The Impact of Visual Feedback and Avatar Presence on Balance in Virtual Reality

Stefan Resch
University of Cadiz
Cadiz, Spain
stefan.resch@alum.uca.es
Frankfurt UAS
Frankfurt am Main, Germany

Rohan Brijesh Tiwari
Frankfurt UAS
Frankfurt am Main, Germany
tiwari.rohan-brijesh@stud.fra-uas.de

Heer Rakeshkumar Vankawala
Frankfurt UAS
Frankfurt am Main, Germany
heer.vankawala@stud.fra-uas.de

Priya Singh
Frankfurt UAS
Frankfurt am Main, Germany
priya.singh@stud.fra-uas.de

Mustafa Rafati
Frankfurt UAS
Frankfurt am Main, Germany
mustafa.rafati@stud.fra-uas.de

Valentin Schwind
Frankfurt UAS
Frankfurt am Main, Germany
valentin.schwind@fb2.fra-uas.de

Diana Völz
Frankfurt UAS
Frankfurt am Main, Germany
voelz@fb2.fra-uas.de

Daniel Sanchez-Morillo
University of Cadiz
Cadiz, Spain
daniel.morillo@uca.es

ABSTRACT

Balance board training is a promising method to enhance physical rehabilitation for humans with motor problems through interactive exercises. Previous work highlighted the benefits of balance board training in virtual reality (VR) compared to conventional methods. However, it is still unclear how visual target feedback and the presence of an avatar influence balance behavior in immersive environments. We conducted an experimental user study with 24 participants without motor impairments to investigate the effects of visual target feedback and a human avatar on balance performance and perceived workload in VR. Quantitative results show that visual target feedback significantly improves balance performance without increasing workload in VR. In contrast, an avatar shows no effect on performance and workload, which is also confirmed by qualitative feedback. Finally, we discuss the implications of our study for future developments of virtual balance board training exercises and highlight potential applications of visual target feedback.

CCS CONCEPTS

• **Human-centered computing** → **Human computer interaction (HCI)**; **Empirical studies in HCI**; **Virtual reality**.

KEYWORDS

Virtual Reality, Balance Board, Visual Feedback, Human Avatar

MuC '24, September 01–04, 2024, Karlsruhe, Germany

ACM ISBN 979-8-4007-0998-2/24/09
https://doi.org/10.1145/3670653.3677472

ACM Reference Format:
Stefan Resch, Rohan Brijesh Tiwari, Heer Rakeshkumar Vankawala, Priya Singh, Mustafa Rafati, Valentin Schwind, Diana Völz, and Daniel Sanchez-Morillo. 2024. The Impact of Visual Feedback and Avatar Presence on Balance in Virtual Reality. In *Proceedings of Mensch und Computer 2024 (MuC '24), September 01–04, 2024, Karlsruhe, Germany*. ACM, New York, NY, USA, 5 pages. https://doi.org/10.1145/3670653.3677472

1 INTRODUCTION AND BACKGROUND

Humans with motor problems often have difficulties with balance, which can lead to gait instability and possible falls. In rehabilitation and prevention, training with a balance board is recognized as a reliable and proven tool for enhancing motor tasks and posture control [6, 20]. Previous work has highlighted the benefits of virtual reality (VR) in balance training [5, 14, 19]. A systematic literature review and meta-analysis by De Rooij et al. [5] showed that training in VR can significantly improve the balance and walking ability of stroke patients compared to conventional therapy.

Based on these findings, the combination of VR training with various feedback modalities (e.g., auditory, visual, or haptic feedback) could further improve balance ability. For example, Alhasan et al. [1] have stated that the addition of visual biofeedback on balance offers great potential for improving balance ability. In immersive environments, such as VR, only a few studies have explored the effects of different feedback modalities on balance performance while balancing on a board. As an example, Mahmud et al. [13] demonstrated that incorporating vibrotactile feedback within VR enhances standing balance. In a follow-up study with 100 participants (50 with balance impairments and 50 without balance impairments), Mahmud et al. [12] compared four different visual feedback approaches for standing balance in VR. They found that static, rhythmic, and center of pressure-based visual feedback significantly enhanced standing balance. In these studies, balance was assessed while participants were standing on a stable, non-moving board. Another approach was demonstrated by Resch et al. [18], who presented a setup with a moving balance board in VR to assess the visual influence of body perception on balance behavior. Nevertheless, a detailed user study to validate the influence on balance behavior is currently missing.

Besides the research on different feedback modalities in immersive environments, the field of Human-Computer Interaction (HCI) increasingly explores the perception of virtual avatars [2, 4, 7, 15, 17]. Research suggests that the presence of avatars can be an effective tool to positively impact users during physical activities [9]. For example, Kocur et al. [10] demonstrated that embodying muscular avatars in VR can decrease perceived effort and enhance physical performance. Additionally, Latoschik et al. [11] showed that realistic avatars can improve user engagement and social interactions in VR. These findings indicate that avatars have the potential to influence both user experience and physical performance. However, it is still unknown how the visualization of a human avatar and visual target feedback influence balance performance and workload in VR. Filling this research gap will provide new insights into how to improve balance board training in a VR environment. In this context, it becomes feasible to develop a feedback-based balance board training in VR for patients with balance disorders in the future.

This paper presents the results of an experimental user study that included 24 participants to evaluate the effects of visual target feedback and a human avatar on balance performance and perceived workload while balancing in VR. The results indicate that visual target feedback improves balance performance without increasing the subjective perceived workload in VR. In contrast, the presence of an avatar shows no effect on balance performance and perceived workload. Based on these findings, future applications of balance training in VR can be optimized through visual user feedback.

2 METHOD

We conducted an experimental user study to investigate the effects of a human avatar and visual target feedback on balance performance and perceived workload in VR. A two-factorial within-subject design was carried out with the independent variables, Avatar and Target, each consisting of two levels: *visible* and *invisible*. We hypothesized that a *visible* Target and a *visible* Avatar improve balance performance without increasing the workload in VR. A balanced Latin square design was used to counterbalance the order of conditions for each participant and prevent any sequencing effects.

2.1 Conditions and Stimuli

Figure 1 compares the virtual environment, featuring a visible avatar balancing in front of a visual target, with the real environment. To enhance the realism of each condition, the laboratory where the user study was conducted has been completely rebuilt as a virtual environment. The Unity project used for the virtual laboratory scene can be found in the supplementary GitHub repository[1]. The virtual avatar was created using Mixamo[2] and animated by an OptiTrack[3] skeleton. The body size of the virtual avatar in VR was scaled according to the real body dimensions that were previously recorded. A 2D canvas was created and placed 150 centimeters in front of the virtual participant to provide visual target feedback. The distance between the canvas and the ground was adjusted according to participant height, ensuring the visual target was displayed at eye level. The visual target was divided into three circular zones (inner, middle, and outer circle) to classify balance behavior. A moving dot represented the balance board's center of gravity. It displayed the board's angular alignment within these three zones in real time to provide visual feedback to participants. The three circle zones were defined as follows:

- Inner circle (angle between 0 and 3.69 degrees): Green dot indicated good balance behavior.
- Middle circle (angle between 3.7 and 7.39 degrees): Yellow dot indicated medium balance behavior.
- Outer circle (angle between 7.4 and 11 degrees): Red dot indicated poor balance behavior.

2.2 Apparatus

The technical setup was based on a motion capture (MoCap) system by OptiTrack. Sixteen cameras (Type: PrimeX 13W) with a frame rate of 240 Hz were used to track the balance performance. The system was calibrated according to OptiTrack specifications, resulting in the following precision: mean ray error = 0.98 mm, mean wand error = 0.23 mm. Motive[4] 3.0.1 software from OptiTrack was used to record all tracking data. The Balance Board MFT Challenge Disc 2.0[5] was tracked as a rigid body through eight markers on the surface (arranged at an angle of 45 degrees). The balance board had a maximum rotation angle of eleven degrees. The HTC Vive Pro 2 with a frame rate of 90 frames per second (FPS) was used as the head-mounted display (HMD). In the laboratory, four HTC base stations were installed for high-precision tracking. To track the human body and create a visual avatar, participants wore a MoCap suit by OptiTrack (consisting of a jacket, pants, foot wraps, and gloves). Forty-nine reflective markers were attached to the human body, three of them to the HMD (template: baseline and passive fingers). Unity[6] 3D engine (version 2020.3.41f1) was used to create the VR environment on a Windows 10 workstation with an AMD Ryzen 5900X, a GeForce RTX 3700, and 16 GB RAM.

2.3 Procedure and Tasks

The user study was conducted under laboratory conditions without external influences, such as environmental noise or interruptions. After signing the informed consent, all participants were surveyed for their demographics and filled out a pre-study questionnaire through a Google form link. This form included questions about previous experience with a balance board or similar devices, VR, and a self-assessment of body balance and fitness level. After finishing the questionnaire, the participants put on a MoCap suit, gloves, and foot wraps (all from OptiTrack). Afterwards, participants set up and adjusted the HMD. Subsequently, the research team manually positioned all 49 marker points. To group the marker points into a skeleton, the participants adopted the T-pose. Before the experiment started, each participant was provided a verbal briefing and

[1]https://github.com/valentin-schwind/frauas-vr-labor
[2]https://www.mixamo.com/
[3]https://optitrack.com/
[4]https://optitrack.com/software/motive/
[5]https://www.mft-bodyteamwork.com/produkte/mft-challenge-disc/
[6]https://unity.com/

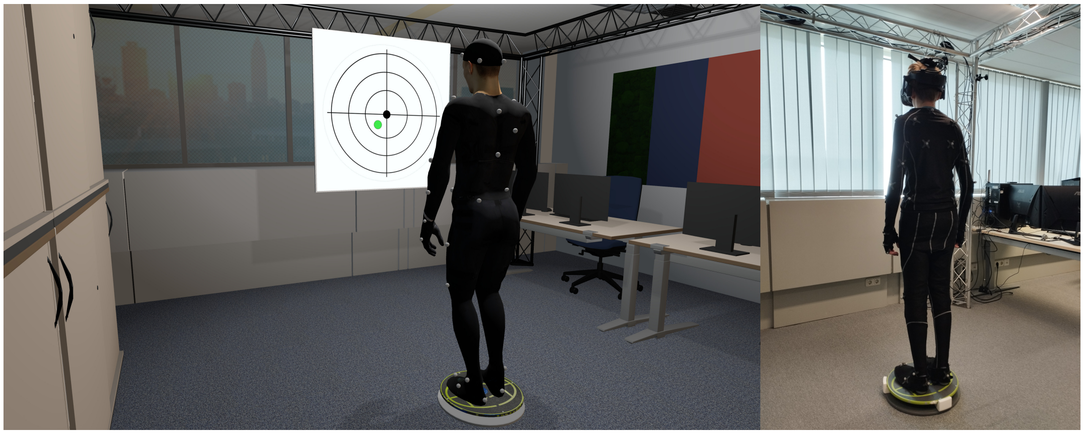


Figure 1: The left side illustrates a participant balancing in the virtual laboratory environment during the condition with a visible avatar and a visible target, whereas the right side shows a photo of the real environment during balancing in the laboratory.

introduced to the VR environment. Depending on the participants' height, the position of the visual target was manually adjusted before the start of the first task. Participants were then placed at a marked spot on the board. Three fixation components, 3D-printed from Polylactide, secured the board in a static position, enabling participants to step onto it. At the beginning of each task, the three fixation elements were removed simultaneously to enable free balancing of the board. Every task began with a noticeable five-second countdown. The duration of each task was four minutes, divided into two phases of 120 seconds of balancing, separated by a one-minute break. At the end of each task, the three fixation components were reattached to secure the board, allowing participants to safely dismount and sit on a chair. Finally, the NASA raw taskload index (RTLX) questionnaire was displayed for participants to complete in the VR environment. This procedure was repeated for each of the remaining three conditions. The order of the four conditions was randomized for each participant using a 4x4 balanced Latin square design. After completing all tasks, the participants received a post-study questionnaire via a Google form link. This questionnaire included closed and open-ended questions on the preferred tasks, the perception of the avatar and target, as well as the reasons for each answer. The duration of the study was approximately 40 minutes per participant.

2.4 Measures and Data Analysis

In this study, we quantitatively measured balance performance (objective) and workload (subjective), and obtained additional qualitative feedback via questionnaires.

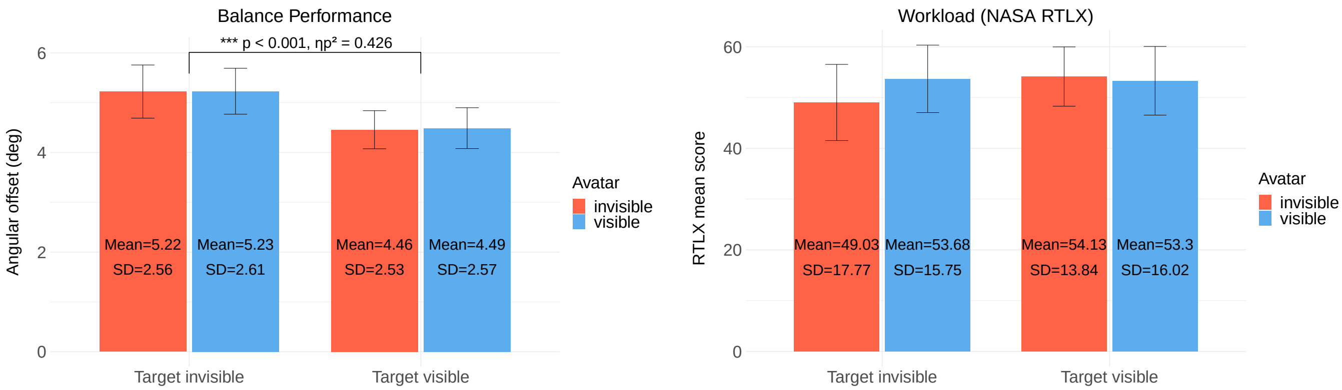
2.4.1 Quantitative objective: Balance Performance. To objectively assess balance performance, the angle of board deflection was measured over the entire task duration. The raw marker data was extracted from the Motive software to evaluate the balancing performance. The Roll and Pitch measurements of the board are relevant for the evaluation process, as they depict the medial-lateral rotation around the sagittal body axis (Roll) and anterior-posterior tilt around the transverse body axis (Pitch). Because all participants had the same foot position on the board, the values for roll and pitch are universally applicable. Over the entire task duration of 240 seconds, these two movements were recorded with a frequency of 90 FPS, which equates to 21,600 data points per task. The quantitative data was analyzed using inferential statistics, a two-factorial repeated-measures (RM) analysis of variance (ANOVA).

2.4.2 Quantitative subjective: Workload. After each condition, participants assessed their perceived workload in VR using the NASA RTLX [8] consisting of six subscales (mental demand, physical demand, temporal demand, performance, effort, and frustration). The standardized questionnaire was completed as a digital questionnaire in VR, as recommended by previous work [16]. The quantitative data was also analyzed using a two-factorial RM ANOVA.

2.4.3 Questionnaires. To obtain a deeper understanding of personal perceptions, each participant completed two questionnaires, one before and one after the study. The preliminary questionnaire included the demographics, as well as questions regarding previous experience with a balance board and VR. Participants were also asked for a self-assessment of their balance behavior and sports activities. The post-study questionnaire included closed and open-ended questions on the preferred balancing task, perceived performance, and personal opinion on training in VR. A thematic analysis [3] was used for the qualitative assessment of the open-ended questions. The anonymized data was coded and analyzed paragraph-wise by two reviewers independently. Finally, the codes were combined and cross-checked to ensure consistency. The closed-ended questions were based on countable feedback (multiple-choice questions) on personal preferences and were analyzed using descriptive statistics.

2.5 Participants

Participants were invited and recruited via mailing lists within our institution. Three exclusion criteria were specified: any impairment of the sense of balance, any physical injuries (e.g., broken bones) or recent surgeries, and a maximum body weight of 120



(a) Quantitative objective results: Balance Performance **(b) Quantitative subjective results: Workload**

Figure 2: Two bar charts - (a) the visual feedback shows a significant effect on the angular offset of the balance board, and (b) the perceived workload shows no effect in each condition.

kilograms. Twenty-six participants (10 female, 16 male) took part in the user study. All of them had a technical background in computer science or engineering. Two participants (one female, one male) were excluded from the evaluation because of interruption due to cybersickness. The age of the included participants ranged from 21 to 32 years (M = 25.17, SD = 3.06). Nine had previous VR experience, six wore glasses, and two wore contact lenses. Ten participants regularly engaged in sports, and one had previously used a balance board or similar device. Participants were given the freedom to pause or discontinue the study at any time. The study received ethical clearance according to the privacy regulations and hygiene protocols for user studies as required by our institution.

3 RESULTS

Evaluation of the quantitative results - objective balance performance (section 3.1.1) and subjective workload (section 3.1.2) - was performed using a two-factorial RM ANOVA and is shown in Figure 2. Qualitative feedback from the post-study questionnaire was assessed using thematic analysis and is documented in section 3.2.

3.1 Quantitative Results

3.1.1 Objective: Balance Performance. Results of the balance performance, including descriptive statistics, are shown in Figure 2a. For the evaluation of balance performance, measured values exceeding 10.5 degrees were excluded, considering that the maximum deflection angle of the board is 11 degrees. This criterion was applied because, at maximum deflection, the board remains in a stationary inclined position, which does not accurately represent free balancing behavior. A parametric test on normal distribution was performed with the Shapiro-Wilk's normality test, which indicated normal distribution (all conditions with $p \geq 0.05$). A two-factorial RM ANOVA showed a statistically significant main effect on TARGET, $F(1, 23) = 17.089$, $p = 0.0004$, $\eta_p^2 = 0.426$ (large effect size). However, AVATAR showed no statistically significant main effect $F(1, 23) = 0.041$, $p = 0.842$, $\eta_p^2 = 0.002$, as well as no interaction effect between AVATAR and TARGET $F(1, 23) = 0.007$, $p = 0.933$, $\eta_p^2 = 0.0003$. Pairwise post hoc comparisons using Bonferroni-corrected t-tests revealed significant differences between TARGET *visible* and TARGET *invisible* ($p = 0.00073$), but no significant differences were found between AVATAR *visible* and AVATAR *invisible* ($p = 0.933$).

3.1.2 Subjective: Workload. Results of the perceived workload, including descriptive statistics, are shown in Figure 2b. Shapiro-Wilk's test confirmed normal distribution of all data (all conditions with $p \geq 0.05$). A two-factorial RM ANOVA on the RTLX scores of AVATAR and TARGET indicated no statistically significant effect on the overall workload. There was no main effect on AVATAR $F(1, 23) = 1.177$, $p = 0.289$, $\eta_p^2 = 0.049$, nor on TARGET $F(1, 23) = 1.934$, $p = 0.178$, $\eta_p^2 = 0.078$, and no interaction effect on AVATAR and TARGET $F(1, 23) = 1.178$, $p = 0.289$, $\eta_p^2 = 0.049$. In addition, there was no statistically significant effect on the six subscales ($p > 0.05$).

3.2 Questionnaires

The final evaluation of questionnaires revealed that seven participants reported a change in their perception of body balance after balancing in VR. Meanwhile, eight responded with "cannot determine," and nine "felt no change." Overall, eleven participants felt "confident" while using the balance board in VR, with an equal number feeling "neutral." Only two felt "unsure" while balancing. As preferred condition, eleven participants chose AVATAR *invisible* and TARGET *visible* because "visible avatar did not add much value for me" (P4, P25) and "avatar distracted me from focusing" (P3, P13). The second highest-rated condition was AVATAR and TARGET *visible* (N=8), followed by the condition AVATAR *visible* and TARGET *invisible* (N=3), and finally AVATAR and TARGET *invisible* (N=2). Visual target feedback was perceived as helpful in improving balance behavior by 22 participants, as it "enhances concentration" (P4, P11, P19). In contrast, two participants voted that it is not helpful and mentioned that "it made [them] more nervous" (P12), and "when [the] target is not visible you feel less pressured" (P9). The presence of a human avatar was perceived as not helpful in improving balance behavior by 13 participants, as they "did not [look] at the avatar" (P11, P12). Lastly, 21 participants found the tasks in VR motivating for future use, compared to three participants who did not.

4 DISCUSSION

In an experimental user study with 24 participants, we investigated the effects of a human Avatar and visual Target feedback on balance in VR. The analysis of balance performance and perceived workload confirmed our hypothesis that visual Target feedback significantly enhances balance control without increasing workload in VR. However, contrary to our expectations, the presence of a human Avatar did not significantly improve balance performance. Similarly, the Avatar had no influence on workload in VR. The qualitative data supports the quantitative results and shows that participants preferred colored Target feedback, while they perceived the Avatar as unhelpful. However, the results have limitations in generalizability. The user study was conducted in a controlled environment with a small sample size, unequal gender distribution, a non-representative age range, and only healthy individuals. In addition, the visualization of the human Avatar was not personalized, which may impair realism. Based on these findings, follow-up studies will be conducted with a representative sample to develop a balance training environment with real-time feedback application. Additionally, future research should investigate the effectiveness of traditional screen-based, VR, and Augmented Reality feedback setups for balance training, as well as conduct long-term studies to assess whether the training leads to lasting improvements in balance performance. Further studies should also include participants with motor impairments and explore the use of different avatars.

ACKNOWLEDGMENTS

This research was funded by the Hessian Ministry of Science and Art - HMWK, Germany (FL1, Mittelbau) and supported by the Frankfurt University of Applied Sciences and the University of Cadiz.

REFERENCES

[1] Hammad Alhasan, Victoria Hood, and Frederick Mainwaring. 2017. The effect of visual biofeedback on balance in elderly population: a systematic review. *Clinical interventions in aging* 12 (2017), 487–497. https://doi.org/10.2147/CIA.S127023

[2] Elizabeth Behm-Morawitz. 2013. Mirrored selves: The influence of self-presence in a virtual world on health, appearance, and well-being. *Computers in Human Behavior* 29, 1 (2013), 119–128. https://doi.org/10.1016/j.chb.2012.07.023 Including Special Section Youth, Internet, and Wellbeing.

[3] Virginia Braun and Victoria Clarke. 2012. *Thematic analysis.* American Psychological Association, Washington, DC. 57–71 pages. https://doi.org/10.1037/13620-004

[4] Natalia Cooper, Ferdinando Milella, Carlo Pinto, Iain Cant, Mark White, and Georg Meyer. 2018. The effects of substitute multisensory feedback on task performance and the sense of presence in a virtual reality environment. *PloS one* 13, 2 (2018), e0191846. https://doi.org/10.1371/journal.pone.0191846

[5] Ilona J. M. de Rooij, Ingrid G. L. van de Port, and Jan-Willem G. Meijer. 2016. Effect of Virtual Reality Training on Balance and Gait Ability in Patients With Stroke: Systematic Review and Meta-Analysis. *Physical therapy* 96, 12 (2016), 1905–1918. https://doi.org/10.2522/ptj.20160054

[6] Lindsay J. DiStefano, Micheal A. Clark, and Darin A. Padua. 2009. Evidence supporting balance training in healthy individuals: a systemic review. *Journal of strength and conditioning research* 23, 9 (2009), 2718–2731. https://doi.org/10.1519/JSC.0b013e3181c1f7c5

[7] Guo Freeman and Divine Maloney. 2021. Body, Avatar, and Me: The Presentation and Perception of Self in Social Virtual Reality. *Proc. ACM Hum.-Comput. Interact.* 4, CSCW3, Article 239 (jan 2021), 27 pages. https://doi.org/10.1145/3432938

[8] Sandra G. Hart. 2006. Nasa-Task Load Index (NASA-TLX); 20 Years Later. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting* 50, 9 (2006), 904–908. https://doi.org/10.1177/154193120605000909

[9] Martin Kocur, Florian Habler, Valentin Schwind, Paweł W. Woźniak, Christian Wolff, and Niels Henze. 2021. Physiological and Perceptual Responses to Athletic Avatars while Cycling in Virtual Reality. In *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems* (Yokohama, Japan) *(CHI '21)*. Association for Computing Machinery, New York, NY, USA, Article 519, 18 pages. https://doi.org/10.1145/3411764.3445160

[10] Martin Kocur, Melanie Kloss, Valentin Schwind, Christian Wolff, and Niels Henze. 2020. Flexing Muscles in Virtual Reality: Effects of Avatars' Muscular Appearance on Physical Performance. In *Proceedings of the Annual Symposium on Computer-Human Interaction in Play* (Virtual Event, Canada) *(CHI PLAY '20)*. Association for Computing Machinery, New York, NY, USA, 193–205. https://doi.org/10.1145/3410404.3414261

[11] Marc Erich Latoschik, Daniel Roth, Dominik Gall, Jascha Achenbach, Thomas Waltemate, and Mario Botsch. 2017. The effect of avatar realism in immersive social virtual realities. In *Proceedings of the 23rd ACM Symposium on Virtual Reality Software and Technology* (Gothenburg, Sweden) *(VRST '17)*. Association for Computing Machinery, New York, NY, USA, Article 39, 10 pages. https://doi.org/10.1145/3139131.3139156

[12] M. Rasel Mahmud, Alberto Cordova, and John Quarles. 2023. Visual Cues for a Steadier You: Visual Feedback Methods Improved Standing Balance in Virtual Reality for People with Balance Impairments. *IEEE transactions on visualization and computer graphics* 29, 11 (2023), 4666–4675. https://doi.org/10.1109/TVCG.2023.3320244

[13] M. Rasel Mahmud, Michael Stewart, Alberto Cordova, and John Quarles. 2022. Standing Balance Improvement Using Vibrotactile Feedback in Virtual Reality. In *Proceedings of the 28th ACM Symposium on Virtual Reality Software and Technology (ACM Digital Library)*, Takafumi Koike (Ed.). Association for Computing Machinery, New York,NY,United States, 1–11. https://doi.org/10.1145/3562939.3565638

[14] Yurong Mao, Peiming Chen, Le Li, and Dongfeng Huang. 2014. Virtual reality training improves balance function. *Neural regeneration research* 9, 17 (2014), 1628–1634. https://doi.org/10.4103/1673-5374.141795

[15] Imogen C. Rehm, Emily Foenander, Klaire Wallace, Jo-Anne M. Abbott, Michael Kyrios, and Neil Thomas. 2016. What Role Can Avatars Play in e-Mental Health Interventions? Exploring New Models of Client-Therapist Interaction. *Frontiers in psychiatry* 7 (2016), 186. https://doi.org/10.3389/fpsyt.2016.00186

[16] Valentin Schwind, Pascal Knierim, Nico Haas, and Niels Henze. 05022019. Using Presence Questionnaires in Virtual Reality. In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems*, Stephen Brewster, Geraldine Fitzpatrick, Anna Cox, and Vassilis Kostakos (Eds.). ACM, New York, NY, USA, 1–12. https://doi.org/10.1145/3290605.3300590

[17] Roland Sigrist, Georg Rauter, Robert Riener, and Peter Wolf. 2013. Augmented visual, auditory, haptic, and multimodal feedback in motor learning: a review. *Psychonomic bulletin & review* 20, 1 (2013), 21–53. https://doi.org/10.3758/s13423-012-0333-8

[18] Stefan Resch, Valentin Schwind, and Diana Völz. 2023. Body position in virtual reality - balancing support for patients with neuropathy. *Proceedings on Automation in Medical Engineering* 2, 1 (2023), 744. https://www.journals.infinite-science.de/index.php/automed/article/view/744

[19] Jinlong Wu, Hui Zhang, Ziyan Chen, Ruijia Fu, Hao Yang, Hongfa Zeng, and Zhanbing Ren. 2022. Benefits of Virtual Reality Balance Training for Patients With Parkinson Disease: Systematic Review, Meta-analysis, and Meta-Regression of a Randomized Controlled Trial. *JMIR Serious Games* 10, 1 (2022), e30882. https://doi.org/10.2196/30882

[20] Astrid Zech, Markus Hübscher, Lutz Vogt, Winfried Banzer, Frank Hänsel, and Klaus Pfeifer. 2010. Balance training for neuromuscular control and performance enhancement: a systematic review. *Journal of athletic training* 45, 4 (2010), 392–403. https://doi.org/10.4085/1062-6050-45.4.392