Assessing the capabilities of the HTC Vive as a tool to assess the risk of falling in older people

Jaime A. Garcia
UTS Games Studio
University of Technology Sydney
Sydney, Australia
Jaime.Garcia@uts.edu.au

Juan Felipe Tenorio
Faculty of Engineering and IT
University of Technology Sydney
Sydney, Australia
Juan.TenorioEguizabal@uts.edu.au

***Abstract*— Falls affect 1 in 3 seniors every year. This can lead to traumatic brain injuries, fractures, and even death. Being able to identify those at risk is imperative. In the past few years, game technologies such as the Xbox Kinect, Nintendo Wii, Dance Mats, among others, have shown to be very effective in discriminating fallers from non-fallers. In a prior study, the authors proposed a Virtual Reality-based system to assess the risk of falling in the senior community. In this paper, we explore the accuracy of this system by comparing it with a well-established fall risk assessment tool. More importantly, we also investigate the effects of using three different avatar visualization modes in delivering this test (top-down view, puppeteer view and first-person view). We hypothesized that: (1) the VR system would show high similarities to the original version of the test; and (2) altering the sense of presence of our subjects would allow them to fully immerse and concentrate on the assessment tasks resulting in more accurate diagnosis data. Results suggest that the proposed VR-based system was fairly accurate in computing the fall risk assessment test. Also, participants reported quicker response times in the VR system suggesting that the proposed tool offers higher levels of immersion and intuitiveness. (*Abstract*)**

Keywords—falls prevention, virtual reality, gamification, clinical assessment

I. Introduction

Falls are rather critical problem in the senior community affecting 1 in 3 people every year. Falling is leading cause of fatality in the elderly [1]. Clinical assessments consisting of time-based stepping systems have been effectively used in the past as a tool to discriminate between fallers and non-fallers. However, to accurately determine those at risk of falling, assessments require specialized equipment, high levels of precision and the proper administration by a health professional. This makes it costly and difficult to access to seniors who need to be regularly assessed.

In the past few years, Virtual Reality (VR) technology has become more accessible and affordable gaining much interest in the research community, especially in the field of health care for the senior community [2]. The immersive nature of such systems in combination with the fun factor inherent in games, make VR ideal to assist the aged cohort in achieving their rehabilitation goals. This is mainly due to its capability to fully immerse players in virtual worlds and new experiences while tracking full body movements in a 3D space.

From a clinical perspective, the capabilities of VR technology have also the potential to implement accurate and reliable methods to collect physiological measurements associated with falling [3]. This is achieved through the collection of measurement that fulfill the requirements of certain clinical tests.

For example, in the work done by Oagaz et al. [4], the HTC Vive VR Headset was utilized to create a neurocognitive function assessment tool. This system presented patients with virtual scenarios in order to evoke specific physical responses for the assessment of cognition. One of the scenarios required subjects to catch a ball in a baseball field. Eye tracking and motion tracking capabilities allowed the researchers to accurately measure the subject's ability to estimate the landing time and position of the ball. Trials on 20 participants (between the ages of 21 and 70) showed that this tool was very effective in assessing several motor and cognitive functions such as: balance, attention, reaction to visual stimuli and memory.

Similarly, Marchetto et al. [5] used the Oculus Rift head-mounted display (HMD) to assess whether shifts in head position could be used as a reliable indicator of whole-body postural stability. According to the academic literature, the movement of a body segment should be sufficient to assess the shift in the center of mass. For this study, 10 participants (average age 26.1 ± 5.47) were asked to complete 6 different testing conditions using the VR headset while their Center of Pressure (COP) was being recorded by the Wii Balance Board. Visual stimuli included a stable scene, a dark scene and a dynamic scene. Correlations between the measurements taken by the Wii Balance Board and the VR headset showed high levels of agreement between the two measurements. This suggest that the VR system could be extremely useful as a cost-effective tool to assess postural stability in a clinical setting.

In the work done by Pallavicini et al [6], a commercial game was used as an alternative for the Trail Making Test, a neuropsychological test of visual attention (and task switching). In the original test, subjects are required to connect a set of 25 dots as quickly and as accurate as possible. The game chosen for this study was Audioshield, a rhythm game for the HTC Vive where players block incoming music notes with a shield of a matching color. A comparison study involving 38 participants (average age 25.8 ± 4.14) using both the traditional Trail Making test and the VR-based video game showed that the test results correlated significantly with the game scores. This suggest that this commercial game could be used as an accurate alternative to the well-established Trail Making Test.

Sylcott at al [7] made use of the position and orientation tracking capabilities built into the HTC vive in order to create a tool to measure postural sway. Postural sway has shown to be an accurate predictor of falls in the senior community. Postural Sway is calculated by measuring the unconscious, small movements that happen around the body's center of gravity in order to maintain balance. For this experiments, visual stimuli were presented through the VR headset while position measurements simultaneously by a force plate and the head mounted display device. Measurements taken by both systems on 21 participants (average age 22 ± 1) show high levels of correlation indicating that the HTC vive could be used as accurate tool for balance assessment.

Overall, these methods rely on the ability to immerse subjects in a virtual space while allowing researchers to obtain information of their body positions and movements in real-time. This suggests that VR could be considered an effective tool when it comes to collection position and time-based measurements.

In a prior study, the authors developed a VR-based tool to assess the risk of falling in the senior community in a more immersive, intuitive and descriptive manner [8]. This VR-based tool captures stepping performance parameters in order to fulfill the requirements of a well-established clinical test for fall risk assessment. The use of virtual reality allows for an immersive experience where elderly users can fully concentrate on the motor and cognitive functions being assessed rather than the technology being used.

The work presented in this paper focuses on evaluating the capabilities of this VR-based system to reliably collect timing variables to fulfill the requirements of the Choice Stepping Reaction Time (CSRT) task, a time-based clinical test that has shown to reliably predict falls in order adults [9]. This study hence evaluates the validity of the proposed VR-based with a validated choice reaction time device.

The rest of the paper is structured as follows. Section 2 presents brief summary of related work in the field of fall risk assessment and describes the Choice Stepping Reaction time. Section 3 sets out the methodology used for this evaluation. Results and Discussion can be found in Section 4 and 5. Finally, conclusions and future work are presented in Section 6.

II. BACKGROUND

The Choice Stepping Reaction Time (CSRT) task is a composite measure of sensorimotor functions, such as balance and strength, and cognitive functions such as attention and central processing speed [9]. The test is able to combine several dimensions of fall risk based on these composite metrics. For the CSRT Task, the person stands on the two central step panels of a wooden board. One of four surrounding panels (front left or LF, front right or RF, rear left or RL, rear right or RR, left or LL, right or RR) illuminates randomly and the person is required to step on this panel as quickly as possible and then return to the center. The sequence is presented randomly as well as the time between trials so that the user is unable to anticipate the time and location of the next stimulus. The mean reaction time of 20 trials is then measured and analyzed for clinical diagnosis.

In the work done by Schone et al.[10], a Dance Mat Choice Step Reaction Time device was introduced and validated against the original CSRT Test. In this system, the CSRT Test is achieved through the use of a custom-made dance mat (or MAT) that contains 12 step panels. The mechanics of the test are the same as the original version of the CSRT, however, visual stimuli are presented on the LCD monitor and the user is expected to step accordingly on respective positions on the MAT. In this work, the MAT showed high correlations with the laboratory-based measure of the CSRT test. Also, the ability to reliably differentiate between fallers and non-fallers was also confirmed. However, one of the pitfalls of this work is that the use of the Dance Mat still imposes an obstacle on the degree of freedom and does not allow for the collection of spatial parameters.

In [8], the authors explored the feasibility of using Virtual Reality (VR) game technology as an alternative to reliably assess the risk of falling in the elderly. This implementation enhances the delivery of the Choice Step Reaction Time test as it allows subjects to fully immerse in the stepping exercises by removing any distractions that could affect their performance. This has been a major factor affecting the collection of reliable data in the past. Users often get distracted, affecting their performance while undertaking these tests. Also, there needs to be a direct connection between the actions being performed and user feedback to avoid the risk of injuries or feelings of frustration.

In order to interact with this tool, users must wear the HTC Vive head-mounted headset. A virtual scenario resembling an empty room is then presented. This room consists of an exercise area (demarked by a light blue square) with two small white rectangles indicating the starting position of the test. Users can walk freely in this room. To eliminate any distractions, light colours and a simplistic level design were chosen. Two red shoes mirroring the movements of the user's feet are also presented. This helps the user to concentrate on the stepping task and allows them to have a sense of presence in the virtual environment. HTC Vive controllers are attached to the user's lower limbs using a set of bands. This is to allow for the tracking of the foot movements and the animation of the virtual shoes in an unobtrusive manner.

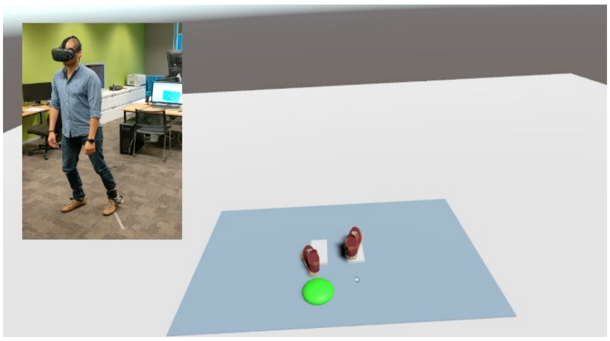

Fig. 1. Interacting with the VR-based version of the Choice Stepping Reaction Time test.

Test mechanics resemble the original CSRT task. Stepping stimuli are presented in the virtual system in the form of a green ellipsoid (or pellet). Users are expected to react to this by taking a quick reactive step towards the pellet with the leg that is closest to the stimulus. As soon as the virtual shoe collides with the pellet, the latter disappears from the screen. Users must then return to the initial position as quickly as possible. Once this is completed, the process starts over in a randomized order and location (front-left, front-right, back-left, back-right, left or right). This is to prevent users from memorizing stepping patterns and instead forcing them to react to the stepping stimuli. The mean reaction time of 36 trials as well as the validation of the correct response is automatically measured by the system and used for the assessment of the risk of falling.

In order to allow for higher levels of immersion, we have included 3 camera views, as explored in [11].

- In the first-person view, the location of the virtual shoes matches the location of the user's feet, hence the user must look down to be able to react to the stepping stimuli. (see Fig 2)

- In the top-down view, stepping stimuli are presented as if the user was taking steps on a wall in front of them. While this is at first confusing, studies have shown that participants often find this view-mode very intuitive. (see Fig 3)
- In the puppeteer view, the field of view is slighted shifted in a way that the user can see themselves from behind. Previous studies have indicated that this view-mode could offer a more comfortable and immersive experience. (see Fig 4)

While in principle all these new features make this system potentially useful in the clinical practice, the effectiveness and validity of the new system needs further evaluation.

Consequently, the work presented in this paper focuses on: (1) assessing whether the proposed VR system is as accurate as the validated Mat-based device, and (2) investigating the effects of using three different view modes for delivering the stepping test. The following section sets out the methodology used for this evaluation.

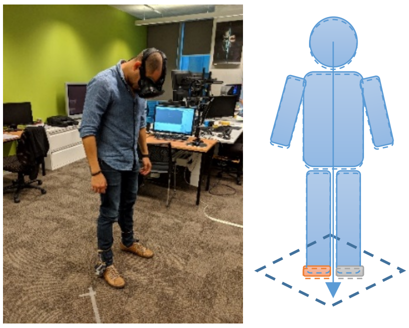

Fig. 2. First Person View. Visual stimuli matches the physical location of the subject.

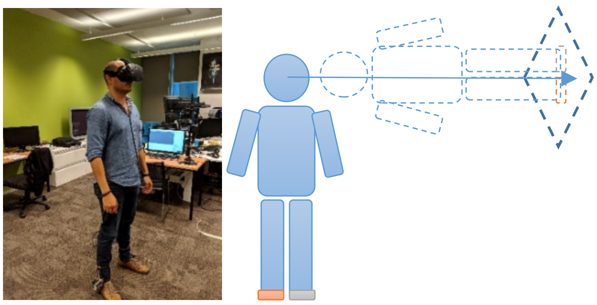

Fig. 3. Top Dow View. Visual stimuli are roated 90 degrees. The player is able to look at the pellets in a standing position.

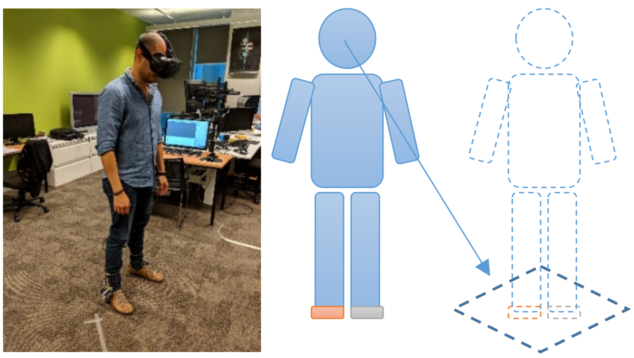

Fig. 4. Puppeteer view. The horizontal plane is slighly shifted towards the front, allowing the participant to look at the pellets from a 45 defree angle.

III. Methods

Since the aim of this study is to validate the accuracy of the system and investigate the effects that the 3 view modes can have in the performance of the stepping task, we opted for recruiting a younger sample size in order to push the system to its limits, similarly to [4-7]. Ethics Approval Number: HREC ETH19 - 3452 / CSS 2021-1.

A. Hypotheses

Based on the related work and our study design, we formulated the following hypotheses:

- H1: Reaction Times values for the Mat-based device will show high similarity to the values recorded by the VR system under the Top-Down view mode (Condition 1 = Condition 2)
- H2: values for the Puppet View in the VR system will show quicker reaction times that the other view modes (Condition 4 < Condition 2 < Condition 3).

B. Participants

A convenient sample of 12 young individuals was recruited for this experiment. The eligibility criteria are described as follows: (1) Not contributed to the design of these instruments. (2) Able to walk independently without assistance, and (3) Fluent in the English language.

C. Experimental Setup

Test were conducted in the UTS Games Studio Research Lab. This room was prepared to allow participants to fully concentrate on the task. Distractions were removed and only one of our researchers was present during the experiment. This is to prevent external factor from interfering with the performance of the subjects.

The room was equipped with a HTC Vive headset, a high-specs VR-capable computer and a Dance Mat. A 2 x 2 meters play area was allocated for participants to perform the stepping activities.

D. Study Design

Participants were exposed to four conditions:

- Condition 1 - MAT: Stepping activity on the Mat-based CSRT Device.
- Condition 2 – VR_TD: Stepping activity on the proposed VR System using the Top-Down View.
- Condition 3 – VR_FP: Stepping activity on the proposed VR System using the First-Person View.
- Condition 4 – VR_PP: Stepping activity on the proposed VR System using the Puppet View.

E. Procedures

Participants were asked to perform the CSRT task on both systems (VR and Mat-based). For both systems, participants were given a practice trial in order to familiarize with the mechanics of the test and to confirm the fully understanding of the instructions. Later, they were instructed to complete a full CSRT task where execution of the test was recorded by the corresponding controlling software (Condition 1). Once the test was completed, they were asked to complete a practice trial and a full CSRT task on the other platform (Condition 2). When performing the CSRT on the VR-system, participants were also asked to complete the test under condition 3 and 4 to examine the effects of changing their sense of presence in the VR environment.

At the end of the session, pparticipants were asked several questions to assess their overall impression of the game-like system and identify usability issues present in the VR version of the CSRT test.

Note: In this experiment, the software that controls the VR-based tool and the Mat-based test were run in the same computer to minimize bias in the measurements due to variability in computational power.

F. Measures & Analysis

In order to determine the validity of the VR-based CSRT, this evaluation was conducted as follows: Firstly, we use the Shapiro-Wilk test to assess the distribution of the time-based variables. Secondly, we assessed consistency and association of the reaction time per participant per panel for Condition 1, 2, 3 and 4. This was assessed by calculating the Pearson Correlation Coefficient and the Intraclass Correlation Coefficient model 3,1 for the four conditions.

Then, we used a Bland-Altman plot and compute the CSRT test to assess the agreement of the different view modes and how these affected our participants' performance.

IV. RESULTS

A. Normality

Shapiro-Wilk Tests showed that all the data for this experiment are normally distributed. As shown in Table I, all Sig. values are greater than 0.05.

TABLE I. TESTS OF NORMALITY

Shapiro-Wilk Tests			
Measure	***Statistic***	***df***	***Sig.***
MAT	.989	60	.855
VR First Person	.987	60	.765
VR Puppeteer	.990	60	.900
VR Top Down	.990	60	.891

B. Association

Pearson Correlation Coefficients indicated a large positive association between our outcome measures. As shown in Table II, all Pearson *r* values are greater than 0.5, suggesting a high statistical relationship between our variables.

TABLE II. TEST OF ASSOCIATION

Pearson Correlations	
Comparison	***Pearson r***
MAT vs VR First Person	.716
MAT vs VR Puppeteer	.683
MAT vs VR Top Down	.604
VR First Person vs VR Puppeteer	.687
VR First Person vs VR Top Down	.639
VR Puppeteer vs VR Top Down	.781

C. Absolute Agreement

Intraclass Correlation Coefficients (ICC) indicated high-level of consistency and reproducibility of the measurements taken by the two devices (VR and MAT). As shown in Table III, the ICC value for the average measures is greater than .8 suggesting a high inter reliability between the measures.

TABLE III. TEST OF AGREEMENT

Intraclass Correlation	
Average Measures	.827
95% Condidence Interval - Lower Bound	.635
95% Condidence Interval - Upper Bound	.910

D. CSRT measures

Table IV presents the results of the mean reaction time for all participants under the four conditions.

Condition 3 reported the quicker reaction times, followed by Condition 2, Condition 4 and Condition 1 respectively.

While the values differed slightly one from another, Bland-Altman plots comparing Condition 1 (the original CSRT test) against the other conditions (the proposed VR solution) showed high levels of agreement between the two devices. See Fig 5, 6 and 7.

TABLE IV. MEAN REACTION TIMES

CSRT Measures (n=12)		
Measurement	***Mean Reaction Time (s)***	***Std Dev***
MAT	.807	.121
VR Puppeteer	.710	.120
VR Top Down	.691	.104
VR First Person	.685	.104

E. Relationships Between the CSRT measuremtents

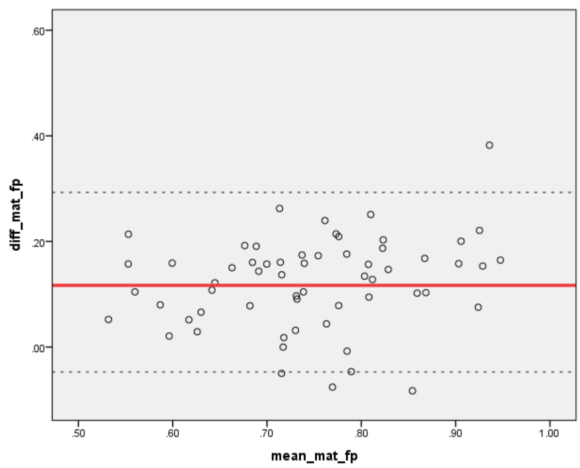

Fig. 5. Bland-Altman Plot: MAT vs VR First Person View.

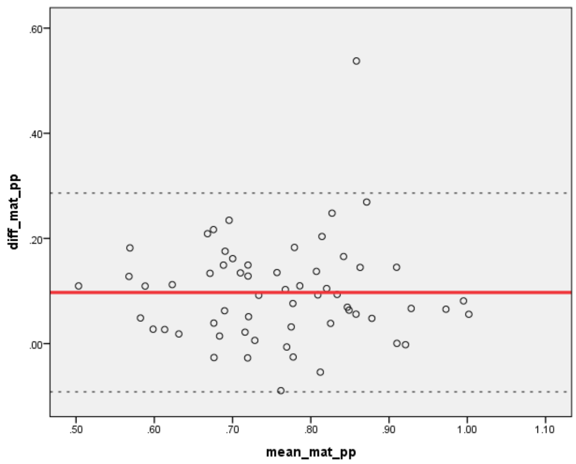

Fig. 6. Bland-Altman Plot: MAT vs VR Pupetter View

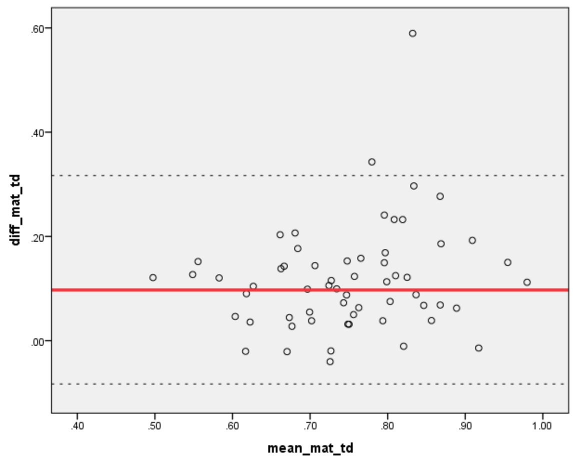

Fig. 7. Bland-Altman Plot: MAT vs VR Top Down View.

V. Discussion

Overall, this study shows that our VR-based system is able to compute the Choice Stepping Reaction Time (CSRT) task. Timing variables such as Reaction Time (RT) were analysed to assess the capabilities of the HTC Vive to reliably perform this time-based clinical test. The variability of the reaction times was assessed and reported to be equivalently distributed in the VR system and the MAT. Correlations between the HTC Vive (under three different conditions) and the MAT were highly suggesting that the HTC Vive could fulfil the requirements of the CSRT Test.

Mean reaction time values also presented a set of interesting findings:

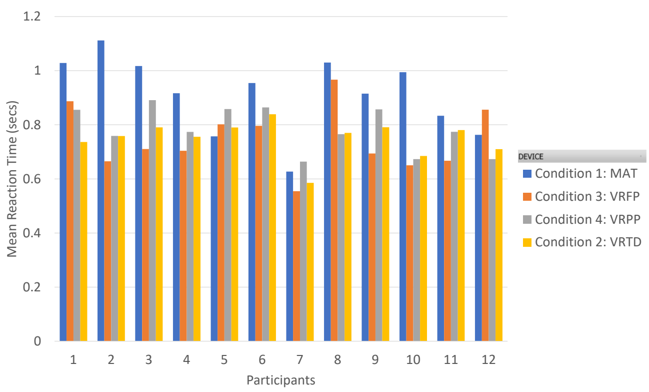

Fig. 8. Mean Reaction Times for each Participant for each Condition assessed.

Condition 1: the original test reported slower reaction times for most participants (as shown in Figure 9). This could have been due to the additional time it takes for participants to look at the screen, process the stimuli, then look at the mat and execute the corresponding movement. *"I felt clumsy because my feet would catch on the mat, I feel I did not do as well as I could have"*, a participant said. Also, in some cases participants slightly shifted from the centre of the mat, which resulted in them stepping on the panels incorrectly. One participant expressed his *"experience with the MAT was overall good. but, I wasn't sure If were successfully being recognised"*. Similar results were observed in similar study that compared the MAT with a Kinect-based implementation of the CSRT Test, where participants reported slower responses on the MAT and raised usability concerns [12].

Condition 3: This condition reported the closest reaction time values to the original test. This behaviour was expected as both formats are almost identical. There was a smaller difference with the VR First-Person view reporting slightly faster reaction times, which could have been due to the immersive nature of the VR system that takes away the need for looking at a screen, processing the stimuli, then executing the movement. A participant stated, *"immersive experience, easy to follow, more responsive, I was looking at one screen only, it felt very real"*. One of the complains raised by most participants is that the weight of head-mounted display made it uncomfortable for them to use, making this view the least popular choice among the testing subjects. These findings align with previous studies that evaluated at the usability of Head Mounted Displays in the elderly community [13].

Condition 4: the puppeteer view in the VR-bases system surprisingly reported quicker reaction times than the original test and the First-Person view. It is worth noting that this view is only possible on a Virtual Reality environment, where participants are able to see themselves from a few meters behind. The majority of participants expressed a stronger preference towards this view compared to the first-person view or the MAT. One participant expressed that the puppeteer view *"combines the realism of the first-person view, with the comfort of a top-down view and the ability to see [their] own feet easily"*. When we asked them why they preferred this view, one of them said *"because I do not have to bend my neck"*, a key usability concern for both the MAT and First Person view.

Condition 2: the top-down view in the VR system was the preferred choice among our participants. Subjects not only reported faster reaction times under this condition, but also expressed higher levels of comfort and immersion. While we initially expected this to cause some confusion as the world appears 90 degree rotated (giving the participants the impression they are walking vertically on a wall), participants found this view the most intuitive out of the 4 conditions. *"I like how everything was very clear, from the position of my feet to the targets I needed to hit"*. These results are in alignment and agreement with the results of a prior study using the Kinect version of the CSRT test where stimuli were presented in a screen in front of the participants [12] allowing them to fully immerse in the activity.

In regard to the hypotheses formulated earlier in this paper:

- H1 was successfully validated: Reaction Times values for the Mat-based device showed high similarity to the values recorded by the VR system, with the Top-Down view being the prefer choice by our participants.
- H2 was partially validated: values for the Puppet View in the VR system showed quicker reaction times than the original CSRT device (MAT), however, it did not show faster reaction times than Condition 2 or Condition 3. As explain earlier in this paper, the top-down view offered higher levels of immersion and control.

Overall, results from this study suggest that VR-based measure of the CSRT confidently agreed with the CSRT values computed by the MAT. Reaction Time values obtained had a strong agreement with the MAT and other CSRT devices used in larger studies on healthy non-faller older adults [14], suggesting that the proposed tool is meaningful in the clinical context. In addition to this, the data presented show that RT for the HTC Vive was overall shorter than for the MAT as shown in Figure 8, suggesting that this test might be slightly less cognitively demanding, similarly to [12]. The immersive nature of this system and the appropriate provision of real-time feedback removed the extra processing time required to operate with the MAT. Additionally, participants reacted very positively to the virtual environment, *"it felt intuitive and natural to use, and I feel like I performed better than with the mat",* a participant said.

One of the main limitations for this experiment is the age bracket of our subjects. While the intend of this study was to assess the capabilities of the VR tool to compute the CSRT test, we are not yet able to generalize our findings as no older adults were involved in the validation of this tool. That will be the future direction for this project.

Despite this, the proposed VR system offers accurate and homogenous testing conditions for all participants, making this system potentially useful in a clinical setting.

VI. Conclusion

This paper describes an evaluation where we assessed the ability of a Virtual Reality-based system to reliably perform the Choice Stepping Reaction Time (CSRT) task. This study involved a technical assessment where the VR time-based measurements were compared with a validated reaction time device that has been shown to reliably discriminate between fallers and non-fallers. The results showed a strong association and agreement between the Reaction Times (RT) values obtained in both systems. RT values were utilized to compute the CSRT test in order to assess the responsiveness of the system. Statistical analysis showed that both systems have a high positive correlation, suggesting that the proposed VR-based system could be used as a reliable tool for assessing the risk of falling in the senior community. More importantly, this evaluation showed that the use of Virtual Reality technology can offer an accurate, intuitive and immersive testing conditions, making this an ideal system for a clinical scenario. Future stages in this study include usability studies among the elderly population and clinical trials to assess the effectiveness of the system in predicting falls.

Acknowledgment

We would like to thank our participants for their time and efforts to make this a successful study.

References

[1] A. E. Stuck, J. M. Walthert, T. Nikolaus, C. J. Büla, C. Hohmann, and J. C. Beck, "Risk factors for functional status decline in community-living elderly people: a systematic literature review," *Social science & medicine,* vol. 48, no. 4, pp. 445-469, 1999.

[2] G. Juras *et al.*, "Standards of virtual reality application in balance training programs in clinical practice: a systematic review," *Games for Health Journal,* vol. 8, no. 2, pp. 101-111, 2019.

[3] F. Muhla *et al.*, "Impact of using immersive virtual reality over time and steps in the Timed Up and Go test in elderly people," *Plos one,* vol. 15, no. 3, p. e0229594, 2020.

[4] H. Oagaz, B. Schoun, M. Pooji, and M.-H. Choi, "Neurocognitive assessment in virtual reality through behavioral response analysis," *IEEE Journal of Biomedical and Health Informatics,* vol. 23, no. 5, pp. 1899-1910, 2018.

[5] J. Marchetto and W. G. Wright, "The validity of an oculus rift to assess postural changes during balance tasks," *Human factors,* vol. 61, no. 8, pp. 1340-1352, 2019.

[6] F. Pallavicini, A. Pepe, and M. E. Minissi, "Taking neuropsychological test to the next level: Commercial virtual reality video games for the assessment of executive functions," in *International Conference on Human-Computer Interaction*, 2019: Springer, pp. 133-149.

[7] B. Sylcott, K. Williams, M. Hinderaker, and C.-C. Lin, "Comparison of HTC Vive™ Virtual Reality Headset Position Measures to Center of Pressure Measures," in *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, 2019, vol. 63, no. 1: SAGE Publications Sage CA: Los Angeles, CA, pp. 2333-2336.

[8] J. A. Garcia, "A virtual reality game-like tool for assessing the risk of falling in the elderly," *Stud Health Technol Inform,* vol. 266, pp. 63-69, 2019.

[9] S. R. Lord and R. C. Fitzpatrick, "Choice stepping reaction time: a composite measure of falls risk in older people," *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences,* vol. 56, no. 10, pp. M627-M632, 2001.

[10] D. Schoene, S. R. Lord, P. Verhoef, and S. T. Smith, "A novel video game–based device for measuring stepping performance and fall risk in older people," *Archives of physical medicine and rehabilitation,* vol. 92, no. 6, pp. 947-953, 2011.

[11] W. L. Raffe and J. A. Garcia, "Combining skeletal tracking and virtual reality for game-based fall prevention training for the elderly," in *2018 IEEE 6th International Conference on Serious Games and Applications for Health (SeGAH)*, 2018: IEEE, pp. 1-7.

[12] J. A. Garcia, Y. Pisan, C. T. Tan, and K. F. Navarro, "Assessing the Kinect's capabilities to perform a time-based clinical test for fall risk assessment in older people," in *International*

conference on entertainment computing, 2014: Springer, pp. 100-107.

[13] M. R. B. Postal and R. Rieder, "A Usability Evaluation Experiment of 3D User Interfaces for Elderly," *Revista Brasileira de Computação Aplicada,* vol. 11, no. 3, pp. 28-38, 2019.

[14] A. Ejupi, Y. J. Gschwind, M. Brodie, W. L. Zagler, S. R. Lord, and K. Delbaere, "Kinect-based choice reaching and stepping reaction time tests for clinical and in-home assessment of fall risk in older people: a prospective study," *European review of aging and physical activity,* vol. 13, no. 1, pp. 1-7, 2016.