Balance-Land: a gamified rehabilitation program for people with Persistent Perceptual Postural Dizziness (PPPD) and visual vertigo

Nathan Goodwin[1,2], Petroc Sumner[1], Fernando Loizides[2], Hannah Derry-Sumner[3], Deepak Rajenderkumar[3], Georgina Powell[1] (corresponding author)

[1] School of Psychology, Cardiff University

[2] School of Computer Science and Informatics, Cardiff University

[3] University Hospital of Wales

Email: powellg7@cardiff.ac.uk

1. Abstract

BACKGROUND: Persistent Perceptual Postural Dizziness (PPPD) is typically treated through vestibular rehabilitation, which can be unpleasant and not well adhered to. Gamification has helped rehabilitation adherence in other domains.

OBJECTIVE: To create a virtual rehabilitation tool with patients and clinicians that is: accessible to novice game users; engaging to increase treatment adherence; flexible over pace and visual complexity.

METHODS: We developed *Balance-Land* over three phrases of feedback and improvement. In Phases 1 and 2, people with PPPD and visual vertigo symptoms (N =21) provided feedback via questionnaires and interviews, and 6 clinicians provided feedback in Phase 3.

RESULTS: By phase 2, accessibility and usability was rated 79 on the System Usability Scale, placing it well within the range of commercial games. Enjoyment was rated moderately low (3.4/10 ± 2.0), partly due to symptom provocation, but participants said it was more enjoyable than standard rehabilitation. Participants confirmed that the virtual worlds and adaptable speed control provided flexibility over symptom stimulation. All participants said they would play the game if shown to improve symptoms.

CONCLUSIONS: Balance-Land is potentially a useful rehabilitation tool for PPPD, but rehabilitation efficacy is yet to be tested.

Keywords: PPPD, visual vertigo, Vestibular Rehabilitation, Virtual Environment, Visually-induced Dizziness

2. Introduction

Persistent postural perceptual dizziness (PPPD) is the leading cause of chronic, functional dizziness [28]. The diagnosis evolved from four previous conditions that shared overlapping symptoms [28]: visual vertigo [3]; phobic postural vertigo [2]; chronic subjective dizziness [27]; and space and motion discomfort [14]. Patients experience symptoms of dizziness, unsteadiness and non-spinning vertigo that are exacerbated by motion and complex visual environments ('visual vertigo') and upright posture [20]. Anxiety is common, with patients often developing fear of situations that are likely to trigger symptoms ([20]). PPPD can be difficult to manage; treatment for visual vertigo symptoms often involves patients carrying out daily vestibular rehabilitation exercises, which they find uncomfortable, unengaging, and difficult to maintain over the period needed for efficacy [18]. In this paper, we describe the development of a new online rehabilitation game ('*Balance-Land*') for visual vertigo symptoms of PPPD. We have developed the tool in consultation with patients and clinicians, to ensure that it is user-focused and can be tailored to individual patient needs. We report initial feedback from user-groups on the design and usability of the tool.

PPPD often develops following a peripheral vestibular disorder, neurological condition/injury, or psychological stress [28]. Patients develop compensatory strategies to these triggering events, such as an over-reliance on visual-somatosensory cues for balance and postural hyper-vigilance and control strategies [20, 21, 28]. It is thought that these acute compensatory mechanisms develop into chronic maladaptation if they persist after the original vestibular disorder resolves [20]. Predisposing factors may also exist prior to triggering events, since our research has suggested that visual vertigo symptoms of PPPD are also common in the general population, with 9% of a large healthy volunteer cohort from Wales reporting symptoms in the patient range, although general population values would likely be below 9% [22]. Anxiety is correlated with PPPD and can lead to environmental hyper-vigilance and avoidance, which ultimately perpetuates both dizziness and anxiety symptoms [21].

Current treatment options for PPPD include behavioural rehabilitation, cognitive behavioural therapy (CBT) and selective serotonin re-uptake inhibitors (SSRIs), to try and break the perpetuating anxiety-dizziness cycle and to help patients cope with symptoms in everyday life [21]. Behavioural rehabilitation for PPPD involves exposure to motion and movement that triggers symptoms [21]. For example, classic vestibular rehabilitation exercises (for chronic dizziness) require patients to perform head and eye movements while fixating or following an object (e.g. a fingertip). Optokinetic stimulation has also been shown to be helpful [18], with findings that watching recorded optokinetic stimuli for up to 45 minutes each day for 8 weeks could improve posture, gait, and dizziness symptoms (situational characteristic questionnaire (SCQ) [19] and the vertigo symptom scale (VSS)) [31]. More generally, people with visual vertigo symptoms are often advised to view videos with radial optic flow or with moving patterned stimuli with the aim to ‘down-weight’ and ‘desensitise to’ visual information, relative to information from their vestibular system [13, 18, 21].

However, an important issue with current behavioural rehabilitation options for chronic dizziness is that they tend to be repetitive and unengaging ([10]). Coupled with the fact that they are designed to trigger symptoms, this results in an unenjoyable experience for patients and low treatment adherence [18]. Gamification has helped rehabilitation adherence in other domains, including chronic disease management, physical activity, nutrition, mental health, and hygiene [26].

A second limitation is insufficient flexibility for individual patient need [21]. PPPD patients are known for their heterogeneity – with different severities of symptoms and different situational triggers for dizziness and anxiety [7, 20, 28]. There are a variety of treatment modalities that can help individuals, but easily available online videos or games containing optic flow tend to contain high levels of motion and visual complexity that are too intense for many patients.

Therefore, we set out to develop a new rehabilitation game for the visual vertigo symptoms of PPPD that, while based on the principles of optokinetic stimulation, would also be:

1. Accessible to novice game users.
2. Engaging to increase treatment adherence.
3. Flexible over pace and visual complexity, provoking symptoms in a graded way in a range that can be tolerated.

Based on a user-centred approach, we iteratively developed and improved the game based on multiple rounds of feedback from patients and clinicians. Alongside game design and usability, we also wanted to find out if and how clinicians would integrate it into their management of PPPD and how patients might use it in their daily lives living with PPPD. Here we report the results of this iterative development process. The game has not yet been tested for rehabilitation efficacy, although rehabilitation tools relying on similar principles of optokinetic stimulation have been shown to be effective for people presenting with similar symptoms [18]. Rather, we report the experiences of patients who have played the game for a short-period and discussed their experiences.

3. Methods

3.1 Description of the Game

We designed “Balance-Land” as a web-based rehabilitation tool for symptoms of PPPD and visual vertigo. In the game, players travel round different virtual environments (e.g. desert, forest, supermarket) and solve puzzles (e.g. word games, finding objects). Movement through the virtual environments produces the optokinetic stimulation that is needed for desensitisation to visual motion cues.

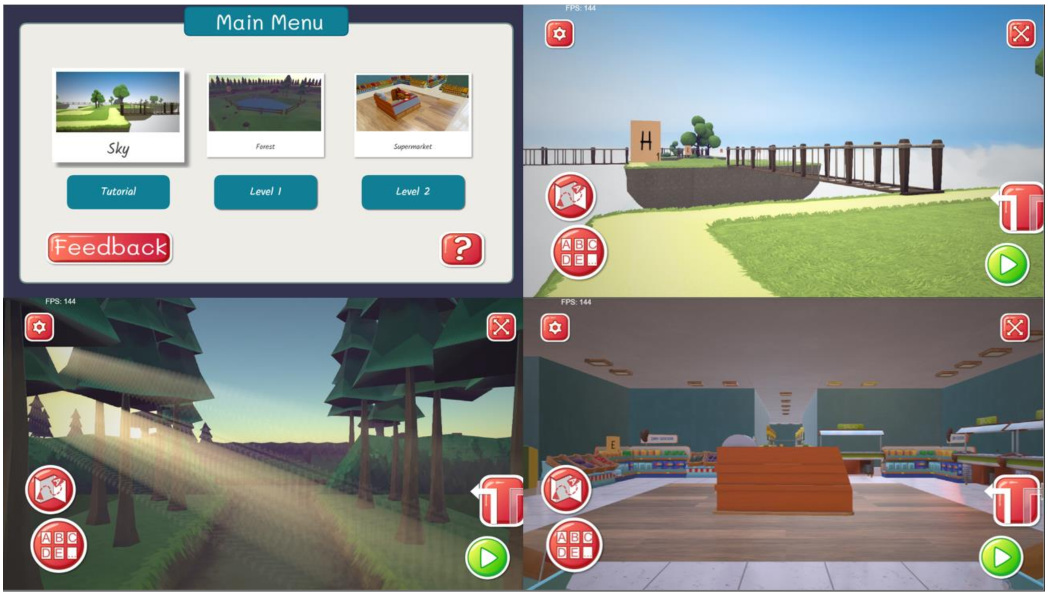

Figure 1, Images from Phase 1. The environment selection screen (top left); the Island environment (top right); the Forest environment with flickering light (bottom left); and the supermarket (bottom right). All game modes showing the one game mode: Make Words.

The intensity of optokinetic stimulation can be controlled in a number of ways within the game. The different worlds in the game provide different intensities of stimulation: the desert world is low contrast and spatial frequency, with a limited colour palette and few objects; the supermarket world is high contrast and spatial frequency, brightly coloured, with many objects; the forest world is in between the two. Within each world, players can change the movement speed and steadiness, choose to enter more visually complex areas, and choose puzzles that provide more or fewer breaks from visual stimulation.

The most current version of the game can be found at: https://game.cudizzylab.org

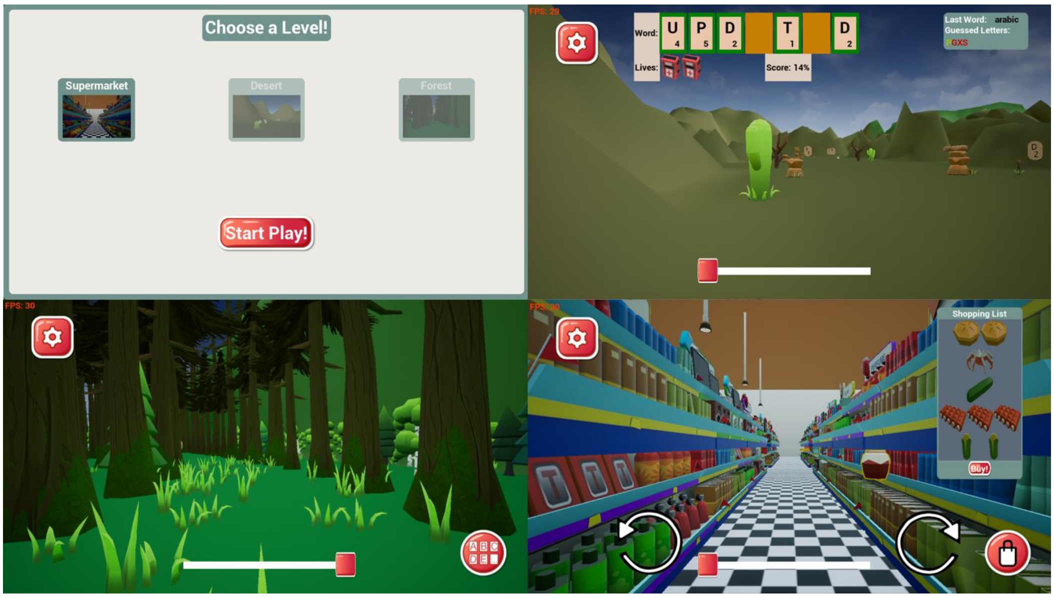

Figure 2, Images from Phase 3, which the clinicians played. Level select (top left); the Desert environment with Find Words game mode (top right); the Forest environment with the Make Words game mode (bottom left); and the Supermarket environment with the Shop game mode (bottom right).

The most challenging virtual world, the supermarket, was chosen to simulate a common situation that patients report triggers symptoms (e.g. [6, 30]).

Puzzle games were selected because they are most accessible to a wide range of users and do not require much experience with computer game controls [25]. Puzzle games also crucially allow for the gameplay difficulty (i.e. puzzles) to be decoupled from the difficulty of the rehabilitation (e.g. speed and complexity of optokinetic stimulation). Within the game, these elements can therefore be adjusted independently to suit user need, which is generally not possible with available commercial games.

We chose a web-based platform to ensure quick and easy access for a wide range of users accessing the game from different types of devices. An additional benefit of a web-based game is that information from users can be recorded in real-time. This allows for accurate and comprehensive information to be relayed to clinicians about the adherence and progress of the rehabilitation. The game can be downloaded as an application and played without internet for Windows, with a Mac build being planned.

The game for Phase 1 was developed via BabylonJS ([5]) with TypeScript. The world was designed to be procedurally generated, with the idea that a novel game environment each gameplay session would be more engaging for users. For Phase 2, after feedback from participants and evaluation against game aims, development was swapped to Unreal Engine v4.23 ([11]) with C++ as the primary language. Due to the goal still being to deploy a web-based game, the game was built for HTML5, and the C++ was converted to JavaScript by Emscripten. For Phase 3, the game moved away from a procedurally generated world, instead utilising a static base world containing the different virtual environments in different locations. Different densities of visual features load into the base world depending on chosen user settings.

3.2 User-centred design

It was important that the game was designed to suit the needs of the end users: patients with PPPD/ visual vertigo and audio-vestibular clinicians. User-centred design is an approach where users are involved in the design and development of a product [1]. We took an iterative approach where users provided feedback on the game, which was followed by refinement, then another round of feedback and refinement. In total, there were three phases of game development (see Figures 1 & 2). Two rounds of feedback involved patients (Phases 1 & 2) and one round involved clinicians (Phase 3).

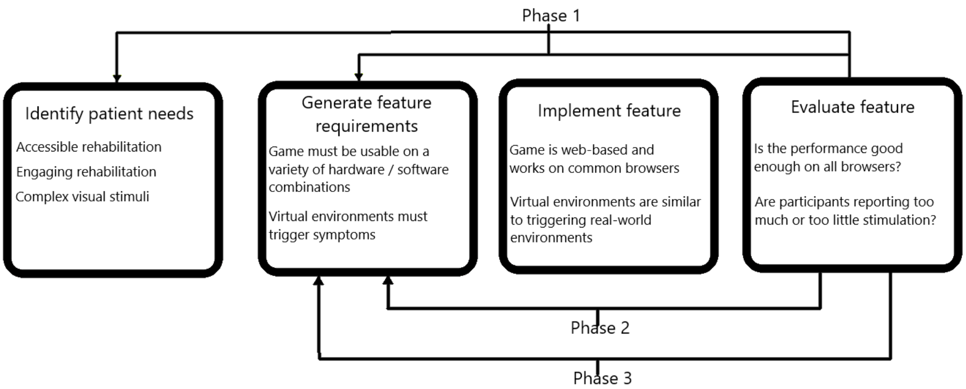

Figure 3, Illustration of the user-centric design approach. The examples given in each box illustrate the process for a subset of the features implemented in the game.

The aims of Phase 1 were to find whether the game was usable, accessible, and enjoyable. We wanted to ensure that the visual environments in the game triggered symptoms in a tolerable range (a predicted requirement for rehabilitation). We also asked patients for their suggestions for improvement. The game was then refined based on feedback from participants. In Phase 2, we tested whether the changes had been effective and investigated how patients saw the game potentially fitting into their life and rehabilitation plan. The flexibility of settings was increased within the game to better suit individual preferences. In Phase 3, we interviewed audio-vestibular clinicians to further improve the game design, find out how clinicians would envisage using the game in their practice, and determine the procedure for a future randomised controlled trial.

All procedures were approved by the Cardiff and Vale Health Board and the School of Psychology, ethics committee.

3.3 Participants

Participants were recruited from three sources: 1) Patients attending a vestibular clinic at the University Hospital of Wales (N= 11, Phase 1 and 2); 2) Individuals using a social media support group for people with PPPD (N = 10, Phase 2); 3) Clinical scientists in audiology and consultant audio-vestibular physicians who had treated patients with PPPD (N = 6, Phase 3). We also consulted with Mark Brown, a professional video game analyst.

Participants with PPPD/visual vertigo all completed a screening questionnaire, which collected basic demographic information (e.g. age) along with common measures of PPPD and visual vertigo symptoms (Niigata PPPD questionnaire, NPQ, Visual Vertigo Analogue Scale, VVAS) [6, 30]. Participants were also asked about any other current or previous vestibular conditions that they may have recovered from or were currently being treated for.

Participants who were recruited from hospital settings had all received a diagnosis of PPPD from a clinical scientist in audiology or a consultant audio-vestibular physician. Participants recruited from social media went through a screening survey and had a self-reported diagnosis of PPPD and/or clinically relevant scores in the Niigata PPPD Questionnaire (NPQ) (total score >= 27) [30] and Visual Vertigo Analogue Scale (VVAS, total score >10) [6] along with a history of PPPD symptoms that were not explained by other vestibular disorders. Participants did not receive payment or compensation. Table 1 shows participant number and demographics for each phase.

Demographic information of participants

	Phase 1	Phase 2
Recruited from	NHS (N = 7); Contacted Researchers (N = 4)	NHS (N = 4); Social Media (N =3); Contacted Researchers (N = 3)
Age (years)	53.5 (± 9.2)	41.7 (± 17.5)
VVAS Score	32.8 (± 16.8)	59.34 (± 19.49)*
NPQ Score	51.4 (± 22.39)	42.3 (± 6.51)**

Meniere's Syndrome	2	1
BPPV	2	2
Vestibular Neuronitis	2	0
Labyrinthitis	1	1
Vestibular Migraine	3	4
Vertigo due to stroke	1	0
Vertigo from head trauma	1	0
Non epileptic seizure vertigo	1	0
Mal de Embarquement	0	1
Senorineural hearing loss (non-vestibular)	0	1

Table 1, All participants withheld gender information. (*) One VVAS score from an NHS patient was not completed. (**) Only Social Media invites took the NPQ for being invited.

3.4 User-centred design procedure

Phase 1

Participants were initially contacted via email, then provided with a web link to the game and asked to play it for a minimum of 10 minutes, with no maximum time limit. The game was designed to be easy to pick up and play, but they were able to access a tutorial that explained the controls and different levels. At frequent points throughout the game (after 60 seconds and every ~30 seconds thereafter) the participants were asked to rate their current level of dizziness, nausea, or visual discomfort on a scale of 1-5 (1 - None, 2- A little, 3 - Moderate, 4 – A lot, 5 – A Great Amount).

After playing the game, the participants were asked to complete a Feedback Survey (delivered via Qualtrics ([23])). In the survey, participants were asked: whether they understood how to play the game, whether the game was easy to use, and whether they enjoyed playing it. Participants recorded which levels and environments they played, for how long they spent playing the game in total, and how long their symptoms persisted for. We also asked free response questions about what aspects participants liked, disliked, would add, remove, change, and whether they would play the game if it helped with symptoms. Participants also ranked the unpleasantness of doing different actions in the game. Participants were then asked the frequency that they typically played any video games (if they did), what hardware they used (e.g. phone, console), what types of game they played, and why they played games. For a full list of questions, see Supplementary Materials 1.

Quantitative survey data were averaged and plotted (see figure 4). Qualitative survey data were reviewed and coded on what types of changes participants wanted, what they liked, and what they disliked.

After the pilot with participants, we sought advice from a professional video-game analysis (Mark Brown from Game Maker's Toolkit) on how to improve the enjoyment and usability of the game, and we made modifications based on this feedback. Some of the changes included: adding additional puzzle modes, making the game controls more intuitive, experimenting with interactable world-based controls (making objects in the world the controls, e.g. signs to turn), and integrating sound cues.

Phase 2

In Phase 2, participants played the game while taking part in a one-hour online semi-structured interview (via Zoom, see Supplementary Materials 2). Interviews lasted for 60-90 minutes. The interview contained three sections: pre-game, gameplay, and post-game. The pre-game section involved asking the participants about their history with PPPD, their difficulties with getting a diagnosis, and their experiences with PPPD rehabilitation. The gameplay section involved the participants playing the simple and difficult versions of the Island and Forest environments. However, due to hardware limitations, or symptom limitations, not every participant did all four combinations. During this section, participants were prompted to vocalise their experiences as they were occurring, with follow-up dialogue based on this. If the participants did not comment on certain features, they were prompted on them (see Supplementary Materials 2). The post-game section involved asking the participants to provide feedback on what they liked, did not like, and where they think the game should go in the future. Whilst coping strategies and how to minimise experience symptoms were not part of the semi-structured interview prompts, they were mentioned by all participants either as coping with everyday life or specifically whilst playing the game. After all interviews were conducted, the interviews were transcribed and analysed by one of the authors (NG). There were three a priori areas for a directed analysis: Enjoyment & Engagement, Symptoms & Flexibility, Accessibility &

Usability. The interviews were then thematically analysed with each constructed theme being placed into one of these three areas, or not fitting into any of the three.

Participants also completed the system usability scale (SUS) [4], which provides a comparison of usability across different pieces of software. A score above 80 on the system usability scale indicates an above-average user experience in comparison to 241 industrial usability studies, with a score of 70 being above the median (50th percentile) [15].

Phase 3

Audio vestibular clinicians were sent a weblink to the game along with a feedback survey (see Supplementary Materials 3). The survey questions elicited feedback on what evidence clinicians would want before they would use the game, when they would use the game, and what features would need to be added or altered to improve the game. We wanted feedback from the clinicians that would allow the game to better suit their needs and fit in with how they treated their patients. Two of the six clinicians opted for a virtual meeting to complete the interview, whereas the other four provided written feedback.

4. Results

Participants played an average of 40 minutes of the game in Phase 1 (std = 37 minutes, range= 2.4 124) and 30 minutes in Phase 2 (exact timing not recorded because it was part of the interview). Feedback from phase 1 was used to improve the game ahead of phase 2. Every participant with PPPD or visual vertigo in Phase 2 said that they would play the game if it were shown to aid with rehabilitation.

4.1 Was the game accessible and useable?

During Phase 1, the game was rated as moderately easy to use (4.5, $\pm$ 2.9, out of 10), with moderately clear instructions (5.4, $\pm$ 2.8, out of 10), with nine participants experiencing smooth visuals (7.9, $\pm$ 2.4, out of 10) and one having technical issues and one not responding. 7 of 11 participants mentioned in feedback that the instructions needed to be clearer, and the game controls explained better. Of the participants in Phase 1, only 1 of 11 reported (who was 1 of the 7) not having played a computer or puzzle / board game before, indicating the issue was with the controls themselves rather than the gameplay.

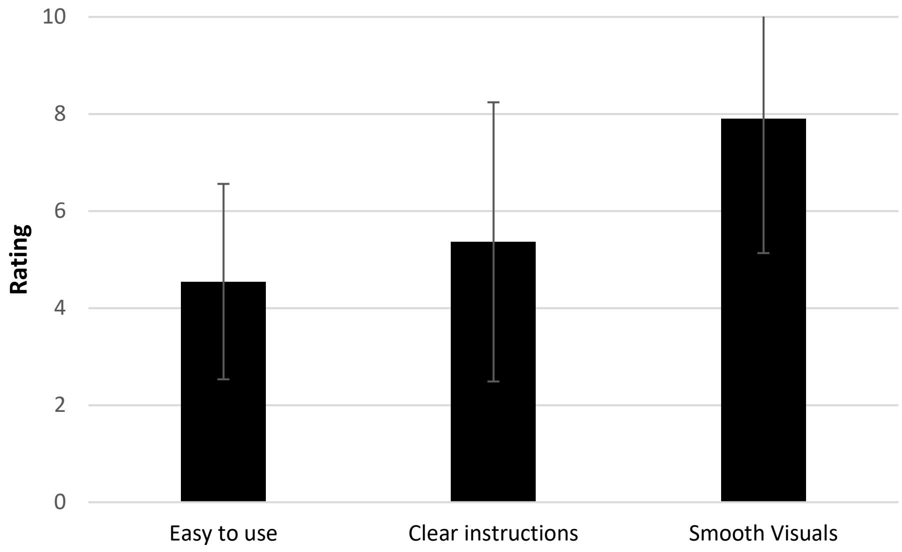

Figure 4, Mean ratings (from Phase 1) for whether participants found the game easy to use (n=11), having clear instructions (n=11), and smooth visuals (n=10). Error bars are ± standard deviation.

In Phase 2, participants completed the System Useability Scale, which is a standard measure of different aspects of usability in products and services [4]. As shown in figures 5A and 5B, the positive aspects of usability were rated generally high, while the negative aspects were rated generally low. Overall, the game had a usability score of 79, which corresponds to the 84th percentile relative to other pieces of software that have used the same scale [15]. Therefore, the modifications after Phase 1 appeared to lead to an improvement in usability in Phase 2. Some participants commented that the game was accessible even though they were not regular video game players: *"For someone who's not used to gaming at all, this would be good".*

However, 6 participants made at least one comment about having difficulty with at least one part of the user interface. We used this feedback to improve the game ahead of phase 3.

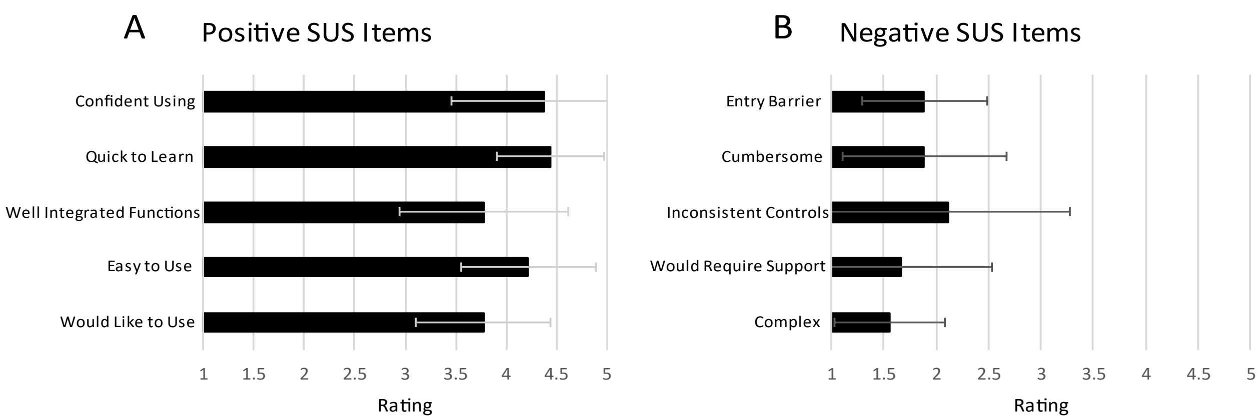

Figure 5, 5A shows the mean positively scored and 5B the mean negatively scored scales from the system usability scale (from Phase 2). Error bars are ± standard deviation.

4.2 Was the game enjoyable and engaging?

A key aim in the development of the game was that it was more enjoyable than currently available optokinetic stimuli, which lack active interaction or variation in visuals. In Phase 1, we asked participants with PPPD or visual vertigo rated the enjoyability of the game rated moderately low (3.4, ± 2.0 on a scale of 0 to 10). Follow-up questions confirmed that participants rated their enjoyment lower because they were experiencing more symptoms. Four of the participants specifically mentioned their symptoms being triggered was an aspect of the game they disliked; however, when asked if they would play the game if it was shown to improve symptoms, they said that they would.

During Phase 2, all 10 participants made comments on their enjoyment or engagement with the game. There was variation across participants in how much they enjoyed the game. One participant commented: "*It's a fun thing to do; you know it's going to help you*." Others said that they did not particularly enjoy playing the game – some because it triggered symptoms and some because they do not enjoy playing games in general.

However, all of the participants said they would play it if it was shown to reduce symptoms: *"I'd use it as much as I can on a daily basis, 100% as much as possible"; "If somebody said this will treat you, sign me up"; "I would play it probably. I would probably overplay it."*

A number of participants discussed how the game was better than alternative treatment, such as standard vestibular rehabilitation exercises: *"I'm probably more likely to do something like this [than] my [vestibular] exercises, because the exercises get monotonous",* and *"[if the physiotherapist had said] 'we're going to have you play this game for 20 minutes each day and as a replacement [to vestibular] exercises', I for sure would have".* Participants in Phase 2 requested more real-world situations in the future, including: driving, walking along a street, walking along a road with cars passing, walking to a supermarket, compared to abstract patterns or vestibular rehabilitation exercises.

One participant commented that the distraction of playing a game would be helpful while receiving rehabilitation: *"it is nice to have something simple and recognisable that you're actually focusing on that is relaxed, but you're also still testing your vestibular [system]".*

4.3 Did the game trigger symptoms in a tolerable range?

In Phase 1, we asked people with PPPD and visual vertigo symptoms to report the degree they were experiencing dizziness, visual discomfort, and nausea after 60 seconds and then approximately every

30 seconds afterwards whilst playing the game. The participants reported experiencing these symptoms in the range of 'a little' to 'a lot', with a mean dizziness rating of 2.76 (± 0.7), mean nausea rating of 2.22 (± 0.76), and a mean visual discomfort rating of 3.29 (± 1.37), all out of 5. The modal duration that participants reported triggered symptoms persisting for after playing the game was 15 minutes. This ranged from a minimum of less than 5 minutes to a maximum of over an hour.

In Phase 2, we asked participants to report the amount of dizziness they were currently experiencing on a scale of 0 (no dizziness) to 10 (worst possible dizziness), before, during, and 15 minutes post gameplay. As shown in figure 6, a repeated measures ANOVA found that ratings differed significantly between time points ($F_{2,18}$=17, $p < 0.001$, $\eta^2 = .66$). Post hoc analysis with a Bonferroni adjustment revealed that symptoms were rated significantly higher 'during' (2.8 (95% CI [1.60 to 4.00]), $p < 0.001$) and 'post' (2.8 (95% CI [1.27 to 4.33]), $p < 0.001$) gameplay than 'before' gameplay. During and post-gameplay ratings were not significantly different from one another (0.00 (95% CI [-2.03 to 2.03]), *n.s.*), suggesting that symptoms can remain at the same intensity even 15 minutes after the participants had stopped playing the game.

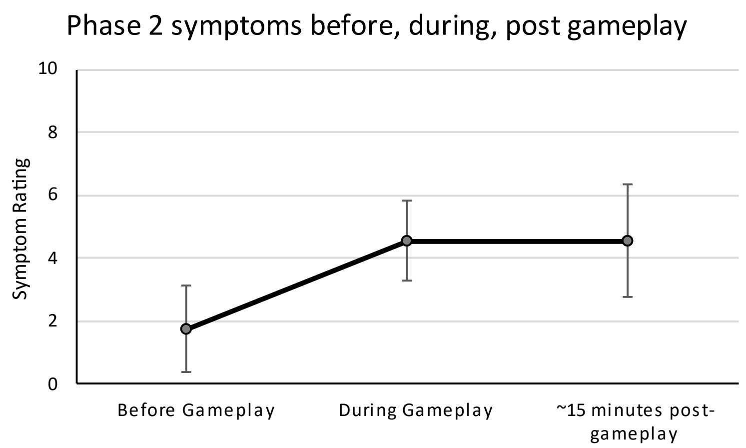

Figure 6. PPPD symptom rating of participants (N= 10) before, during, and 15 minutes post gameplay on a scale of 0 (no dizziness) to 10 (worst possible dizziness). Error bars are ± 1 Standard Deviation.

4.4 Was symptom intensity moderated by different worlds and settings in the game?

All of the participants in Phase 2 reported that symptoms were triggered by the game, and symptoms tended to increase with the intensity of the environmental levels, as intended. Some participants reported that 'unpredictability' or 'randomness' was particularly triggering, with one commenting that this made the experience more 'life like': *"I think that... the randomness of it is certainly much more triggering than [the] structure of it…, which makes it very like real life to me."* Aspects of the game that were particular triggering varied by participant, but some common themes emerged such as: horizontal screen movement, patterned floors, and swaying objects (particularly trees).

We also found that allowing participants to change the speed resulted in a change in symptoms, with faster speeds producing more symptoms (Table 2).

Participants' symptom response to speed

	Worse	No difference	Better	Did not alter speed
Faster Movement	4	5	0	2
Slower Movement	1	5	3	2

Table 2, Participants in Phase 1 reporting the effect of in-game movement speed on their symptom severity.

A key aim in development was to achieve very low levels of symptom provocation when participants started to play the game, so that patients with intense symptoms or high anxiety would not be put off rehabilitation. Feedback from participants in phase 2 suggested that this aim was achieved: *"It triggers symptoms for me on a very light level at the start of the experience."*

In Phase 2, 8 out of 10 participants reported using at least one coping strategy to reduce the intensity of visual stimulation and symptoms. For example, 7 participants said that they fixated on one area of the screen (e.g. bottom, centre, or the user interface) in order to reduce visual stimulation. Other forms of avoidance were also used, including closing the eyes or looking away from the screen.

4.5 Anxiety

It is well known that anxiety plays an important role in PPPD and visual vertigo as an outcome and exacerbator of dizziness symptoms. Although anxiety was not our main target for rehabilitation, we hypothesised that exposure to more realistic virtual environments might help to reduce anxiety towards the same environments when encountered in the real world. We did not specifically ask participants about their anxiety in Phase 1 or 2, however, some participants made comments spontaneously. One participant suggested that experiencing some of the environments in the game had helped to build their confidence in the real world: *"I find in real life I can't walk comfortably over a bridge. This game got me to feel better about it."*.

However, other participants talked about how playing the game could trigger some symptoms of anxiety: "*So .. that's anxiety inducing. It's like 'ohh where am I going and how fast and what's behind that corner? Am I going [to] bump into something?'*". Anxiety is likely to be a key factor that discourages people from engaging with the game for rehabilitation and is another reason why we have ensured that participants can start off with very low levels of visual stimulation.

4.6 Responses from clinicians

In Phase 3, we interviewed 6 audio-vestibular clinicians about the game and recorded their suggestions for improvement. All of the clinicians said that they would recommend the game to patients if there were evidence of improvement in symptoms. Interestingly, most (5) of the clinicians said that they would prioritise a reduction in anxiety over dizziness symptoms. Clinicians suggested that we measure improvements in dizziness symptoms via self-report questionnaires (e.g. vestibular rehabilitation benefit questionnaire [16, 17]) and posturography.

Suggestions for gameplay changes to improve the rehabilitation included: increased complexity to challenge patients, new virtual environments that are commonly encountered, and introducing moving objects on the screen. Based on this feedback: we implemented optional floor patterns in the Supermarket environment to increase visual intensity; the Desert environment went through a small redesign to become simpler to navigate; the spawned tree placement in the Forest environment was altered and had additional options; finally, their feedback influenced the final settings for the camera movement options.

We asked the clinicians how they saw the game fitting into their clinical practice. They discussed the best stage to fit the game into their treatment pipeline, and all said they would most likely introduce it during their second meeting, with the initial meeting explaining PPPD to the patient and going over how it affects them, and what to expect. The game would only be recommended to patients if clinicians thought they were technologically adept enough to play it unsupervised. Even though the game could be utilised during a waiting list, there were concerns over whether patients would know what environment and visual difficulties to target. The primary concern was that patients would set the starting visual intensity too high.

An issue that was identified in both Phase 1 and Phase 2 was how to effectively teach users how to play the game. The clinicians suggested using short tutorial videos, going through instructions with their patients during consultations, pop-ups within the game, and written instructions. Following this feedback, we have developed a set of tutorial videos for learning how to use the game, which can be viewed on YouTube or the CUDL website (https://cudizzylab.org/guide-to-balanceland/).

5. Discussion

We have presented the development process for Balance-Land, a new rehabilitation game for PPPD and visual vertigo based on the principles of visual desensitisation. We wanted Balance-Land to be: 1) Accessible to novice game users; 2) Engaging to increase treatment adherence; 3) Flexible over pace and visual complexity, provoking symptoms in a graded way. The game was developed over three phases of feedback with patients, clinicians, and a video game analyst. People with PPPD and visual vertigo said that they would use the game if there was evidence that it helped to reduce symptoms. Clinicians also said they would recommend the game to patients, if efficiency was established. Both groups felt that the game-based approach was better than current alternatives because it was more engaging and allowed greater control over visual stimulation intensity.

5.1 Accessible

A key aim in the development of the game was that it was accessible for people who did not play video games or had low digital experience. We chose word-based games that did not require complex controls and where the puzzle difficulty was de-coupled from the visual stimulation intensity. People with PPPD completed the System Usability Scale (SUS), which measures usability in comparison to other digital tools. Balance-Land had a usability score of 79, placing it at the 84th percentile relative to other software [15]. We assimilated feedback from all three phases of the development to make the game as accessible and easy to use as possible. We also ensured that the game could run on relatively low computer processing power, graphics processing, and hardware specifications. Despite this, it is still possible that some individuals may face barriers to accessing the game. Very low digital skills or access to hardware are key feasibility concerns to consider in a future RCT. The benefit of standard vestibular rehabilitation exercises is that they require no equipment or resources. However, Balance-Land should be accessible to those with mainstream computer equipment (laptops, tablets), and we argue that it is more accessible than approaches requiring specific hardware such as computer game consoles and virtual reality headsets, due to their cost and technical knowledge requirement.

5.2 Engaging

One of the often-quoted issues with current rehabilitation exercises is that they are repetitive and dull, and patients can find it hard to keep going. We wanted to ensure that the game was enjoyable and engaging in order to encourage patients to continue rehabilitation. One difficulty is that visual desensitisation tends to trigger dizziness, nausea, and visual discomfort, and we found this was also true for Balance-Land. We intended for the game to trigger some symptoms because this is thought to be a pre-requisite for the desensitisation effect, similar to other forms of visual rehabilitation, such as a virtual reality rollercoaster [24], the Wii [29], abstract optokinetic patterns [18], and virtual reality stimulation [8]. We found that symptom provocation was (unsurprisingly) a reason why participants did not always enjoy playing the game. However, all of our participants said that they would play the game if it were shown to be effective. Furthermore, a number commented that the game was more enjoyable and engaging than their standard vestibular rehabilitation exercises.

5.3 Flexible

Balance-Land was designed so that the visual stimulation delivered could be tailored to the individual needs of the patient. Users can select from three ‘worlds’ different in visual intensity, adjust the speed of movement, and add in additional motion (e.g. head bob). In particular, we wanted to ensure that patients could start the game with very low level of intensity if needed. This feature is something that could make Balance-Land more appealing than off-the-shelf video games (e.g. Wii Balance board, skiing simulators), which have been used by patients and clinicians in the past. These off-the-shelf games only allow minimal adjustments in visual intensity. They also do not generally target the real-world environments that are most problematic for patients, such as supermarkets. Real world environments were often requested by patients and clinicians in our study. While there is currently no concrete evidence that real-world environments enhance sensorimotor rehabilitation, our hypothesis, shared by the patients and clinicians in our study, is that exposure to virtual versions of problematic environments would help to reduce anxiety when visiting the real environments. We found some initial support for this from patient feedback. One interesting finding from the study was that most of the clinicians mentioned that addressing anxiety was often a higher priority than visual-vestibular rehabilitation itself. This supports promising new research by Herdman et al. suggesting that cognitive-behavioural therapy (CBT) could provide better health outcomes than visual-vestibular therapy alone for PPPD [12]. In the future, we intend to examine how Balance-Land could be integrated with approaches focusing on anxiety and depression.

5.4 Improvements to Balance-Land following this study

The most current version of the game can be found at: https://game.cudizzylab.org . The user interface has been streamlined, focusing on removing anything that is not necessary and making the controls intuitive and accessible. The more advanced controls are gated behind menus, to ensure participants do not accidently aim for settings that are too triggering. The gameplay has been expanded to include three game modes: Make Words, Find Words, and Shop (see figure 2). These games all offer a different style of playing through the level, and feedback can be provided to participants on their gameplay and progress to keep them engaged, such as their discriminability in Find Words (d’). To decrease loading time, the world is now a permanent map with three virtual environments of differing visual complexity: Desert, Forest, and Supermarket (see figure 2). The map can be expanded to include other environments that participants have requested.

5.5 Limitations and next steps

It is important to emphasise that the efficacy of Balance-Land for rehabilitation has not yet been tested. The next step will be a feasibility trial for a 6-week period to assess frequency and duration of use in an everyday context, duration of symptoms, and any further issues of accessibility and usability. Based on clinician feedback in phase three, we anticipate a clinician would potentially use Balance-Land as one tool in their arsenal to treat PPPD or symptoms of visual vertigo in other conditions, introducing the game to a patient and recommending appropriate levels and features for each patient's need. As recommended by clinicians and patients, in the future, we plan to add more environments into the game to help build confidence in visiting similar environments in real life.

If Balance-Land is to be accessible on commonly owned IT equipment, then it will always be limited in terms of screen size and field of view. It is likely that stimulating the visual periphery with motion is helpful for rehabilitation, but doing this in a game context would require bespoke equipment or VR headsets (which also are limited in field of view, but less so than laptops or iPads). However, our initial exploration with VR headsets indicated that most patients would likely suffer too much dizziness and nausea in such an environment. There is also some evidence that VR can increase visual dependence, rather than lessen it [9]. Therefore, we envisage that it may remain necessary to complement Balance-Land with other rehabilitation exercises that are not screen-based, so as to utilise a wider field of visual stimulation.

6. Conclusion

Balance-Land appears to fulfil its aims as a usable, moderately enjoyable, and flexible game that could potentially become one of the available options for rehabilitation of PPPD and visual vertigo symptoms in other conditions. We emphasise that rehabilitation efficacy has not yet been tested, although the game is based on clinically used and evidenced principles of desensitisation to visual flow.

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8. References

[1] C. Abras, D. Maloney-Krichmar and J. Preece, User-centered design, *Bainbridge, W. Encyclopedia of Human-Computer Interaction. Thousand Oaks: Sage Publications* **37** (2004), 445-456.

[2] T. Brandt, Phobic postural vertigo, *Neurology* **46** (1996), 1515-1519.
[3] A.M. Bronstein, The visual vertigo syndrome, *Acta Oto-Laryngologica Supplement 520 Pt 1:45-8, 1995* **520 Pt 1** (1995), 45-48.
[4] J. Brooke, SUS-A quick and dirty usability scale, *Usability evaluation in industry* **189** (1996).
[5] D. Catuhe, Babylon.js, github.com/BabylonJS/Babylon.js, 2013.
[6] E. Dannenbaum, G. Chilingaryan and J. Fung, Visual vertigo analogue scale: An assessment questionnaire for visual vertigo, *Journal of Vestibular Research: Equilibrium & Orientation* **21** (2011), 153-159.
[7] M. Dieterich and J.P. Staab, Functional dizziness: from phobic postural vertigo and chronic subjective dizziness to persistent postural-perceptual dizziness, *Current Opinion in Neurology 30(1):107-113, 2017 02* **30** (2017), 107-113.
[8] P.-A. Fransson, M. Patel, H. Jensen, M. Lundberg, F. Tjernström, M. Magnusson and E. Ekvall Hansson, Postural instability in an immersive Virtual Reality adapts with repetition and includes directional and gender specific effects, *Scientific reports* **9** (2019), 1-10.
[9] M. Gallagher, R. Choi and E.R. Ferrè, Multisensory interactions in virtual reality: optic flow reduces vestibular sensitivity, but only for congruent planes of motion, *Multisensory research* **33** (2020), 625-644.
[10] R. Gamble, *Exploring factors associated with persistent postural-perceptual dizziness (PPPD): A mixed-methods approach*, Cardiff University, 2022.
[11] E. Games, Unreal Engine, Unreal Engine, https://www.unrealengine.com, 2023.
[12] D. Herdman, S. Norton, L. Murdin, K. Frost, M. Pavlou and R. Moss-Morris, The INVEST trial: a randomised feasibility trial of psychologically informed vestibular rehabilitation versus current gold standard physiotherapy for people with Persistent Postural Perceptual Dizziness, *Journal of Neurology 2022 Apr 10* (2022).
[13] I. Indovina, V. Maffei and F. Lacquaniti, Anticipating the effects of visual gravity during simulated self-motion: Estimates of time-to-passage along vertical and horizontal paths, *Experimental Brain Research* **229** (2013), 579-586.
[14] R.G. Jacob, M.S. Redfern and J.M. Furman, Space and motion discomfort and abnormal balance control in patients with anxiety disorders, *Journal of Neurology, Neurosurgery & Psychiatry* **80** (2009), 74-78.
[15] J.R. Lewis and J. Sauro, Item benchmarks for the system usability scale, *Journal of Usability Studies* **13** (2018).
[16] A.E. Morris, M.E. Lutman and L. Yardley, Measuring outcome from Vestibular Rehabilitation, Part I: Qualitative development of a new self-report measure, *International journal of audiology* **47** (2008), 169-177.
[17] A.E. Morris, M.E. Lutman and L. Yardley, Measuring outcome from vestibular rehabilitation, part II: refinement and validation of a new self-report measure, *International journal of audiology* **48** (2009), 24-37.
[18] M. Pavlou, A.M. Bronstein and R.A. Davies, Randomized trial of supervised versus unsupervised optokinetic exercise in persons with peripheral vestibular disorders, *Neurorehabilitation and Neural Repair* **27** (2013), 208-218.
[19] M. Pavlou, A. Lingeswaran, R.A. Davies, M.A. Gresty and A.M. Bronstein, Simulator based rehabilitation in refractory dizziness, *Journal of neurology* **251** (2004), 983-995.
[20] S. Popkirov, J.P. Staab and J. Stone, Persistent postural-perceptual dizziness (PPPD): a common, characteristic and treatable cause of chronic dizziness, *Practical Neurology 18(1):5-13, 2018 Feb* **18** (2018), 5-13.
[21] S. Popkirov, J. Stone and D. Holle-Lee, Treatment of Persistent Postural-Perceptual Dizziness (PPPD) and Related Disorders, *Current Treatment Options in Neurology 20(12):50, 2018 Oct 13* **20** (2018), 50.

[22] G. Powell, H. Derry-Sumner, D. Rajenderkumar, S.K. Rushton and P. Sumner, Persistent postural perceptual dizziness is on a spectrum in the general population, *Neurology* **94** (2020), e1929-e1938.
[23] Qualtrics, Qualtrics, Qualtrics, https://www.qualtrics.com, 2005.
[24] R. Riccelli, L. Passamonti, N. Toschi, S. Nigro, G. Chiarella, C. Petrolo, F. Lacquaniti, J.P. Staab and I. Indovina, Altered Insular and Occipital Responses to Simulated Vertical Self-Motion in Patients with Persistent Postural-Perceptual Dizziness, *Frontiers in neurology [electronic resource] 8:529, 2017* **8** (2017), 529.
[25] J.P. Salmon, S.M. Dolan, R.S. Drake, G.C. Wilson, R.M. Klein and G.A. Eskes, A survey of video game preferences in adults: Building better games for older adults, *Entertainment computing* **21** (2017), 45-64.
[26] L. Sardi, A. Idri and J.L. Fernández-Alemán, A systematic review of gamification in e-Health, *Journal of biomedical informatics* **71** (2017), 31-48.
[27] J.P. Staab, Chronic subjective dizziness, *CONTINUUM: Lifelong Learning in Neurology* **18** (2012), 1118-1141.
[28] J.P. Staab, A. Eckhardt-Henn, A. Horii, R. Jacob, M. Strupp, T. Brandt and A. Bronstein, Diagnostic criteria for persistent postural-perceptual dizziness (PPPD): Consensus document of the committee for the Classification of Vestibular Disorders of the Barany Society, *Journal of Vestibular Research 27(4):191-208, 2017* **27** (2017), 191-208.
[29] D.H. Verdecchia, M. Mendoza, F. Sanguineti and A.C. Binetti, Outcomes after vestibular rehabilitation and Wii® therapy in patients with chronic unilateral vestibular hypofunction, *Acta Otorrinolaringologica* **65** (2014), 339-345.
[30] C. Yagi, Y. Morita, M. Kitazawa, Y. Nonomura, T. Yamagishi, S. Ohshima, S. Izumi, K. Takahashi and A. Horii, A Validated Questionnaire to Assess the Severity of Persistent Postural-Perceptual Dizziness (PPPD): The Niigata PPPD Questionnaire (NPQ), *Otology & Neurotology 40(7):e747-e752, 2019 08* **40** (2019), e747-e752.
[31] L. Yardley, E. Masson, C. Verschuur, N. Haacke and L. Luxon, Symptoms, anxiety and handicap in dizzy patients: development of the vertigo symptom scale, *Journal of psychosomatic research* **36** (1992), 731-741.