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Does the Management of Visual and Audible Motion Information during an Immersive Virtual Reality Timed Up and Go Test Impact Locomotor Performance in the Elderly?

Frédéric Muhla^{a, b} Karine Duclos^{a, b} Fabien Clanché^{a, b} Philippe Meyer^c
Séverine Maïaux^c Sophie Colnat-Coulbois^b Jérôme C. Gauchard^{a, b}

^aUFR STAPS, Faculty of Sport Science, Université de Lorraine, Villers-lès- Nancy, France; ^bEA 3450 DevAH, Development, Adaptation and Handicap, Faculty of Medicine, Université de Lorraine, Vandœuvre-lès-Nancy, France; ^cOffice d'Hygiène Sociale de Lorraine Centre Florentin, Nancy, France

Keywords

Immersive virtual reality · Timed Up and Go · Elderly

Abstract

Background/Aims: Falling among the elderly is a major public health issue, especially with the advancing age of the baby boomers. The fall risk assessment tests for many lack a context that would bring them closer to everyday life. Thus, immersive virtual reality, which makes it possible to simulate everyday situations, could make it possible to strengthen the quality of the assessment of the risk of falls. However, it is necessary to understand how the use of a virtual reality device influences the motor control of elderly participants. If vestibular physiotherapists use VR to virtualize their tools, what impact would a visual simulation of movement have on motor control in a locomotor task, if this simulation were plausible? **Methods:** Sixty-two elders (70.8 ± 6.7 years old) completed a Timed Up and Go task under 3 conditions: real, virtual reality, and virtual reality with visual and sound movement information. The virtual reality task takes place in a train either stationary at a station or in uniform linear motion. The time and number of steps were recorded using video, and comparisons between conditions were made using

Friedman's test. **Results:** The results show a significant increase in the time and number of steps in "virtual reality" condition compared to the "real" condition. They do not show significant differences between the 2 virtual conditions. **Conclusion:** The use of a running virtual train to provide plausible movement is particularly distinguished from vestibular physiotherapy applications with first a fixed visual support partially obscuring the optical flow. This visual aid coupled with the attention dedicated to the task inhibits the effect of the moving environment on locomotion. However, the visual optical flow will potentially have an effect in people with fear of falling. Virtual reality shows great potential for the simulation of realistic environments for the assessment of the risk of falls and opens up avenues for the development of tests.

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Introduction

With increasing life expectancy and the proportion of baby-boomers arriving at an advanced age, we are going to approach a period when aging and its human and financial consequences will occupy an even more important

place in the health system. Affecting the motor, sensory, or cognitive systems, the phenomenon of aging can lead the elderly to fall.

The fall seems, for example, influenced by age, gender, or even level of education [1, 2], and it will result in fractures, functional decline, and frailty and lead to hospitalization or institutionalization. These physical consequences are accompanied by psychological effects such as fear of falling, which will be both the cause and the consequence of activity restriction [3]. Thus, limiting risk factors to maintain the independence of seniors is becoming a major public health issue.

In the 2000s, virtual reality qualified as nonimmersive was widely used as an exergame in rehabilitation centers, institutions, and nursing homes [4–6]. More recently, due to its democratization and innovations, virtual reality qualified as time immersive has started to replace older technologies and offer new possibilities. Thanks to its level of immersion, we can expect it to initiate mechanisms considered to be more natural. HMDs are also used today by psychologists to give their patients a progressive exposure to the subjects of their phobias [7] or by vestibular physiotherapists for the virtualization of some of their tools [8–10].

However, most of the disturbances induced by this type of vestibular application purposely simulate an unrealistic situation with inconsistencies where the ocular and vestibular systems give conflicting information. Stimulations where the eyes perceive movement unlike the vestibule only exist in very specific cases such as the movement of clouds which would also be reflected in water, thus giving a wide panorama in movement. Most of the time, people have at their disposal a fixed point serving as a visual support, consistent with the vestibular information. The design of an environment close to everyday life that would include movement must therefore avoid a strong sensory inconsistency.

A study by Lier et al. [11] showed that the level of presence in VR, characterized by the score on the Igroup Presence Questionnaire, is positively correlated with the physical and electrical detection thresholds in active or passive experiences in virtual reality. In this study, the movement was simulated by a stream through a canyon, thus with a scrolling panorama. The results of this study then showed that the level of attention dedicated to the virtual environment was modulated by activity at a high scrolling speed compared to the passive condition. This study therefore suggests that a modulation of the attentional level induced by the virtual environment, if it impacts the levels of perception, it could possibly also affect

motor skills. This was shown by another study with the influence of presence level on walking speed since the addition of visual optical flow allowed to increase walking speed [12].

Using virtual reality to contextualize a test environment to assess the risk of falls [13] requires an interest in motor changes induced by VR. In a previous study [14], we used the Timed Up and Go task [15] to compare the time and number of steps required to complete the task in real life and in a virtual environment simulating a real-life situation. The Timed Up and Go is a gold standard in fall risk assessment, and the task it offers, with a sit to stand, walk, turn around, and sit, is both relevant regarding daily activities that may indicate a risk of fall in the elderly but also for reproduction in a virtual environment. In this study, we showed that the times and the number of steps increased significantly in “virtual reality” condition compared to the “real” condition, for the complete task and for the different phases that make it up. These increases also appeared to be positively correlated with the level of presence.

This previous study having shown the impact of HMD and the virtual environment on motor control, it would now be interesting to assess the impact of the scenario on this same motor control by adding a condition proposing a moving environment. But a movement that would be more plausible than that offered by vestibular physiotherapy applications. We hypothesize that the use of a virtual reality device with a stable virtual environment would increase the time and number of steps required to complete the task, in accordance with Muhla et al. [14] study, but that the simulation of a movement because it would be “plausible,” would then have little or no influence on the time and the number of steps compared to the stable virtual reality condition.

Materials and Methods

Participants

Sixty-two participants (47F-15M, age 70.8 ± 6.7 years) autonomous and living at home were recruited at the Rehabilitation Center Florentin (Office d'Hygiène Sociale of Meurthe-et-Moselle) in Nancy (France). Participants followed a rehabilitation protocol mostly after joints replacement (28 for knee, 12 for hip, and 13 for shoulder) or for a few spine joints problems (9 musculotendinous or discs pathologies). They had to be 65 years and older, to be able to perform locomotor tests during their rehabilitation sessions. All participants had to be able to understand TUG-related instructions. People with cognitive or neurodegenerative issues, with epilepsy, and with still auditive and visual impairment after correction were excluded. They volunteered to participate just before being discharged

Fig. 1. Train bar car viewed from the chair (first person looking by the windows), when the train is “running,” it is going forward from that point of view. On the left, the blue suitcase can be seen and the post seen through the middle window is traveling in the visual field from the left window to the right one. The posts alternate regularly to avoid acceleration feeling.

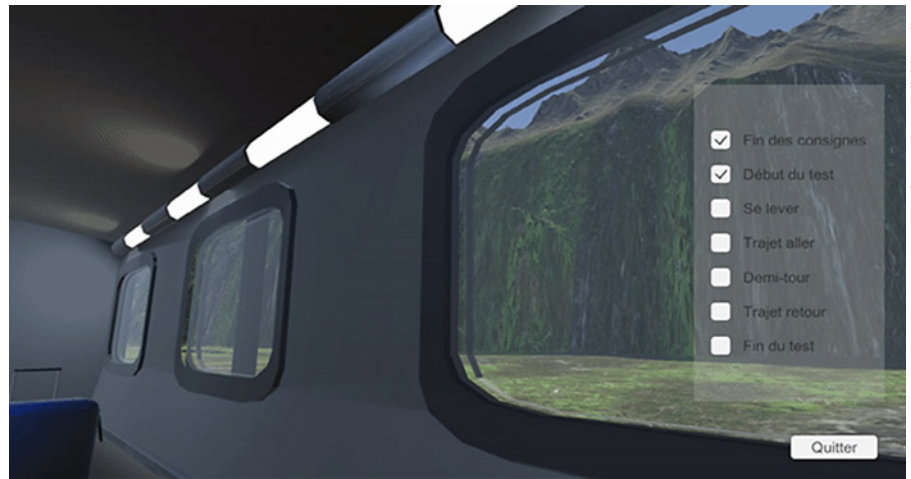


Table 1. Medians (interquartile range) of the times and the number of steps in the 3 conditions (real, VR, and VRp), phases and total

TUG phase	Time (s)	Time VR (s)	Time VRm	Steps	Steps VR	Steps VRm
GU	1.21 (0.35)	1.34 (0.46)	1.36 (0.44)			
Go	2.91 (0.88)	3.07 (1.00)	3.19 (1.19)	5.00 (1.67)	5.33 (1.33)	5.33 (1.33)
TA	1.82 (0.57)	2.17 (0.85)	2.25 (0.90)	3.33 (1.00)	3.67 (1.67)	4.00 (1.50)
Re	2.89 (1.04)	2.95 (0.94)	2.98 (0.91)	4.83 (1.50)	5.00 (1.17)	5.17 (1.33)
SD	2.93 (0.90)	3.37 (1.01)	3.49 (1.18)	3.67 (1.00)	4.00 (1.33)	4.00 (1.67)
Total	11.82 (2.80)	12.77 (4.13)	13.03 (4.40)	16.67 (3.67)	18.50 (4.50)	18.83 (5.17)

GU, Get Up; TA, Turn Around; Re, Return; SD, Sit Down.

from the rehabilitation center at the end of their rehabilitation protocol. Tests were done in the morning before their rehabilitation session and performed with or without walking aid (9 participants used a cane and seventeen other participants a forearm crutch as they usually do) [15], and participants had to use comfortable outfit and their usual shoes.

Tasks to Perform

Each participant performed 3 TUG trials (condition 1), 3 TUG VR trials (virtual reality without disturbances – condition 2) and 3 TUG VRm trials (virtual reality with added visual and sound motion information – condition 3) starting randomly from 1 condition or the others to avoid a fatigue or learning effect. The procedure of TUG was identical to that described by Podsiadlo and Richardson [15], that is, sitting comfortably on a chair (2 armrests and seat about 46 cm height), back against the backrest, forearms on the armrests, walking aid in hand, feet on the ground for the initial position, and, on signal given by the investigator, the participant must get up and walk at a comfortable and safe speed for 3 m, turn around and then return to sit down.

To provide spatiotemporal parameters (time and number of steps), a video recording (1,920 × 1,080 p, 60 fps, time displayed on

the video player, cut to the closest frame) was made during the TUG tasks. Due to space constraints, the camera was located on the side, slightly set back from the chair to see the back getting off the backrest and to see the participant turning around 3 m away. The video analyses allowed the TUG to be studied as a whole but also according to 5 specific consecutive phases which are (1) Get Up (GU): starts when the back gets off the backrest, (2) Go: starts when the participant is standing and starts walking, (3) Turn Around (TA): starts when the participant starts to turn (first step of turning [16]), (4) Return (Re): starts when the participant initiates the gait in the direction of the chair and (5) Sit Down (SD): starts when the participant starts to turn (first step of turning [16, 17]) to sit down. The motor necessities and constraints of these different phases could reflect different difficulty levels to accomplish them. Thus, it seems that the easiest phases to perform are the Go and Re phases, using more automated walking. The 2 phases with intermediate difficulty are the Get Up and the TA phases, the first requiring a sufficient level of strength in the lower and upper limbs, but with the possibility to use armrests, the second requiring balance maintaining in a rotation on the spot. The most complex phase is the SD phase, because it involves the combination of both a half-turn to go in the right direction and sitting down also requires enough muscular strength to control the

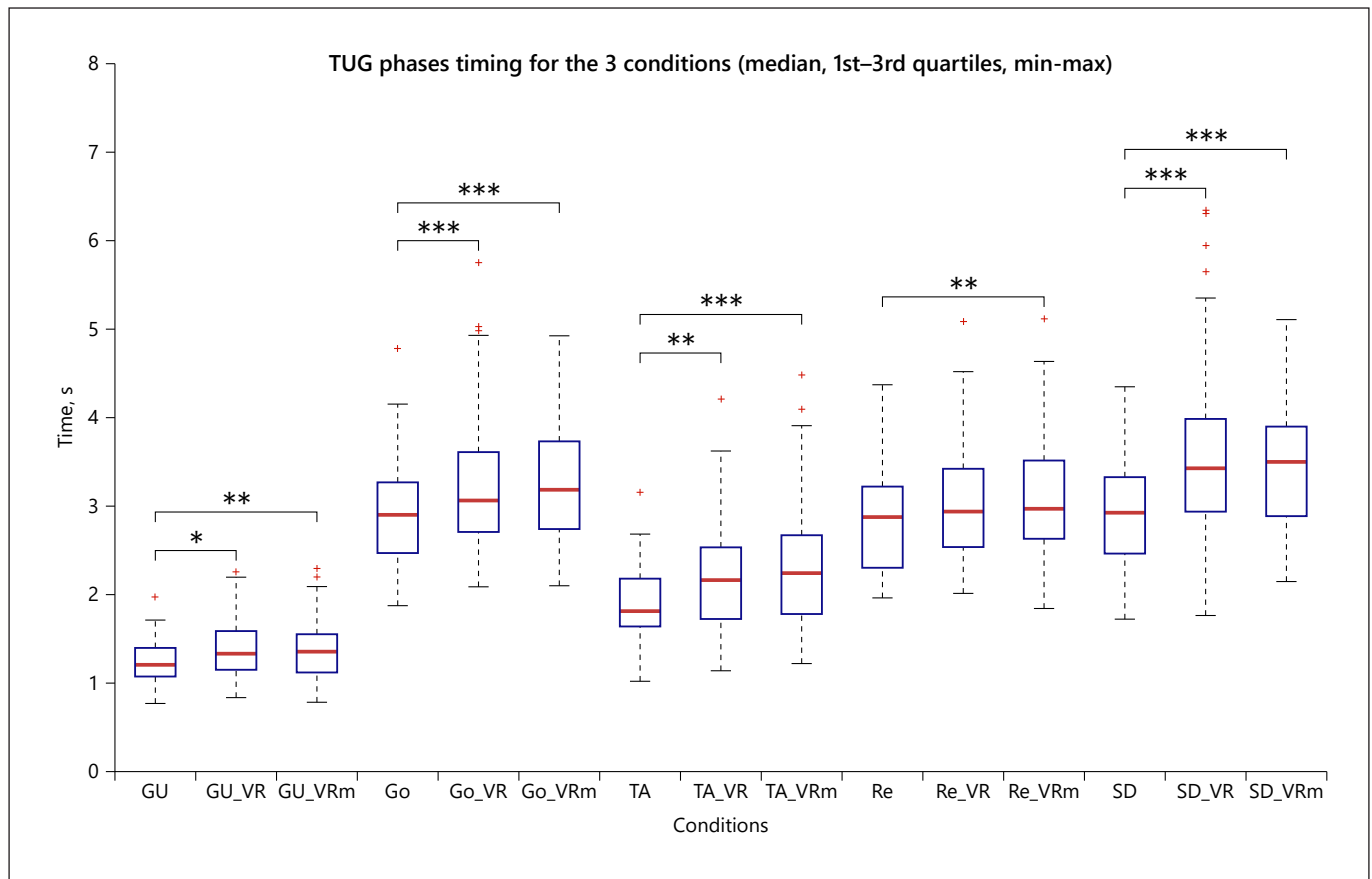


Fig. 2. Timing results for every phase of the TUG comparing the 3 conditions (* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$).

descent to the seat [18]. For TUG, TUG VR and TUG VRm conditions, mean times of completion of the whole test and of its different phases (Get Up, Go, TA, Re, SD) were compared, as well as the mean number of steps.

Virtual Reality Devices and Immersive Scenario

The TUG VR was performed using a virtual reality set including a HTC Vive Headset (Framerate: 90 Hz, $2,160 \times 1,200$ combined pixels, 110° field of view) and an Nvidia Geforce GTX 1070 GPU equipped PC to run the VR software smoothly. The virtual reality TUG was designed on Unity game engine, simulating the interior of a train bar car (shown in Fig. 1). The real chair was placed at the same spot as the virtual train seat.

Safety was guaranteed by the permanent presence of a physician close to the participant for every try, and by a collaborator dedicated to managing the headset wire, so it never interfered with the participant movements. Moreover, the virtual exploration was set in a larger real zone exempt of any obstacles, and the chair was kept in place by another collaborator.

Statistics

Based on a benchmark study in the field of using Timed Up and Go for nonfallers [19] and on a study using virtual reality in the

context of TUG [14], the difference in the means is fixed at 3.4 s. For a delta of 3.4 s, a standard deviation of 5.02 s, an alpha risk of 0.05, a power of $1 - \beta = 0.9$ and a bilateral approach, the number of subjects required is 47. In case of nonnormality of the times obtained [14], a nonparametric test will be used, increasing the number of subjects required by 10%. Similarly, if we consider 20% of participants for whom the results would not be usable and lost to follow up, 62 subjects will be included for safety reasons.

Since each participant achieved the test under the 3 conditions, in 1 real condition and 2 conditions in virtual reality. As nonnormal distributions, results were compared using a nonparametric for dependent samples Friedman test and the Nemenyi post hoc test. The results of the 3 trials in each condition were averaged for each subject and are presented by median (interquartile range).

Results

On 62 participants, 60 managed to complete the 3 conditions; only 2 were unable to perform the virtual reality in motion condition, preventing statistical analy-

sis on their data. For the remaining 60 participants, results show an increased time in both VR and VRm conditions compared to real condition. Time also increased in VRm compared to VR. The number of steps increased both in VR and VRm compared to real and in VRm compared to VR, except for the Go and SD phases (shown in Table 1).

Between real and VR conditions, statistically significant differences indicating higher time were observed for total time completion and the TUG phases, except for the Re phase. Between real and VRm conditions, statistically significant differences indicating higher time were observed for total time completion and every TUG phase. Between VR and VRm conditions, no statistically significant difference were observed neither for the total time of completion nor the various phases (shown in Fig. 2, 3 and in Table 2).

The number of steps shows an increase between real and VR conditions for the entire test and every TUG phase, except the TA, one which tend to be significantly higher in VR. Between real and VRm conditions, the number of steps increased significantly too, this time for every phase and the entire test. As well as for timing, the number of steps shows no statistically significant differences between the VR and VRm conditions for the entire test and the various phases (shown in Fig. 4, 5 and in Table 2).

Discussion

Regarding the comparison between the “real” condition and the “stable virtual reality” condition, the results coincide with those of our previous study [14], with an increase in the time and number of steps to perform the task. Now regarding the absence of significant differences observed between the 2 conditions in virtual reality, various factors may be involved. Indeed, the desired realism during the design of this virtual scene could drastically reduce the impact of movement on motor control for several reasons:

Locomotion is based on automated motor strategies where sensory cues act as feedback. Here, the movement of the subjects took place within a landmark itself moving in a geocentric landmark. This difference in benchmarks led the participants to focus on the “train” frame of reference, thus neglecting the movement between the wagon and the external environment. This difference of reference is what distinguishes this scene in virtual reality from that proposed by the vestibular physiotherapists who rather use a movement in an egocentric reference mark. In these applications, the complete visual environment moves around

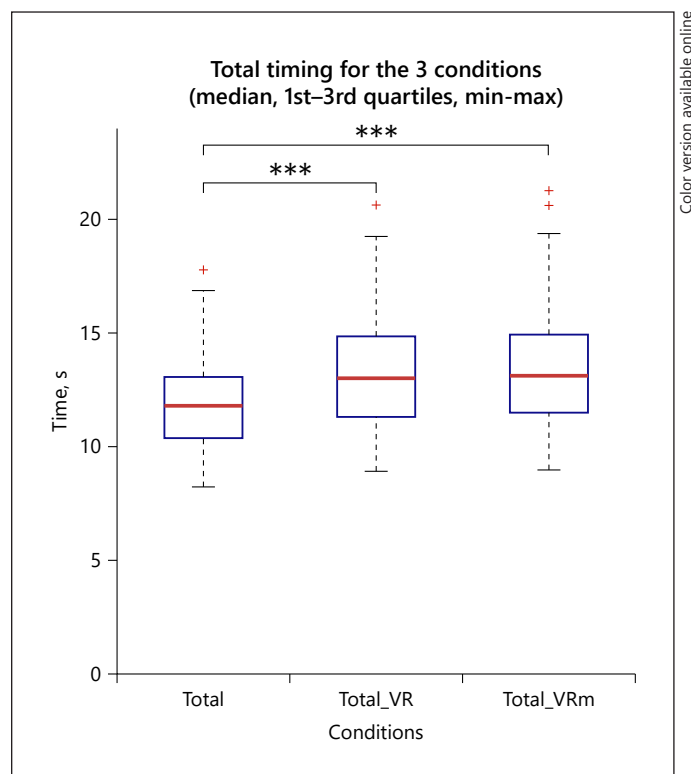


Fig. 3. Timing results for the total time of the TUG test comparing the 3 conditions (* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$).

the participant however in our study the train frame of reference, modeled by a wagon surrounding the participants (Fig. 1), served as a visual crutch, a stable support to gaze. This stable mount provides much the same benefit as the stationary environment that surrounds a simple television. Peripheral vision, sensitive to movement, and perceiving the environment surrounding the screen as fixed thus confirm the vestibular information [20].

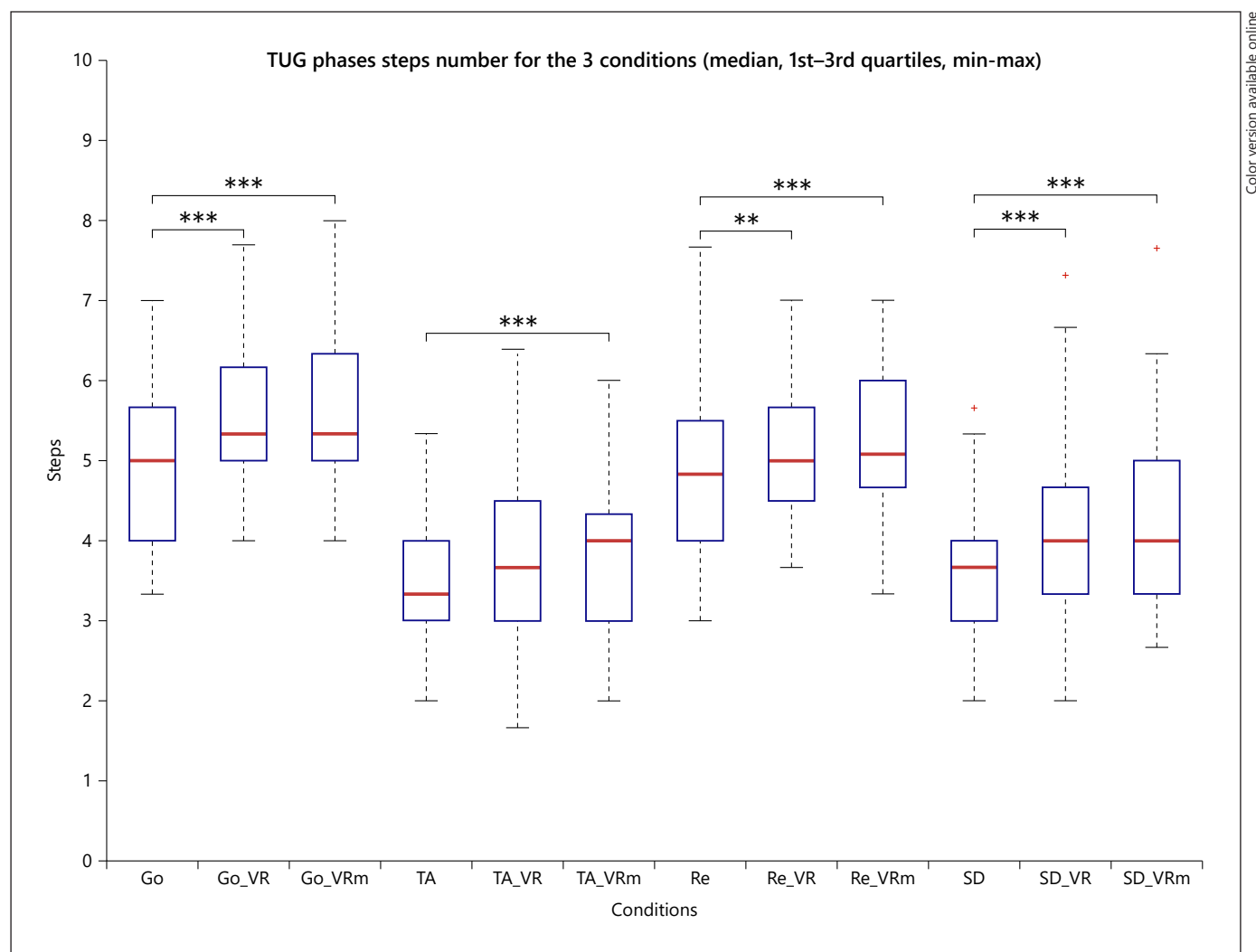
The train also offers a close environment. Because of the parallax, this gives the advantage of having finer visual information during oscillations than in a more distant environment [21]. Finding your way around the walls of the wagon, rather than the outside environment, can potentially make it easier to maintain balance. It would then be a safer strategy to use the train wall as a visual cue rather than the environment visible through the windows.

For the maintenance of balance, it turns out that the information from vision, proprioception and vestibules are complementary. Thus, since the setting in motion of the environment could potentially disturb only vision, other sensory inputs were able to compensate for the disturbance. The sound of the moving train, not spatialized

Table 2. Statistical differences between the 3 conditions (real, VR, and VRm) 2 × 2

TUG phase	Time			Steps		
	VR versus real	VRm versus real	VRm versus VR	VR versus real	VRm versus real	VRm versus VR
GU	VR > real $p = 0.036$	VRm > real $p = 0.007$	VRm > VR $p = 0.847$			
Go	VR > real $p = 0.000$	VRm > real $p = 0.000$	VRm > VR $p = 0.847$	VR > real $p = 0.000$	VRm > real $p = 0.000$	VRm = VR $p = 0.400$
TA	VR > real $p = 0.002$	VRm > real $p = 0.000$	VRm > VR $p = 0.133$	VR > real $p = 0.053$	VRm > real $p = 0.000$	VRm > VR $p = 0.110$
Re	VR > real $p = 0.310$	VRm > real $p = 0.001$	VRm > VR $p = 0.110$	VR > real $p = 0.002$	VRm > real $p = 0.000$	VRm > VR $p = 0.216$
SD	VR > real $p = 0.000$	VRm > real $p = 0.000$	VRm < VR $p = 0.981$	VR > real $p = 0.000$	VRm > real $p = 0.000$	VRm = VR $p = 0.610$
Total	VR > real $p = 0.000$	VRm > real $p = 0.000$	VRm > VR $p = 0.161$	VR > real $p = 0.000$	VRm > real $p = 0.000$	VRm > VR $p = 0.063$

GU, Get Up; TA, Turn Around; Re, Return; SD, Sit Down. Values in bold indicate $p < 0.05$.

**Fig. 4.** Number of steps results for every phase of the TUG comparing the 3 conditions (* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$).

but nonetheless coherent, could also have improved postural control [22]. In a recent study, participants had to achieve a TUG using a HMD with and without visual disturbance, authors found no significant differences between these 2 conditions, except for vertical acceleration and range of mediolateral only in the get up phase (sit to stand) for visual dependent participants. Their results between VR and real conditions support the increased time we observed. Nonetheless, their method using cameras to see through the HMD belongs more to augmented reality than to virtual reality and the visual disturbance to optokinetic for vestibular physiotherapy [23]. In addition to the environmental characteristics that may have reduced the impact of movement on motor control, the task and more particularly the attentional resources it mobilizes, certainly amplified the inhibition of the simulated movement. Indeed, having to move quickly to the suitcase and then to the seat may have mobilized too many attentional resources for the environment scrolling through the windows to occupy this attention. This diversion of attention to the task rather than the environment would have been more difficult if the motion simulation included vibrations or lateral movements that promote immersion.

The tests were done the same way for each participant, and they were sat on the running train direction (forward), implying the Re phase to be on the opposite direction. As it was observed that the visual flow can increase gait speed [12], it is assumed that the impact on 3 m gait done on 1 way and on the opposite way is probably reduced. It could be interesting to test if the train moving backward impacts the participant locomotion in an inverted way. Studies show [24] that the unbalanced hemispheric dopamine level gives for most people a natural side to turn around, the right handers tend to turn left, while non-right handers (left handers and ambidextrous) tend to turn right, associated with the fact that more than 90% of the population is right-handed [25–27], participants tend to turn mostly on their left side. So, they were naturally facing the bar and not the nearest windows during the TA phase, but they were facing the window during the 180° turn of the SD phase. Facing the window means seeing the moving landscape and the posts passing regularly in a larger field of view. As most of the participants tend to turn on their left side, they were facing the window closely while turning around during the SD phase. It means that the moving panorama took a larger field of view, thus reducing visual fixed crutches during this moment. Visual motion could have had more impact in this setup. It should be tested with a symmetric environment (then, not facing the window) to evaluate its impact on this specific phase.

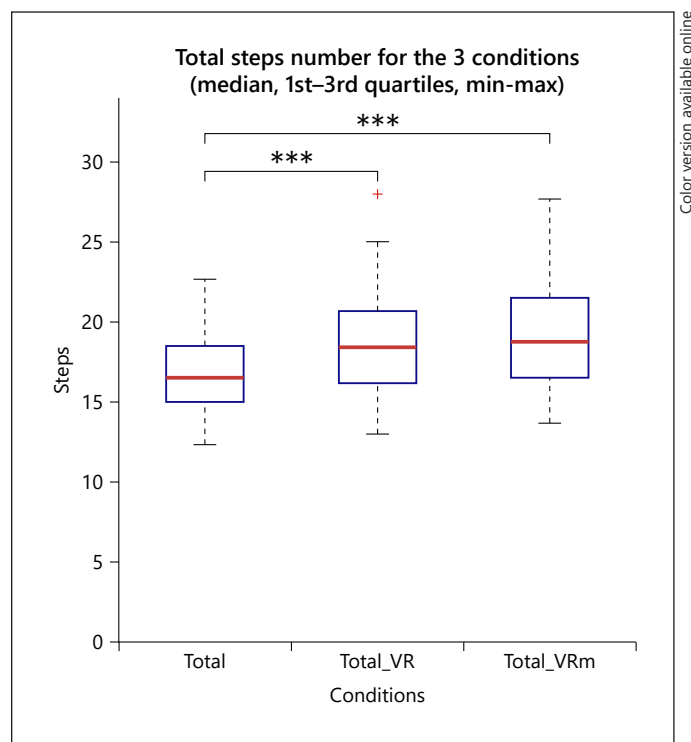


Fig. 5. Number of steps results for the entire TUG test comparing the 3 conditions (* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$).

Some features and perspectives should be considered. For space constraints, the camera had to be placed on the side back to the participant. With this angle, videos only gave the simple parameters used for this study. An improved recording set-up using more cameras and/or the HMD trajectories would give more gait parameters, especially in the medial-lateral axis and could provide interesting data on stabilization strategy adaptations occurring in the elderly. The use of virtual reality to enrich the environment could have modified the mechanism of visual exploration and dedicated attention compared to the real condition. Attention may have been different in the “new” virtual environment requiring to consciously ignore the least important cues to achieve the task or to maintain balance. In this study, the instructions were told as Podsiadlo used to for their participants. This point is an interesting limit of this paradigm because trying to give a contextualized environment should be done with contextualized and meaningful instructions too. Thus, motor control differences might be observed between instructions telling what to do and the detailed instructions telling how to do it. The original instructions might modify the way participants move, from automatic locomotion to adapted to the sequential instructions-based locomotion.

Conclusion

Immersive virtual reality is a promising technology allowing, in evaluation procedures, to transform clinical tests into activities that better represent everyday life. Moreover, it provides reproducibility and safety criteria. Considering the use of VR as part of the clinical assessment of motor skills requires the consideration of precautions like the physical parameters of the scenario. They must not go against the effects sought by this virtual environment, explaining here perhaps the difference between the steady virtual condition and the mobile virtual condition. It cannot be excluded that the instructions given may not run counter to an ecological task, since locomotion is more automatic in nature. Thus, it should be followed with ecological and meaningful instructions telling what to do and not how. Further studies using virtual reality to simulate daily-life environment should consider these points.

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Statement of Ethics

Verbal informed consent was obtained from participants prior to the study. This protocol was conducted as part of a broader study of risks factors for falls in the elderly, which was approved by the "Comité de Protection des Personnes Grand Est III" with the approval number n°2018-A02637-48.

Conflict of Interest Statement

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Author Contributions

F.M., K.D., F.C., and G.G. conceived the study idea. All authors planned the study. F.M., F.C., S.C.C., and G.G. acquired ethical approval. F.M., P.M., and S.M. collected the data. F.M. analyzed the data. F.M. and G.G. wrote the first draft of the manuscript. All authors revised and approved the manuscript.

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