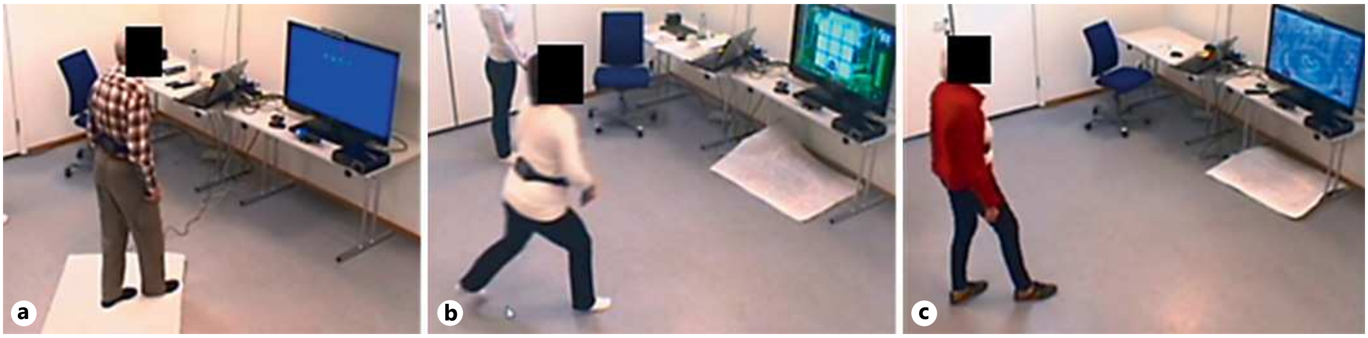

Fig. 2. Participants playing DDR (**a**), The Mole (**b**), and LightRace (**c**).

limited variation in exergame tasks may constrain the potential to increase flexibility in movements. Variation can be increased by a larger playing space and a game purpose that elicits variation in step length. For example, step length variation can be increased by presenting targets at different distances from the player.

Guideline 4: Variation in Movement Direction

Elicit variation in movement direction during the gameplay. Having a limitation in movement direction does not increase movement in terms of complexity. To ensure variation, the player should be enticed to step in all directions. One way to achieve variation in movement direction is to offer exergame tasks that require the player to move around by, for example, having stepping targets appear at different locations of the playing area.

Guideline 5: Visual Independency

Help the players to maintain visual independency and focus their attention on the exergame activity or task rather than on how to control the game. The visual attention or focus of the player during the gameplay should be on the exergame activity or task itself, not on where to place the feet in order to make a correct step. There should be no need for the players to focus on the ground, implying that proper information should be provided on the screen.

Conclusion

Relating differences in movement characteristics to differences in game elements provided several important lessons for the design of exergames that can be used in fall prevention programs in senior citizens. First of all, it is important to use a physical space and sensor technology that allows for movements in all directions with a variation in size and speed. Secondly, although the game should provide some representation of the player's movements on the screen, a fully animated 3-D avatar is not necessary to achieve the required movement quality in the player's gaming behavior. Thirdly, a dynamic time interval should be used in which the player receives credit for playing at higher speed. Finally, a natural mapping in the game narrative improves players' movements and increases game compliance. This study illustrates the benefit of investigating how different game elements may contribute to eliciting specific movement characteristics when designing for movement quality in exergames.

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