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Published online: 12 Apr 2018.

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Acceptability of a custom-designed game, CityQuest, aimed at improving balance confidence and spatial cognition in fall-prone and healthy older adults

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ABSTRACT

Virtual reality or video games show great potential as low-cost and effective interventions for improving balance and cognitive function in older adults. This research describes the design and acceptability of a serious game (CityQuest) aimed at improving balance confidence, spatial navigation, and perceptual function in older adults with the use of a virtual environment and a balance board. Community-dwelling healthy ($N = 28$) and fall-prone ($N = 28$) older adults were pseudo-randomly assigned to train with CityQuest or one of two control games developed to evaluate the specific effects of the CityQuest game. Following completion of 10 training sessions, participants completed questionnaires measuring their acceptability of the game as a falls-related intervention, game experience, and subjective cognitive or balance confidence changes associated with the game. The results revealed high acceptance scores of the game and positive game experiences for all three game conditions. Older adults prone to falls reported a greater reduction in fear of falling and greater improvement in vigilance following training, compared to healthy older adults. These findings suggest that a serious game based on VR technology that trains both motor and cognitive processes is perceived to be beneficial and acceptable to healthy and fall-prone older adults.

1. Introduction

The likelihood of experiencing a fall increases with age (Barrett et al. 2011; Campbell et al. 1990), with approximately 30% of adults over 65 years old experiencing at least one fall each year (Kenny, Romero-Ortuno, and Cogan 2009). Falls are a leading cause of disability and mortality in older age, accounting for 40% of all injury-related deaths (World Health Organisation 2007). Furthermore, experiencing a fall may also affect the mental well-being and quality of life of older persons (Painter et al. 2012).

The primary causal factors related to falls risk have yet to be identified, as the pathology of falls is multifaceted and involves complex interactions between physiological (Davies and Kenny 1996; Li et al. 2014), sensory (Kulmala et al. 2009; Lord and Menz 2000; Menant, Smith, and Lord 2008; Tromp et al. 2001), and cognitive (e.g. Donoghue et al. 2013) factors. Despite the large amount of studies on the causes of falls, prevention and rehabilitation are still lacking a comprehensive solution.

In particular, loss of postural steadiness or balance is recognised as an important intrinsic risk factor for falls. Balance control involves a complex process that relies on the optimal integration of information from the visual,

vestibular, proprioceptive, and auditory modalities (Angelaki and Cullen 2008; Chang, Uchanski, and Hullar 2012; Fetsch et al. 2009; Fetsch, DeAngelis, and Angelaki 2010; Lord and Sturnieks 2005). A review of existing falls prevention programs has shown that exercise and balance training interventions appear to be most effective at reducing the risk and rate of falls (Gillespie et al. 2012). A growing number of studies have used commercial or custom-made video games using the Wii Balance Board (WBB), Kinect, or Dance Dance Revolution dance mats to train physical and motor function in older adults (for reviews, see Nawaz et al. 2016; Skjæret et al. 2016). Several studies have shown that dynamic standing balance can be improved in older adults with video games that incorporate visual feedback of the player's centre of pressure position into the game using a balance board (Merriman et al. 2015; Szturm et al. 2011; Whyatt et al. 2015).

Several studies have also found that older adults have more difficulty managing posture or walking tasks concurrently with demanding cognitive tasks (Boisgontier et al. 2013; Maylor and Wing 1996; Siu et al. 2008; Woollacott and Shumway-Cook 2002). Greater dual-task motor-cognitive costs and worse executive function

have been linked with a higher occurrence of falls (Herman et al. 2010; Mirelman et al. 2012; Nagamatsu et al. 2011; Shumway-Cook et al. 1997). Given that motor and cognitive tasks appear to recruit shared resources when the tasks are sufficiently challenging, many studies have sought to improve dual-task motor-cognitive performance. This research has shown that training physical and cognitive functions simultaneously fosters larger improvements in single-task and dual-task performance compared to physical or cognitive training alone (Silsupadol et al. 2009; Theill et al. 2013; for review, see Wollesen and Voelcker-Rehage 2014). A recent review examining the effect of interactive cognitive-motor training interventions on reducing falls risk in older adults concluded that such interventions were able to reduce cognitive and physical risk factors for falls, as well as to improve balance confidence and fear of falling when training lasted four weeks or more (Schoene et al. 2014).

A key cognitive ability is spatial navigation, which has been shown to be adversely affected by the ageing process (for review, see Moffat 2009). Sensory integration is also important for path integration, a crucial component of spatial navigation in which the representations of one's current spatial location and orientation are continually updated over time (e.g. Berthoz and Viaud-Delmon 1999; Wiener, Berthoz, and Wolbers 2011). While path integration has been shown to deteriorate with age (e.g. Mahmood et al. 2009), Barrett et al. (2013) found that path integration was particularly worse for fall-prone relative to healthy older adults during a navigation task, particularly when visual inputs were reduced. Interestingly, some studies found that visuospatial tasks interfere more with postural control than verbal tasks in young adults (Barra et al. 2006; Riley et al. 2012). Completing spatial memory tasks during motor tasks also affects balance function in older adults (Maylor, Allison, and Wing 2001; Sturnieks et al. 2008), demonstrating a link between spatial processing and postural control. Computerised cognitive training interventions have been successful in improving cognitive processes in healthy older adults, including those with low familiarity with technology (see Kueider et al. 2012 for a review). Similarly, spatial navigation abilities of older adults can be improved with computerised training. For example, Lövdén et al. (2012) conducted a four-month-long spatial memory training programme within a virtual environment, combined with treadmill-walking, resulting in training-related improvements in spatial navigation ability of older adults relative to those who engaged in treadmill-walking alone.

Age-related changes in perception and attentional processing have also been linked to increased risk of falls in older adults (Lord 2006; Menant, Smith, and

Lord 2008; Nagamatsu et al. 2009; Owsley and McGwin 2004). Efficient visual processing is crucial for navigating in complex dynamic environments characteristic of our everyday life. Peripheral visual information plays a particularly important role in guiding locomotion (Marigold 2008). The ability to process information in the periphery declines with ageing, especially under conditions of divided attention (Sekuler, Bennett, and Mamelak 2000). Older adults are also worse at judging the time to contact of approaching objects in the presence of self-motion (Andersen and Enriquez 2006). Older adults are also less sensitive to changes in visual optic flow when walking (Berard et al. 2009) and require more time to process visual information when asked to execute precise steps or to walk among obstacles (Chapman and Hollands 2006, 2010; Keller Chandra et al. 2011). These studies suggest that improving processing of visual dynamic information across the visual field may be beneficial for reducing falls risk in older adults.

Recent years have seen a rapid increase in the use of technology in interventions designed to improve a range of functions in older age. Despite their success, one of the main challenges associated with behavioural interventions is older adults' willingness to engage with the associated technology. Older adults have shown a relatively low engagement with information and communications technology (Selwyn et al. 2003) and also report higher levels of anxiety than younger adults when administered a computer-based task (Laguna and Babcock 1997). Additionally, many commercially available digital gaming technologies are not adapted to the cognitive and sensorimotor capabilities of older adults (Gerling, Schild, and Masuch 2010; Whyatt et al. 2015). For example, the use of parallel input across user interfaces (e.g. pressing buttons on a control pad at certain time points while also maintaining postural control on a balance board) may be particularly difficult for older adults in terms of fine motor skills, dexterity, and cognitive load (Gerling et al. 2012; Whyatt et al. 2015).

However, older adults have been shown to be more positively disposed to technology that had an obvious benefit for their day-to-day activities (e.g. Melenhorst, Rogers, and Bouwhuis 2006; Mitzner et al. 2010). Indeed Wang, Rau, and Salvendy (2011) argued that the use of technology by older adults is influenced by its perceived usefulness or ability to meet their needs. Moreover, Diaz-Orueta et al. (2012) explored the motivating factors for older adults to engage with digital gaming technology and found that social interaction, experience of challenge in the games, the combination of cognitive and physical activities, and the learning of new skills were necessary components for sustained interest. Given the number

of barriers and facilitators for older adults to engage with gaming technology, it is important to assess the acceptability of novel technology-based interventions that are designed to target the needs of this particular cohort.

There is now clear evidence that interventions based on changes in everyday behaviour are successful at improving or preserving cognitive functions in older age (see e.g. Hertzog et al. 2008). However, for adults who may be fall-prone, their fear of falling may result in curbing their social activities (Donoghue et al. 2013), thus interventions based on changing social behaviours in a natural setting (such as going out and about more often) may be unrealistic for this population. Instead, a game-based intervention, that can be played in the comfort of their own home and designed to improve balance/ motor, cognitive, and perceptual tasks simultaneously, may be more effective. The use of an enriched virtual environment, in particular, that trains multiple cognitive functions in addition to balance and motor performance, may improve outcomes more than traditional exercise training due to its ecological validity as well as the involvement and interaction of additional physical and cognitive risk factors (Schoene et al. 2014), thereby reducing falls in older adults. Furthermore, the use of computer and video games which are designed to be engaging to older adults may increase motivation and lead to a lower attrition rate in the participation of older adults in the intervention (Kueider et al. 2012). Similar to the findings of Schoene et al., adaptive cognitive training that challenges and stimulates the participant is more likely to result in a transfer to outcome measures of cognitive performance from the intervention effects, particularly with at least 10 training sessions (Kelly et al. 2014; Klusmann et al. 2010).

On the basis of these findings, we reasoned that a game designed to train balance control whilst incorporating spatial navigation features that allowed for the visualisation of the position of the body, such as through virtual reality, and the addition of an adaptive, cognitively demanding task may have positive impacts on physical function and cognitive processes (Wollesen and Voelcker-Rehage 2014).

The current study describes the design of a video game aimed at improving balance confidence, spatial cognition, and perceptual function in fall-prone older adults, as well as the evaluation of its acceptability as a falls-related intervention to older adults. A secondary aim was to evaluate the enjoyment and experience of the game and its features, as well as to assess whether participants felt that the intervention had an impact on their cognition and balance confidence.

1.1. Summary of the CityQuest game

The CityQuest game, created by Testaluna© using Unity software, is a virtual cityscape in which the participant navigates by shifting their weight on a WBB to control the movements of a male or female character (see Figure 1). The main aim of the game is to guide the character to visit several target landmarks presented in a given order using the most efficient route possible. Each session begins with a learning phase where participants are familiarised with the target landmarks, followed by three levels in which they locate the same landmarks again. Thus, one game session requires learning the layout and landmarks of a virtual city. Whilst the participant navigates the virtual city, they also need to ensure that the character avoids all obstacles in their path by shifting their weight on the

Figure 1. A screen-shot from CityQuest depicting the virtual character whose movements were controlled via the participant's balance shifts on a Wii balance board. The participants' goal was to find the target landmark whose logo is shown in the bottom left. The red arrow on the aerial 2D map in the top left corner shows the character's current location within the city, which is updated as the character moves. The poles, bollards, and the puddle are examples of static obstacles to be avoided.

Table 1. Summary of the characteristics of the game conditions, including changes in task difficulty within and across sessions.

	CityQuest	Spatial-only control game	Obstacles-only control game
Processes trained and associated game tasks			
Balance control	YES – gameplay using weight shifting on balance board	YES – gameplay using weight shifting on balance board	YES – gameplay using weight shifting on balance board
Spatial cognition	YES – Learn new city layout every session by locating 4 target landmarks 4×	YES – Learn new city layout every session by locating 4 target landmarks 4×	NO – navigate in a new city each level to collect gems at intersections
Perception/attention	YES – avoid static and dynamic obstacles	NO – no obstacles present in the city	YES – avoid static and dynamic obstacles
Level progression within a session			
Learning phase	Locate 4 landmarks in a new city starting from different locations in city	Locate 4 landmarks in a new city starting from different locations in city	New city of certain size, avoid *static* obstacles
Level 1	Locate same landmarks in given order using most efficient route + avoid *static* obstacles	Locate same landmarks in given order using most efficient route	New city of certain size, avoid *static* obstacles
Level 2	Locate same landmarks in given order using most efficient route + avoid *dynamic* obstacles	Locate same landmarks in given order using most efficient route	New city of certain size, avoid *dynamic* obstacles
Level 3	Locate the same 4 landmarks using most efficient route + avoid *static and dynamic* obstacles	Locate same landmarks in given order using most efficient route	New city of certain size, avoid *static and dynamic* obstacles
Changes in task difficulty across sessions			
Navigation	Increase city size if navigation efficiency reached 80% in level 3	Increase city size if navigation efficiency reached 80% in level 3	Increase city size to match progression in CityQuest
Obstacles	Increase number and transparency of obstacles if avoidance rate > 80% in level 3	N/A	Increase number and transparency of obstacles if avoidance rate > 80% in level 3

balance board. The obstacles include static objects (e.g. puddles or bollards) or moving objects (e.g. moving balls or pedestrians). The presence and unpredictable nature of the moving obstacles promotes vigilance and distribution of spatial attention across the whole display.

Two simplified versions of the game were also created to act as control conditions to examine the effect of specific game characteristics on spatial cognition and obstacle avoidance. The Spatial-only game is identical to CityQuest, except that it does not contain any obstacles to avoid. The Obstacles-only game requires directing the virtual character through a city to collect gems as quickly as possible, whilst avoiding static and dynamic obstacles. The gems appear in the middle of intersections throughout the city. This game maintains the balance and obstacle avoidance components of CityQuest but is designed not to train spatial cognition (see Table 1 for an overview of all three game conditions).

The difficulty and complexity in all three games were varied both within and across game sessions, starting from an easy level and increasing in difficulty once the participant's performance reached a criterion level. This approach has been shown to lead to better learning and help to maintain motivation and arousal (Green and Bavelier 2008). Two different kinds of feedback and rewards were also incorporated to maintain motivation.

1.1.1. Balance control component
For all aspects of the intervention, balance control training was implemented by requiring participants to shift their weight on the WBB to control the location of the virtual character within the cityscape. Previous research has found the WBB to be an acceptable game interface

for use with older adults (e.g. Merriman et al. 2015; Whyatt et al. 2015). The character's movements were controlled using a discrete system where one lean forward followed by a return to an upright position signalled for the character to start walking, a second lean increased the speed of the character, a single lean backwards slowed the character, and a second lean backwards stopped the character. This method was preferred over continuous control because it required less effort and precision and was more suitable for older people. We also implemented the ability to do a 180° turn by leaning backward from a stopped position. This feature was required to obtain more accurate measures of participants' spatial navigation ability. Leaning left and right allowed for left and right turns to be made at intersections and to avoid obstacles while walking on a street. The use of the character, as opposed to a first-person perspective, was preferred as the visual representation of the character provided more precise feedback on the success of balance shifting. To accommodate different preferences, participants could choose to navigate at one of two speed levels during the game.

Prior to the intervention, participants were presented with a tutorial on how to use the balance board to control the movement of the virtual character. The tutorial provided a visualisation of participants' centre of pressure and guided the participant through separate steps illustrating how to start and stop walking, walk faster, turn around, turn at an intersection, find a landmark, and avoid an obstacle.

1.1.2. Training spatial cognition
Both the CityQuest game and Spatial-only control game began with a learning phase which served to familiarise

participants with the virtual city and the target land-marks. The learning phase consisted of the virtual char-acter appearing at a random starting point within the city. The name of the target landmark to be located was then presented on the screen and participants had to explore the city to find the target landmark. After find-ing the landmark, the character would appear at another random location in the city and the name of another tar-get location to be found was presented. This method encouraged participants to familiarise themselves with the city layout. A map of the city was always visible in the top left corner of the screen that showed a red arrow indicating the participant's current location and facing direction at all times (see Figure 1). Once the learning phase was complete, participants were required to locate the same four target landmarks within the same city, in the order that they were presented, to complete a level. Participants were encouraged to use the most efficient route possible. Feedback on their navigation performance was presented once they had located the target. To complete a session, participants had to find the four targets 3 times in levels 1, 2, and 3. In the City-Quest game, levels 1–3 contained different types of obstacles (levels 1–3 were identical in the Spatial-only version of the game).

Across sessions, the spatial navigation task became incrementally more difficult by increasing the number of streets and intersections in the city layout. There were a total of four complexity levels to the cityscapes corresponding to 8, 12, 16, and 22 intersections per com-plexity level from 1 to 4, respectively. This increase in task difficulty was contingent on the participant's per-formance reaching 80% navigation efficiency on level 3 of the previous session. Navigation efficiency was derived by dividing the distance of most efficient route to locate the target (e.g. 100 distance units) by the actual distance travelled (e.g. 120 distance units, to yield a score of 0.83). If a participant did not achieve a navigation efficiency score of 0.8 or above by Level 3, the same city complexity was repeated in the next session.

In the Obstacles-only control game, we removed all features of the game that specifically targeted spatial cognition. As such, participants were not required to memorise locations of landmarks or to attend to these landmarks. Their goal was to collect gems that appeared at all the intersections. To ensure that visual environments were comparable in both game con-ditions, the city size increased across sessions to cover the same range of city sizes as in the CityQuest version of the game. However, a new city was pre-sented for each of the three levels within a session to reduce the possibility of participants learning the city layout.

1.1.3. Obstacle avoidance component

For the CityQuest and Obstacles games, vigilance and spatial attention were trained by incorporating static and dynamic obstacles that participants had to avoid by adjusting their weight on the balance board. Obstacles were located in the lower and upper visual fields to pro-mote a distributed focus of attention. Examples of static obstacles include puddles, rubbish piles, poles, and dynamic obstacles were balls, trolleys, carts, and ped-estrians. Dynamic obstacles began to move toward the participant at a random time point when the character approached an obstacle, requiring quick reactions from the participants. Dynamic obstacles also had congruent sounds to enhance the perceptual qualities of the environment.

Within each session, level 1 of the game involved avoiding static obstacles only (see Figure 1), level 2 involved avoiding dynamic obstacles only, and level 3 avoiding both static and dynamic obstacles. The fre-quency of objects along any one street remained constant across levels within any one session. Across sessions, the obstacle avoidance task became more challenging if a participant avoided at least 80% of the obstacles on level 3 of the previous session. Obstacle complexity was increased by increasing the transparency of the obstacles, the number or density of obstacles on each street, and the speed of moving obstacles. Increasing object transpar-ency allowed the increase of the perceptual load by redu-cing the contrast of the obstacles with the background. Higher number of obstacles and higher obstacle speeds required faster visuomotor response times to avoid the obstacles. There were eight complexity levels of obstacle avoidance in total. If a participant did not achieve the sufficient obstacle avoidance rate at level 3 of the pre-vious session, then the previous level of obstacle avoid-ance complexity was repeated.

1.1.4. Feedback

We incorporated real-time feedback on performance to maintain motivation during the game. For the spatial navigation component (CityQuest and Spatial-only), a star system was used to reward efficient spatial naviga-tion once each target was located. Specifically, three stars were given for the most efficient route taken, two stars for medium efficiency, and one star for simply locating the target. A score of 20 points was also awarded for each target landmark located. For obstacle avoidance (i.e. CityQuest and Obstacle-only), both positive and negative feedback were used with one point awarded for each obstacle successfully avoided and two points deducted for each obstacle hit. This feedback was made salient by briefly flashing the character in red, playing a low-pitched sound tone, and showing the points

added/subtracted next to the character. In the Obstacle-only condition, further points were awarded for each gem collected. At the end of each level, a summary table showed the total time taken to locate the targets, total numbers of obstacles avoided and hit, and/or the number of gems collected, as applicable.

1.1.5. Implementation

The choice of apparatus and software implementation was driven by considerations of portability, reusability, and low cost. The WBB was chosen as the main game controller because it has been used previously with older adults with success and because it is affordable and accessible. We designed the game to forgo the use of additional controllers, such as remotes or joysticks to increase the portability of the games and reduce the cognitive and sensorimotor burden of the older adults. We chose Unity3D as the software platform due to its versatility and compatibility across all platforms.

An important requirement for CityQuest was to create an authoring toolkit that allowed the experimenters to control and configure multiple aspects of the games. This was accomplished with the use of simple configuration files in which the experimenters were able to pre-define scenes and scenarios by indicating the required city size and layout, number of target landmarks, types and number of obstacles, speed of navigation, background music, sound effects, etc.

Each game session also generated a detailed record of the game play allowing the experimenters to track participants' performance on a range of measures, including time taken to locate a target landmark, number of wrong turns made, total distance travelled for each level of the game, number and type of obstacles hit, average speed of movement, etc. A detailed analysis of some of these performance measures is reported elsewhere (see Merriman et al., forthcoming).

2. Methods

2.1. Participants

Participants were recruited by advertising through local ageing organisations and local media within Dublin, and all were community dwelling. We targeted older adults with and without a history of falls in our recruitment materials. A total of 86 older adults volunteered to take part in the experiment and completed the screening process. Of this group, 70 subsequently took part in the intervention on the basis of our exclusion/inclusion criteria (described below) but of this group, 14 failed to complete the intervention: 5 due to ill health and 9 due to the time commitment involved. A final total of 56

participants (35 female; $M = 71.82$, SD = 4.64, range 65–84) successfully completed the study.

The inclusion criteria were to be aged 65 years or older, have normal or corrected-to-normal vision and hearing, have no evidence of cognitive impairment, have no diagnosis of vestibular disorders, be able to walk without aid, and being able to follow instructions for testing. For all participants, we confirmed age-normal cognitive function (Montreal Cognitive Assessment; MoCA; $M = 26.93$, SD = 2.03; Nasreddine et al., 2005), age-normal visual acuity (ETDRS acuity chart; $M = 0.09$ logMAR, SD = 0.1) and contrast sensitivity (Pelli-Robson Contrast Sensitivity Test; $M = 1.93$, SD = 0.07), and hearing ability (Hughson–Westlake Audiogram at 4 kHz; $M = 33.81$ dB HL, SD = 15.99). None of the participants reported a history of psychiatric or neurological illness. Within the final sample of 56 participants, 28 were classified as 'fall-prone' due to having experienced at least one fall in the absence of obvious environmental hazard (Todd and Skelton 2004), and the other 28 participants were classified as 'healthy', with no history of unexplained falls in the last five years. The experiment protocol and recruitment procedures were approved by the School of Psychology Research Ethics Committee, Trinity College Dublin prior to the start of the study. Accordingly, all participants provided informed, written consent prior to taking part in the experiment.

2.2. Testing environment and apparatus

Testing and training took place in a quiet laboratory at Trinity College Dublin. There were two set-ups: (1) a Dell Alienware Aurora 875W computer connected to a 50′ Sony Bravia LED-backlit LCD flat panel display with a refresh rate of 120 Hz, and (2) a Dell Optiplex 7010 computer with a refresh rate of 60 Hz connected to a standard projector directed at a white screen. A Nintendo 'Wii Balance Board' (Nintendo, Kyoto, Japan) was connected to each PC via Bluetooth. Each WBB was situated on the floor approximately 2 m away from the display. For safety and comfort, the WBBs were embedded into a compliant surface mat that was flush with the platform floor. A waist-high support frame was embedded in the mat around the WBB and surrounded the participant on three sides providing safety and support (Figure 2). Sound was presented via standard wired or wireless headphones. Having two set-ups allowed us to train two participants simultaneously. A large black curtain separated participants to prevent distraction. Training with the LCD display or with the projector was counter-balanced across all participants such that each participant performed five training sessions with the LCD display and five with the projector.
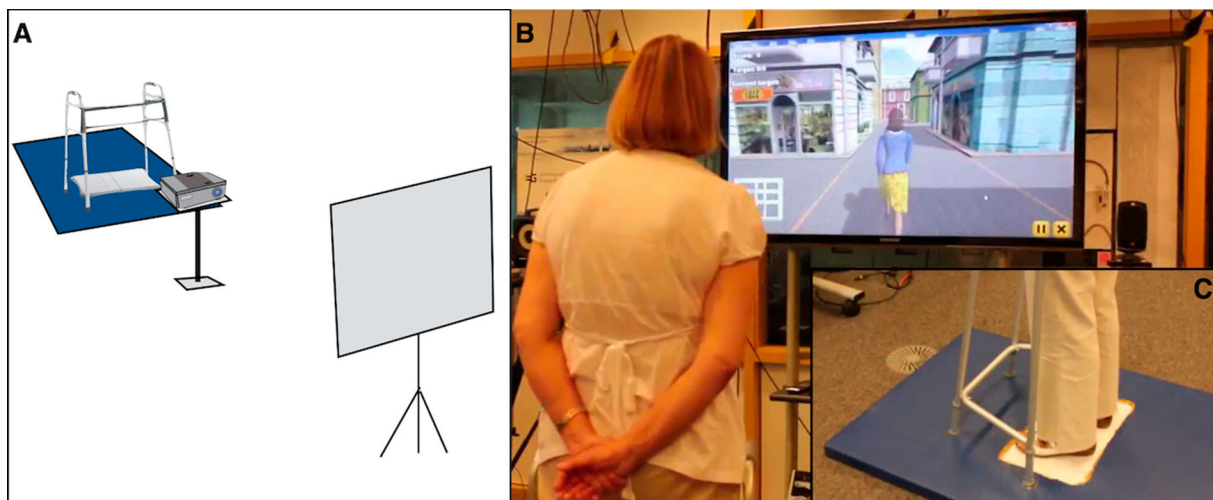
Figure 2. Apparatus used during the delivery of game training. A surround platform was included to provide additional safety.

2.3. Study design and procedure

After completing the cognitive and sensory screening assessments as described in the participant section, participants were assigned to one of the three game conditions in a pseudo-random order, such that the number of healthy and fall-prone older adults (as well as male and female participants) was approximately equal within conditions. Specifically, 11 fall-prone and 10 healthy older adults were allocated to the CityQuest game; 11 fall-prone and 9 healthy older adults to the Spatial-only condition, and 6 fall-prone and 9 healthy older adults to the Obstacles-only condition. They then took part in two pre-training sessions, where they were evaluated on several measures of balance confidence, spatial cognition, executive function, perception, and neuroimaging (see Merriman et al., forthcoming; Merriman 2015; O'Callaghan et al. 2018, for further details). The pre-training sessions were then followed by 10 training sessions, with an average of two sessions per week over 5 weeks. A minimum of 1 day break was required between sessions to allow for sufficient levels of rest and recovery. Training sessions lasted approximately 60 min. After the last training session, participants completed two post-training sessions identical to the pre-training sessions. At the end of the post-training assessments, participants were asked to complete the questionnaires described below.

2.4. Measures

For the purpose of this study, the dependent variables included different measures of acceptability as outlined below.

2.4.1. The Attitude to Falls-related Interventions Scale

The Attitude to Falls-related Interventions Scale (AFRIS) (Yardley et al. 2007) was used to assess participants' attitude to the game as a falls-related intervention. The AFRIS is a validated measure of the acceptability of falls-related interventions (Prevention of Falls Network Europe 2006) (range 6–42, higher scores reflect a greater degree of acceptance of the intervention). High scores, indicating positive attitudes, are defined as 28/42 or above (Mansdorf et al. 2009). The AFRIS uses a 7-point Likert scale, where the participant rates how much they agree or disagree with each statement (1 being strongly disagree and 7 being strongly agree). The questionnaire is based on the 'Theory of Planned Behaviour' (Ajzen 1991), which illustrates how beliefs and attitudes can predict intentions and behaviour. It comprises six items: expectations of the objective benefit of the intervention (item 1; 'I felt that doing the training intervention was good for me'); expectations of the subjective experience of the intervention (item 2; 'I felt that doing the training intervention made me feel confident'); social influences (item 3; 'Other people whose opinions matter to me (e.g. family, friends, doctor) thought it was a good idea for me to do the training intervention'); perceived behavioural control (item 4; 'I felt that it was easy for me to do the training intervention'); identity (item 5; 'I am the kind of person who should do the training intervention'); and intention (item 6; 'I intend to do the training intervention if I am offered the opportunity in the future').

In addition, to assess the willingness to continue with the training in the future, we also asked participants how likely they were to purchase a balance board, recommend the training to a friend, and how frequently they would

play the game at home if they had the possibility to do so. These items were scored on a 5-point scale, from 1 (not likely at all) to 5 (extremely likely).

2.4.2. Game experience questionnaire

Subjective experience of the game was evaluated with the Core and Post-game modules of the Game Experience Questionnaire (GEQ) that evaluate users' experience during and after the game, respectively (IJsselsteijn, de Kort, and Poels, forthcoming). Although the GEQ has previously been used in studies with older adults (Gerling, Schulte, and Masuch 2011; Nacke, Nacke, and Lindley 2009; Nap et al. 2015), its validity and reliability have not been demonstrated in this cohort. Therefore, we examined the internal consistency of each component using Cronbach's α prior to analysis. The Core questionnaire assesses game experience on seven components using 33 rating scale items with scores ranging from 0 ('not at all') to 4 ('extremely'). Internal consistency was high for immersion (6 items, $\alpha = 0.80$, 95% CI [0.72, 0.88]), flow (5 items, $\alpha = 0.69$, 95% CI [0.56, 0.81]), competence (5 items, $\alpha = 0.92$, 95% CI [0.88, 0.95]), positive affect (5 items, $\alpha = 0.88$, 95% CI [0.84, 0.93], and challenge (5 items, $\alpha = 0.64$, 95% CI [0.49, 0.79]). Consistency was poor for negative affect (4 items, $\alpha = 0.41$, 95% CI [0.16, 0.66]) and tension/annoyance (3 items, $\alpha = 0.57$, 95% CI [0.39, 0.76]), but dropping one item per component (items 8 and 22) led to improved consistency for both negative affect (3 items, $\alpha = 0.64$, 95% CI [0.49, 0.79]) and tension/annoyance (2 items, $\alpha = 0.62$, 95% CI [0.43, 0.81]). For the Post-game module, internal consistently was high for two components: positive experience (6 items, $\alpha = 0.87$, 95% CI [0.81, 0.92]), and tiredness (2 items, $\alpha = 0.76$, 95% CI [0.64, 0.88]). Consistency was very poor for negative experience (6 items, $\alpha = 0.44$, 95% CI [0.24, 0.64]) and return to reality (3 items, $\alpha = -0.05$, 95% CI [−0.42, 0.32]), as items 11, 6, and 17 were negatively correlated with their composite scores. Dropping those items led to improved consistency for negative experience (4 items, $\alpha = 0.65$, 95% CI [0.5, 0.79]) and return to reality (2 items, $\alpha = 0.63$, 95% CI [0.45, 0.80]). Consequently, we calculated component scores after excluding data from items 8, 22, 11, 6, and 17. Higher scores reflect a better experience for immersion, flow, competence, positive affect, and positive experience, while lower scores reflect a better experience for negative affect, tension/annoyance, challenge, negative experience, tiredness, and return to reality.

2.4.3. Enjoyment of game features

We used a custom questionnaire to obtain participants' evaluations of particular game features. This questionnaire asked participants to rate from 1 ('not at all') to 5 ('extremely') how much they liked the following game components: the way the city looked, the background music, the other sounds effects (e.g. footsteps etc.), the character (which represented the participant), as well as the obstacles and the pedestrians (for the CityQuest and Obstacles games).

2.4.4. Subjective improvement

To evaluate subjective improvements following the intervention, we asked participants to rate from 1 to 5 how much they thought that engaging in the training improved the following areas of their cognition and balance confidence (1 being 'not at all' and 5 being 'extremely'): vigilance, ability to find one's way around, memory, concentration, balance confidence, and reduced fear of falling. Note that objective measures were obtained at another time and will be reported elsewhere.

2.5. Analysis

Statistical analyses and data visualisation were performed in R (R Core Team 2014) using the psych and ez packages (Revelle 2018; Lawrence 2016) and SPSS version 22. Rating scale questionnaire data were analysed using univariate ANOVAs, with training game (3: CityQuest, Spatial-only, Obstacles-only) and falls status (2: fall-prone, healthy older adults) as between-group factors. Partial eta-squared, η_p^2, was used as a measure of effect size for ANOVAs examining between-subject factors. For ANOVAs containing within-subject factors, the Greenhouse–Geisser epsilon, $\hat{\varepsilon}$, which was used to adjust the degrees of freedom to correct for violations of the assumption of sphericity when calculating p-values, and generalised eta-squared, η_g^2, is reported (Olejnik and Algina 2003).

3. Results

3.1. Characteristics of fall-prone and healthy participants across the three training groups

Although allocation of participants was pseudo-random, the mean age of participants allocated to the three game conditions was statistically different in the final sample, [$F(2, 50) = 6.23$, $p = 0.004$, $\eta_p^2 = 0.2$], with the participants in the CityQuest group being an average of 4 years younger ($M = 69.27$, SD = 2.68) than those in the Spatial-only ($M = 73.10$, SD = 4.59) or Obstacles-only ($M = 73.67$, SD = 5.46) groups. There was no effect of falls status [$F(1, 50) < 1$], nor any interaction between training group and falls status [$F(2, 50) < 1$], indicating that fall-prone and healthy participants groups were of similar ages.

3.2. Attitude to Falls-related Interventions Scale

Figure 3 shows ratings for the separate items of the attitude to falls-related interventions (AFRIS) scale for fall-prone and healthy older adults across all three game conditions. Although ratings took on the full range of responses, average ratings were all positive (5–7), with highest average ratings given to item 1 (objective benefit: $M = 6.27$, $SD = 1.15$) and lowest average ratings for item 5 (identity: $M = 5.34$, $SD = 1.57$).

A mixed-model 2 (falls status) × 3 (game condition) × 6 (item) ANOVA revealed a significant effect of item [$F(5, 250) = 5.38$, $\hat{\varepsilon} = 0.83$, $p < 0.001$, $\eta_g^2 = 0.04$], as well as significant interactions between item and game condition [$F(10, 250) = 2.72$, $\hat{\varepsilon} = 0.83$, $p = 0.006$, $\eta_g^2 = 0.04$], and item, game condition, and falls status [$F(10, 250) = 2.21$, $\hat{\varepsilon} = 0.83$, $p = 0.03$, $\eta_g^2 = 0.04$], indicating that ratings on some items depended on fall status and game condition. There were no main effects of falls status, game condition, or two-way interactions between falls status and group, or falls status and item.

To examine differences across falls status and game condition for each item, we performed separate 2 (falls status) × 3 (game conditions) ANOVAs. There were no effects of falls status, game condition, or two-way interactions for items 2, 3, 4, and 5. For item 1, objective outcome, there was a main effect of falls status [$F(1, 50) = 4.40$, $p = 0.04$, $\eta_g^2 = 0.08$], with fall-prone participants giving on average higher ratings ($M = 6.60$, $SD = 0.73$) than healthy participants ($M = 5.93$, $SD = 1.39$). There was no effect of game condition or interaction between game condition and falls status [$F < 1$]. Finally, there was a main effect of game condition for item 6, intention, [$F(2, 50) = 9.11$, $p < 0.001$, $\eta_g^2 = 0.27$], with ratings in the Obstacles-only group significantly lower ($M = 4.33$, $SD = 2.16$) than those in the CityQuest ($M = 6.05$, $SD = 1.60$, $p = 0.004$) and those in the Spatial group ($M = 6.50$, $SD = 0.83$, $p < 0.001$). There was no effect of falls status or interaction between game condition and fall status [$F < 1.25$].

Figure 4 shows the rating scores provided to the personal relevance of the recommended intervention activities (i.e. intention to buy WBB, likelihood of recommending intervention to a friend, frequency of at home play). Although some participants reported being 'extremely' likely to purchase a WBB, average ratings were low across the three groups. Comparison of average ratings of their intention to purchase a WBB across game training groups and falls status failed to reveal any significant differences: no effect of falls status [$F(1, 50) = 1.34$, $p = 0.25$, $\eta_g^2 = 0.03$], no effect of training group [F
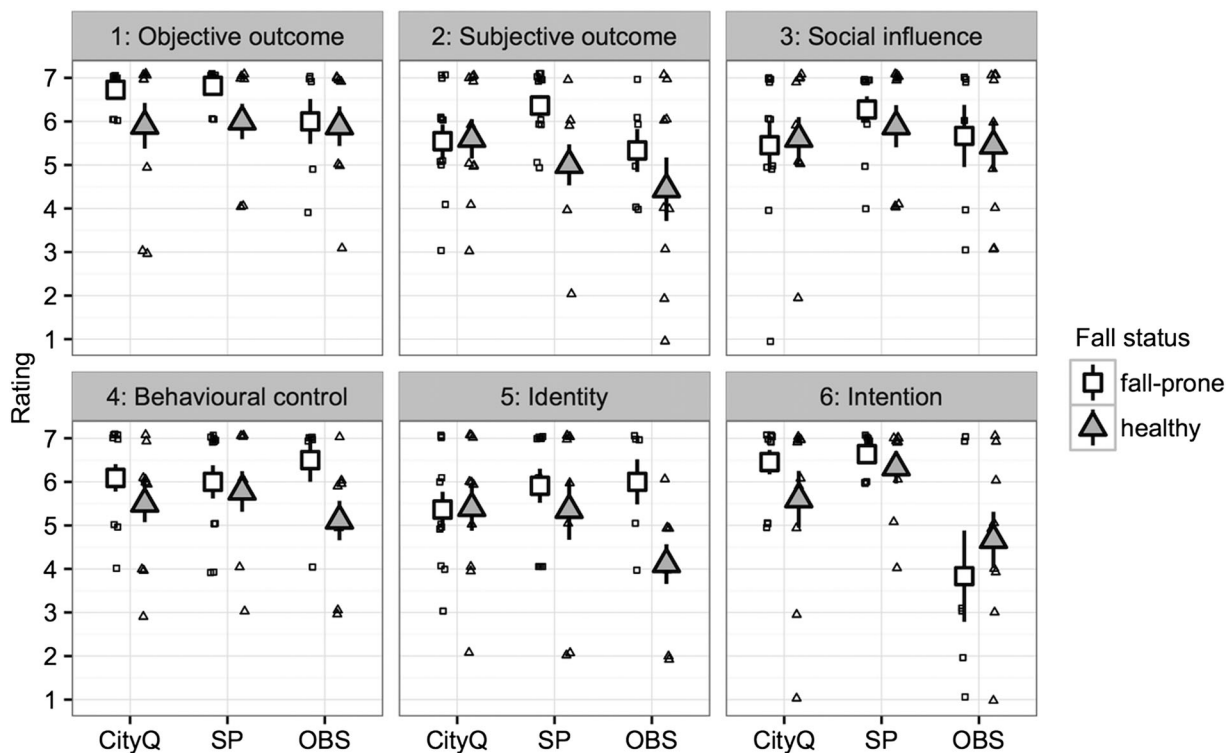

Figure 3. Agreement ratings for individual items on the attitude toward falls-related interventions (AFRIS) scale for fall-prone (squares) and healthy (triangles) older adults across each of the three training games: CityQuest, Spatial-only (SP), and Obstacles-only (OBS). Large symbols show group averages and error bars indicate ± 1 standard error of the mean.
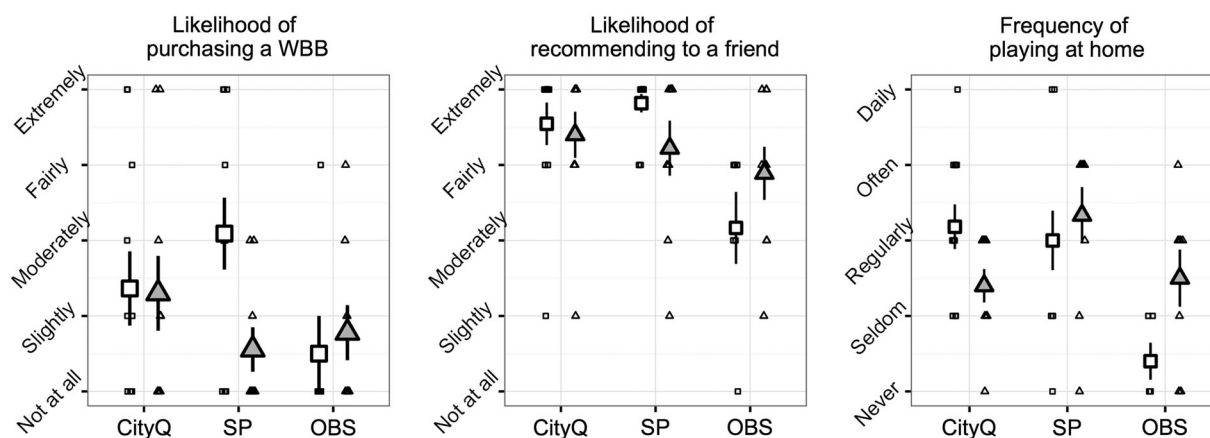
Figure 4. Average (large symbols) and individual (small symbols) scores across ratings provided to the personal relevance of the recommended intervention activities (i.e. likelihood of buying WBB, recommending intervention to a friend, and frequency of playing at home if they had a WBB) for fall-prone (squares) and healthy (triangle) older adults across the three games. Error bars indicate ± 1 standard error of the mean.

(2, 50) = 1.3, $p = 0.28$, $\eta_g^2 = 0.05$], nor any interaction between training group and falls status [$F(2, 50) = 2.19$, $p = 0.12$, $\eta_g^2 = 0.08$].

In contrast, participants were more likely to recommend the intervention to a friend, although this varied across game condition training group [$F(2, 50) = 5.67$, $p = 0.006$, $\eta_g^2 = 0.19$], with those allocated to the CityQuest ($M = 4.48$, SD = 0.93) and Spatial-only ($M = 4.55$, SD = 0.83) conditions more likely to recommend the intervention to a friend than those allocated to the Obstacles-only condition ($M = 3.6$, SD = 1.12). There was no effect of falls status [$F(1, 50) < 1$] and no interaction between training group and falls status [$F(2, 50) = 2.08$, $p = 0.14$, $\eta_g^2 = 0.08$].

As to the anticipated frequency of home play, participants' responses covered the full range from '1: never' to '5: daily'. Here again, there was a significant effect of training group [$F(2, 47) = 5.56$, $p = 0.007$, $\eta_g^2 = 0.19$]. Specifically, the reported frequency of playing at home was lower in the Obstacles-only group ($M = 2.08$, SD = 1.04) compared to those in the Spatial-only group ($M = 3.16$, SD = 1.17), but not compared to those in the City-Quest group ($M = 2.18$, SD = 0.93). There was no effect of falls status [$F(1, 47) < 1$] but a significant interaction between training group and falls status [$F(2, 47) = 3.68$, $p = 0.033$, $\eta_g^2 = 0.14$], which likely reflects the fact that fall-prone participants showed on average higher ratings than healthy participants in the CityQuest group, but the opposite trend in the Obstacles group; however, these differences were not statistically significant.

3.3. Game experience questionnaire

The results of the core GEQ which evaluated game experience on seven core components, with scores

ranging 0–4, are shown in Figure 5. Scores were highest for the positive affect item ($M = 2.94$, SD = 0.77), with responses ranging from '1: slightly' to '4: extremely'. Scores were slightly lower for flow ($M = 2.41$, SD = 0.73), immersion ($M = 2.34$, SD = 0.84), and competence ($M = 2.19$, SD = 0.85). For competence, responses occupied the full range for the CityQuest and Spatial-only game conditions, while most participants in the Obstacles-only group reported a 'moderate' level of competence. Participants in all three game conditions reported being 'slightly' to 'moderately' challenged ($M = 1.54$, SD = 0.60). Finally, the majority of ratings were very low for negative affect ($M = 0.28$, SD = 0.43) and annoyance/tension ($M = 0.62$, SD = 0.74). A comparison of the average scores across game condition and falls status for each component separately failed to find any effect of training group [$F(2, 50) < 1$] or falls status [$F(1, 50) = 1.89$, $p = 0.17$, $\eta_g^2 = 0.04$]. A falls status × training group interaction was observed for immersion ($F(2, 50) = 3.42$, $p = 0.04$, $\eta_g^2 = 0.12$), where the fall-prone participants in the Spatial-only training group reported overall higher immersion scores relative to the healthy group. There was no interaction between falls status and training group for any other components [$F(2, 50) < 2.16$, $p = 0.12$, $\eta_g^2 = 0.07$] (see Figure 5).

Figure 6 shows ratings for the four components evaluated by the post-game module of the GEQ, which assessed how participants felt after the game. Scores for the positive experience component were moderately high ($M = 1.83$, SD = 0.98), with individual ratings covering the full range of the scale. Scores for the negative experience component were very low ($M = 0.11$, SD = 0.3) and ranged from 'not at all' to 'slightly'. Participants also provided overall low ratings for tiredness ($M = 0.43$, SD = 0.74), although some participants in the CityQuest
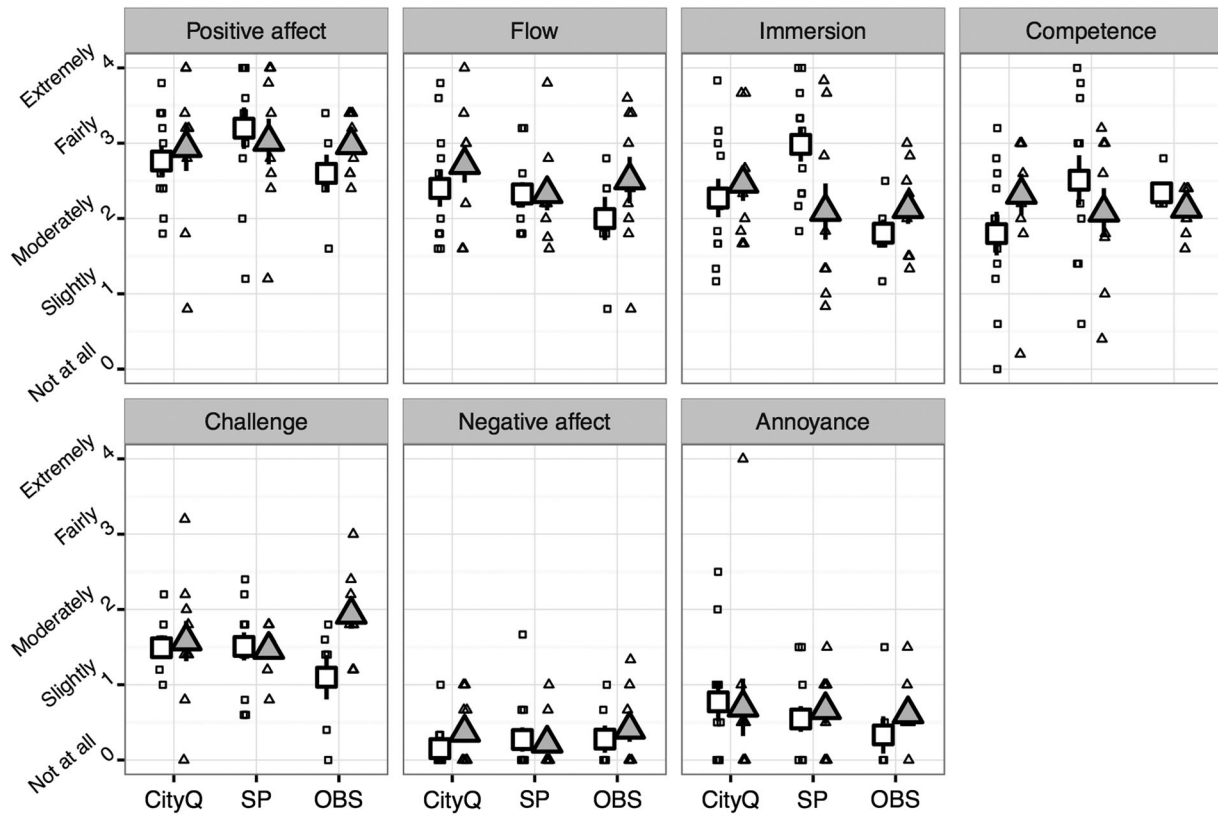
Figure 5. Average ratings for the core components of the GEQ for fall-prone (square symbols) and healthy (triangle symbols) older adults who trained with the CityQuest, Spatial-only (SP), or the Obstacles-only (OBS) game. Large symbols show group average and ± 1 standard error and small symbols show individual data.

group reported feeling 'fairly' tired after the game. Finally, participants reported having no difficulty with returning to reality ($M = 0.43$, SD = 0.74) after playing the game. Comparison of scores across training group and falls status for each component failed to find any differences across falls status [$F(2, 50) < 1.25$, $p < 0.25$], or training group [$F(2, 50) < 2.42$, $p < 0.10$]. There was a significant interaction for the positive experience component [$F(2, 50) = 4.22$, $p = 0.02$, $\eta_g^2 = 0.14$], reflecting higher scores for fall-prone participants in the Spatial-only game only. None of the other components showed evidence of an interaction between falls status and training group [$F(2, 50) < 1$].

3.4. Enjoyment of game features

Figure 7 shows participants' ratings of enjoyment based on the following features of the games: the 'city look', the background music, the sounds effects (e.g. footsteps etc.), the character representing the participant, the pedestrians, and the obstacles. Ratings for all items were highly variable across participants and covered the full range of the scale, except for the 'city look' item, which no one reported not liking at all. To compare ratings across different features, we performed multiple pairwise

comparisons using the Holm correction. This analysis revealed that ratings for the 'city look' ($M = 3.73$, SD = 1.07) were higher than ratings for the background music ($M = 2.93$, SD = 1.4, $p < 0.001$) and the sounds ($M = 3.16$, SD = 1.36, $p = 0.016$), but did not differ significantly from the ratings of the virtual character ($M = 3.34$, SD = 1.21, $p = 0.06$), the obstacles ($M = 3.22$, SD = 1.10, $p = 1$), or the pedestrians ($M = 3.06$, SD = 1.21, $p = 0.16$). There were no other statistically significant differences in average ratings for any other pair of features. Thus, all the visual features received, on average, more favourable ratings, while the sound elements were, on average, less liked.

To examine whether ratings differed across participants depending on their falls status and game condition, we performed separate factorial ANOVAs for each item. These analyses revealed a main effect of game condition for the ratings of the 'city look' [$F(2, 50) = 3.71$, $p = 0.03$, $\eta_p^2 = 0.13$], with ratings from the Spatial-only group ($M = 4.15$, SD = 1.23) being higher than those from the Obstacles-only group ($M = 3.13$, SD = 0.74), but not significantly different than those from the CityQuest group ($M = 3.76$, SD = 0.94). There was no effect of falls status [$F(1, 50) = 1.94$, $p = 0.17$, $\eta_p^2 = 0.04$] and no interaction between falls status and training group [$F(2, 50) = 1.16$,

Figure 6. Average ratings of the four components evaluated by the post-game module of the GEQ for fall-prone (square symbols) and healthy (triangle symbols) older adults who trained with the CityQuest, Spatial-only (SP), or the Obstacles-only (OBS) game. Large symbols show group mean and ± 1 standard error and small symbols show individual data.

$p = 0.32$, $\eta_p^2 = 0.04$]. There were no other statistically significant differences across the three game conditions or between healthy and fall-prone participants on average ratings of any of the other game features ($F < 1.74$, $ps > 0.19$).

3.5. Subjective improvement

Figure 8 shows participants' ratings of the extent to which they felt the training intervention had led to improvements in their balance confidence, a reduced fear of falling, and several cognitive and attentional functions.

In terms of whether participants felt that training had improved their balance confidence, responses ranged from 'not at all' to 'extremely', with moderate average ratings for fall-prone ($M = 3.14$, SD = 1.27) and healthy

($M = 3.00$, SD = 1.21) participants. A 3 (game condition) × 2 (falls status) ANOVA on ratings for balance confidence revealed no effect of group [$F(2, 50) = 1.35$, $p = 0.23$, $\eta_p^2 = 0.06$], no effect of falls status [$F(1, 50) < 1$], but a significant interaction between group and falls status [$F(2, 50) = 3.53$, $p = 0.037$, $\eta_p^2 = 0.12$]. The interaction reflects the fact that ratings tended to be higher for fall-prone compared to healthy participants in the Spatial-only group and the pattern was reversed in the other two groups, although follow up pairwise t-tests failed to find statistically significant differences between fall-prone or healthy older adults across any of the training groups.

Participants' responses to how much they thought that training had reduced their fear of falling also ranged from 'not at all' to 'extremely'. Average responses did not vary across training condition [$F(2, 49) = 1.57$, $p = 0.22$,
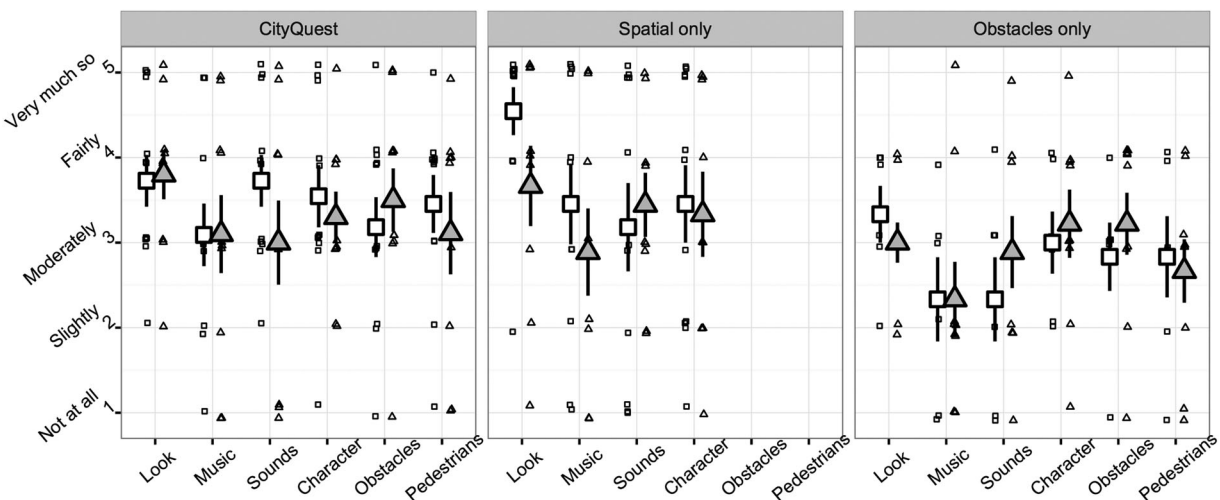

Figure 7. Average (larger symbols) and individual (small symbols) ratings of enjoyment of game features for fall-prone (squares) and healthy (triangles) older adults for the CityQuest, Spatial-only, and Obstacles-only training groups. Error bars show ± 1 standard error of the mean.
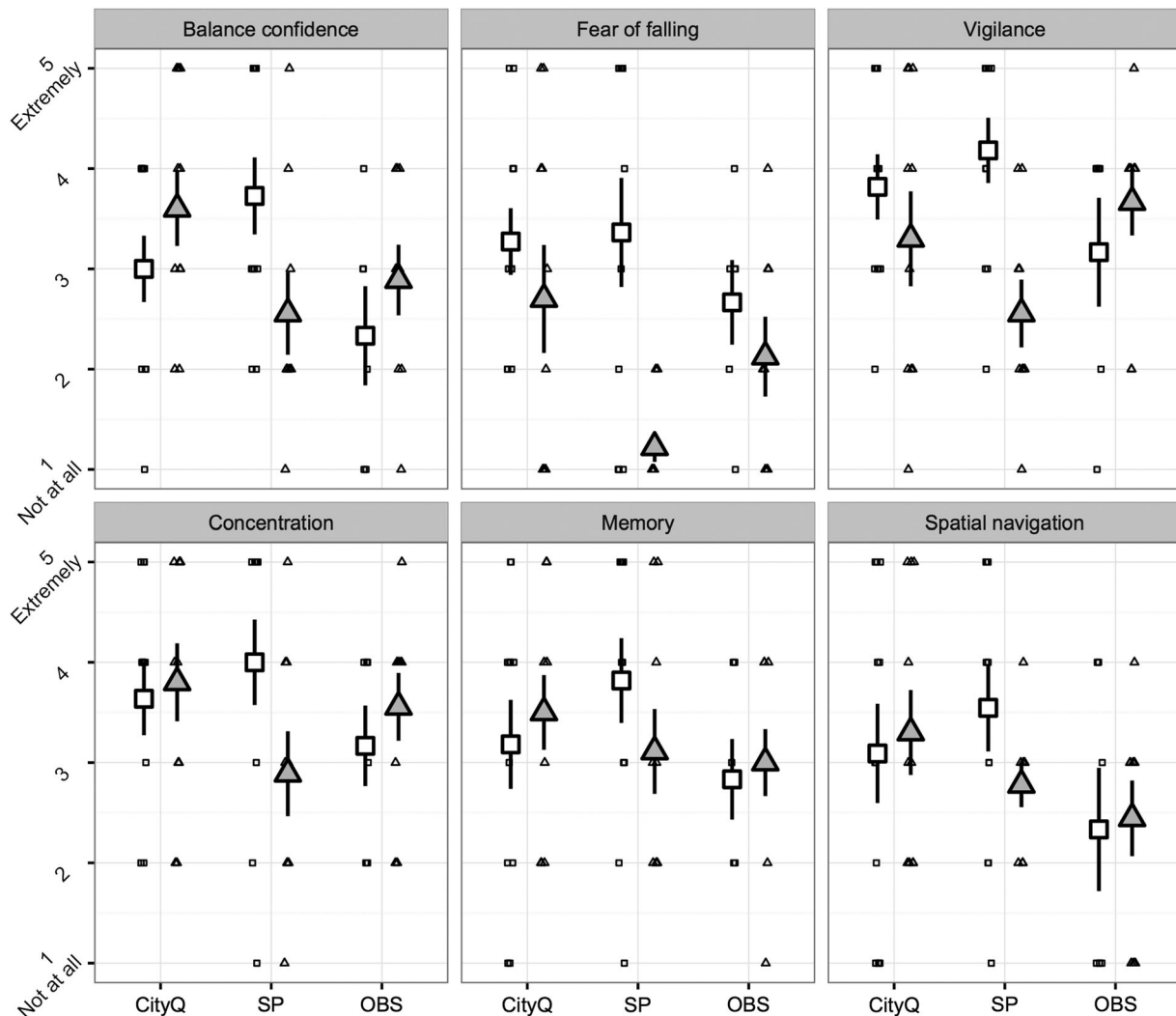
Figure 8. Group average (large symbols) and individual scores for subjective improvement in balance confidence, reduction in fear of falling, improvement in vigilance, concentration, memory, and spatial navigation ability following the intervention for fall-prone (square) and healthy (triangle) older adults across training groups. Error bars indicate ± 1 standard error of the mean.

$\eta_p^2 = 0.06$], but they differed across falls status [$F(1, 49) =$ 8.76, $p = 0.005$, $\eta_p^2 = 0.15$], with fall-prone participants reporting feeling a greater reduction in fear of falling ($M = 3.18$, SD = 1.39) compared to healthy older adults ($M = 2.04$, SD = 1.34). There was no interaction between game condition and falls status [$F(2, 49) = 2.23$, $p = 0.12$, $\eta_p^2 = 0.08$].

The ratings for subjective improvements on cognitive functions were highest for concentration ($M = 3.55$, SD = 1.22) and vigilance ($M = 3.50$, SD = 1.24), followed by memory ($M = 3.29$, SD = 1.25), and navigational ability ($M = 2.98$, SD = 1.34). Thus, participants reported moderate improvement on these measures following the intervention, although with less subjective improvement for spatial navigation. To examine whether ratings differed across game conditions and falls status, we conducted separate 3 (game condition) × 2 (falls status) ANOVAs for each item. These analyses revealed a

significant interaction between game condition and falls status for the vigilance item [$F(2, 50) = 3.5$, $p = 0.04$, $\eta_p^2 = 0.12$]. Follow-up tests showed that, in the Spatial-only group, fall-prone older adults self-reported greater improvement in vigilance than healthy older adults, whereas there were no differences across falls status in the other two groups (see Figure 8). None of the other analyses revealed any significant effects of group, falls status, or interactions between these factors.

4. Discussion

The main goal of the present study was to design and evaluate the acceptability and game experience of a custom-designed video game, CityQuest, in healthy and fall-prone older adults. The CityQuest game trained spatial navigation, obstacle avoidance, and balance control in an adaptive manner. We evaluated acceptability and

enjoyment ratings using standardised questionnaires (IJsselsteijn, de Kort, and Poels, forthcoming; Yardley et al. 2007) in three different groups of healthy and fall-prone participants who underwent 10 training sessions with either CityQuest or one of two control games, which paired balance control with only the spatial navigation task or only with the obstacle avoidance task. A second aim was to assess the role of personally relevant factors on engagement with the intervention (i.e. purchasing a WBB, recommend to a friend, home gameplay) and subjective improvements in cognition and balance confidence across participants and training conditions.

The acceptability of the game (all conditions) as a falls-related intervention, as measured by the AFRIS (Yardley et al. 2007), was high for both fall-prone and healthy older adults. In fact, even the item with the lowest ratings on average ('I am the kind of person that should do the intervention') was still scored positively as it was above the scale mid-point of 4. On average, fall-prone participants felt more strongly than healthy participants that the intervention 'would be good for them'. This result can be explained by the fact that having experienced an unexplained fall in the recent past makes participants in the fall-prone group more likely to agree that a falls-related intervention is good for them. Interestingly, there were no differences between these two cohorts in the extent of their belief that playing the game would make them feel confident, that they were the kind of person that should do the intervention, their estimate of the social support for them participating in the intervention, or their overall intention to do the intervention in the future. This similarity may be due to the fact that some healthy older adults in our cohort had concerns about falls or experienced fear of falling. The high scores obtained on the AFRIS are encouraging, especially because it has been shown that the intention to take up strength or balance training in older adults is closely related to beliefs about enjoying the activity, perceived benefit of the activity to themselves, and belief that friends and family would approve of the intervention (Yardley et al. 2007). Furthermore, the CityQuest game was designed to combine cognitive and physical activities (i.e. spatial navigation, obstacle avoidance, and postural control) in an adaptive and therefore challenging manner, which previous research suggests increases the motivation of older adults to engage with digital gaming technology (Diaz-Orueta et al. 2012).

The average acceptability ratings were similar across the three game conditions and across most items, except for item 6, where fewer of those trained with the Obstacles-only game were likely to report that they intend to take part in the intervention in the future. All three training games comprised similar virtual cityscapes and required precise postural control while simultaneously attempting to complete complex cognitive or perceptual tasks. Therefore, it is not surprising that there was no substantial difference across training groups with respect to their attitudes towards the game as a falls-related intervention. However, participants in the Obstacles-only group also self-reported being less likely to recommend the game to a friend than participants in the other two groups, who both reported a high likelihood of recommending the game to others. One possible explanation for this difference is that the Obstacles-only condition required less cognitive effort than the other two training conditions, as there was no spatial memory component in the game and it may have been deemed as less engaging for that reason. Similarly, De Schutter (2011) found that older adult respondents to a survey relating to digital game-play cited experiencing the challenge of the game as their main motivation for engaging with digital games. Interestingly, there was no difference in ratings of the challenge component of the GEQ across participants, with all three groups rating the game as moderately challenging.

Despite the CityQuest and Spatial-only training groups' reports of being highly likely to recommend the game, all three training groups did not see themselves playing the game regularly in the home, particularly those who trained in the Obstacles-only condition. The likelihood of purchasing a WBB was also quite low across all of the training groups. These findings are in contrast to population survey data collected from over 5000 respondents in which 60% of older adults reported being willing to carry out strength and balance training in the home (Yardley et al. 2008). Likewise, Williams et al. (2010) reported that following a supervised balance training intervention using the Nintendo® WiiFit, community-dwelling, fall-prone older adults indicated their willingness to exercise with the Wii at home. Results from our study should therefore be taken with caution, because of the relatively low sample size compared to the study by Yardley et al. (2008). However, a number of studies have reported that, as well as challenge, the opportunity for social interaction is an important factor for older adults to engage with digit gaming technology (De Schutter 2011; Diaz-Orueta et al. 2012; Nap et al. 2015). Therefore, it is possible that the supervision and social interaction provided by the research team in the current study were important contributing factors in adherence to and recommendation of the intervention, factors that would not necessarily be present in a home setting. Other factors that may explain the reluctance to purchase a balance board include perceived high cost or perceived difficulties with operating the technology.

Game experience as measured by the GEQ and game enjoyment did not differ across the training groups for fall-prone and healthy older adults, with the games rated overall as a positive experience, and only a few occurrences of negative experiences. An examination of participants' enjoyment of specific features of the game allowed us to determine that some components, such as how the cityscape looked, were more liked than others, such as the background music. The other components showed very high variability in ratings (e.g. the other sounds effects, the character, the obstacles, and pedestrians). Overall, those allocated to the Spatial-only group reported greater enjoyment of the look of the city than those in the Obstacles-only group. This may be due to the fact that the group assigned to the Spatial-only game was required to pay attention to the city by locating landmarks, whereas the group assigned to the Obstacles-only game was not. Indeed, across all game components, game enjoyment tended to be slightly lower for those reported by the Obstacles-only group than for the other two groups. Again, this could be due to the less cognitively challenging nature of this training condition manifesting in game enjoyment ratings, as participants in the Obstacles-only group were exposed to the same visual environments as both the CityQuest and Spatial-only groups.

With regard to subjective improvements in cognition, the results demonstrated that all participants reported moderate improvement on measures of vigilance, memory, and concentration following the intervention, although there was less subjective improvement reported in navigational ability compared to the other cognitive functions. One possible explanation for this difference is that older adults have been found to be less aware of navigational difficulties in everyday life (Taillade et al. 2013), with a number of studies reporting that older adults tend to inflate their perceived sense of direction relative to their actual navigational ability (Merriman et al. 2016; Rosenbaum et al. 2012; Taillade et al. 2013), possibly due to age-related decreases in insight into one's own cognitive functioning (i.e. metacognition) (Isingrini et al. 2008). This age-related inflation in perceived spatial navigation abilities appears to be specific to this cognitive function, as cognitively healthy older adults tend to report worse memory function and believe their memory has declined over time relative to younger adults (Vanderhill et al. 2010). We conducted focus groups subsequent to the training interventions and the discussions revealed that older adults are concerned about their ability to remain vigilant of potential obstacles on the footpath, suggesting that vigilance and concentration are functions that older adults would like to improve.

The ratings of subjective improvement in balance confidence, fear of falling, and measures of cognitive function were moderately high and did not differ significantly across the three game conditions. When examining differences between fall-prone and healthy older adults, fall-prone older adults reported a greater reduction in fear of falling as a result of training than those without a history of falling. The average difference was greatest in the Spatial-only group, where fall-prone participants reported greater improvements in fear of falling, vigilance, balance confidence, as well as memory, concentration, and navigational ability (although only vigilance showed a significant interaction). However, the power to detect reliable differences across groups and conditions is low given the relatively small sample size in each training condition, the unequal number of fall-prone and healthy older adults across training groups and that some healthy older adults also experienced fear of falling.

One possible explanation for the prevalence of this finding in the Spatial-only condition might lie with cognitive load. The theory of cognitive load is grounded in research examining interactions between working and long-term memory (Sweller, Ayres, and Kalyuga 2011; Sweller, Van Merriënboer, and Paas 1998). If too much cognitive load is present in a complex learning environment, performance may be hindered due to insufficient working memory resources available to complete the task at hand (Ayres and Paas 2012), whereas if the task is too easy, learning will suffer due to lack of engagement and boredom (Paas et al. 2005). Thus, similar to the positive psychological phenomenon of the state of flow, a model of optimal experience and optimal development (Nakamura and Csikszentmihalyi 2009), a balance between easy and difficult material seems necessary in order to sufficiently challenge the participant to match their skill level without them becoming frustrated with the task or disengaged (Csikszentmihalyi 1990). It is possible that the Spatial-only condition was the optimum condition for fall-prone older adults, but not for healthy older adults, leading to greater subjective improvements in the former group. The Spatial-only condition also appeared to be more engaging than the Obstacles-only condition in general (as suggested by the results of the objective benefits item of the AFRIS and the personal relevance of the recommended intervention activities) and not as challenging as the CityQuest condition, which incorporated obstacle avoidance as well as spatial navigation.

In sum, we found that a video game (CityQuest) that uses balance shifting to navigate in a virtual city while learning the layout of virtual cities and avoiding obstacles is an acceptable falls-related intervention for

community-dwelling older adults both with and without a history of falls, based in particular upon the positive attitude towards the intervention revealed by the AFRIS, a measure developed specifically to assess the attitudes of older adults to interventions to reduce falls risk. Additionally, participants reported a positive game experience and subjective improvements in balance confidence and subjective cognition. The use of a virtual reality game-based intervention that incorporates adaptive, spatial navigation and obstacle avoidance training, coupled with a balance training component, may prove a useful tool in the objective improvement or maintenance of balance function and spatial navigation ability in older adults.

Ethical approval

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed consent

Informed, written consent was obtained from all individual participants included in the study prior to testing.

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

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