

Comparing the effects of diverse, fully immersive virtual reality (VR) training programmes on the functional fitness of free-living seniors, over 75 years of age: a randomised controlled trial

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Key words: functional capacity, older adults, virtual reality (VR) technology.

Abstract

Introduction: Fully immersive virtual reality (VR) solutions are presently acknowledged to enhance overall effectiveness of conventional physiotherapeutic methods pursued in older adults.

Aim of the research: To compare the effect of two fully immersive VR HMD programmes on the functional performance of individuals over 75 years of age.

Material and methods: A total of 60 community-dwelling older adults over 75 were enrolled into the study protocol, and randomly split into 2 equally-sized study groups (VRCZ, OCULUS). The physiotherapy sessions were pursued in the subjects' apartments (for 3 weeks, 3 times a week, for 30 minutes in each group).

Results: Both groups achieved statistically significant improvement in visuospatial function (TMT B). The VRCZ Group also demonstrated improvement in walking (TUG, $p = 0.01$), whereas the OCULUS Group notably enhanced its dual-task walking (TUGMAN, $p = 0.01$). Adverse side effects were reported during the first ten sessions, e.g. dizzy spells, nausea, disorientation. Significantly more subjects experienced dizzy spells in the VRCZ Group ($p < 0.001$); the same holding true for nausea ($p = 0.05$), and a need for longer breaks ($p = 0.04$).

Conclusions: The VRCRR HMD project proved to offer a viable, non-pharmacological intervention in the older adults at risk of progressing functional decline. Despite appreciable improvements in functional performance having been reported in both study groups, the higher scores in visuospatial and balance tests were achieved by the OCULUS Group.

Introduction

Virtual reality (VR) technological solutions have recently been harnessed by researchers to address and tackle the age-induced, individual failings and deficits [1, 2]. Rapid development of VR applications making use of the head-mounted displays (HMD) has contributed significantly. The HMDs fully immerse the subjects in a virtually created simulation of a computer image in 3D [1, 2]. Recently completed studies utilising the VR HMDs highlighted appreciable improvement in cognitive function [3], also in the individuals affected by Alzheimer's disease (AD) [4], as well as reported diminished falls risk, improved static balance, and overall postural control [5, 6]; this consequently translating into appreciably enhanced quality of life [7]. It should be acknowledged that most of those studies focused on the individuals over 60 years of age. Besides, the studies making use of VR 3D had mainly been applied to small groups and for a short duration only [8].

Presently, there is a manifest scarcity of studies focused on the application of VR 3D HMD solutions in

the individuals over 75 years of age. This deficit of conclusive scientific evidence highlights an urgent need for in-depth research to establish whether VR HMD technological solutions actually exert a positive impact on functional performance in the individuals not only in early old age, but also among the ones over 75 years of age, yet unaffected by any cognitive deficits or actual impairment.

Aim of the research

This study aimed to compare the effect of two fully immersive VR HMD programmes on the functional performance in the individuals over 75 years of age.

Material and methods

Study subjects

Free-living individuals aged 75 years or older were prospectively recruited through Senior Citizen Activity Centres. The exclusion criteria applied prior to enrolment were as follows: visual impairment

≤ 2 dioptres, average hearing loss $\leq 40\text{--}70$ dB, functional limb shortening, Alzheimer's disease, Parkinson's disease, unstable cardiovascular disease, active cancer, vertigo attacks (lasting more than 10 min/day – within the last 3 weeks), GDS > 8 points, and inability to operate a VR device. All participants boasted sufficient cognitive functionality (MMSE ≥ 19), and their blood pressure ($< 140\text{--}159$ mm Hg – systolic, and $< 90\text{--}99$ mm Hg – diastolic, GS > 0.8 m/s) remained well within the admissible reference range. Ultimately, 60 participants were enrolled into the study protocol.

Study design

This randomised clinical trial was meant to investigate the effectiveness of the application of a fully immersive VR solution with regard to individual balance training, gait, motor abilities, functional capacity, and establishing overall falls risk in older adults over 75 years of age. The participants were randomly assigned to either the Virtual Reality Carl Zeiss (VRCZ) or OCULUS groups. They completed 16 weeks of training, 3 times a week, attending 30-minute sessions (with the exception of the first one, which lasted 1 h, so as to have each subject sufficiently familiarised with the VR devices and the specifics of the training schedule), i.e. 48 training sessions in total.

The application of the referenced VR programme was prompted by the earlier pilot study, along with

a substantial experience of our research team gained throughout.

On the other hand, the structuring of the actual regimen was based on the specific recommendations issued by the World Health Organisation (WHO) and the American Heart Association (AHA).

A 3-times/week training regimen provides sufficient stimulation of the muscles and musculoskeletal system to induce physiological adaptations without overstressing the body. Excessive training in VR environment may be too intense for older individuals, increasing the risk of cybersickness. Thirty-minute exercises are appropriate for seniors with limited capacity, apart from being much easier to integrate into daily life, consequently reducing overall risk of absenteeism.

A 16-week programme allows for a gradual progression of the exercises followed in both groups, in view of the additional tasks or criteria required to pass each exercise. This also helps maximise the therapeutic effects on balance and overall functional performance in the patients.

The participants were not subjected to any other type of intervention, except for the ongoing, individually administered pharmacotherapy.

VR Carl Zeiss training

Full immersion was ensured with the aid of Carl Zeiss VR One goggles, which “transported” the subject into a virtual maze, i.e. a commercially available “Maze Walk” application. This game was selected for the purpose of creating a VR environment similar to the one proposed in the study by Zak *et al.*, as well as with a view to following the actual methodological guidelines with regard to implementing the successive stages of the Virtual Reality Comprehensive Rehabilitation Rooms (VRCRR) solution [9].

Holding hands with the therapist throughout, the subject walked forward, backward, diagonally, and in a square. The subject also performed basic exercises in the form of a half squat, by raising either one or both upper limbs, making trunk twists, and bending sideways to both sides. Every 5 min there was a 1-minute break to avoid the risk of any unwelcome dizzy spells (Figures 1, 2).

VR OCULUS training

An innovative self-devised VRCRR programme was developed with the aid of Blender software (V. 2.93). Subsequently, the file was transferred to UNREAL software package, and ultimately converted into the OCULUS Rift goggles.

A cross-sectional photo depicts the actual arrangement of the rooms on a map of virtual space. The OCULUS Rift device is fitted with a number of controllers used to guide the implementation of respective exercises with the special pointers.



Figure 1. The first level of difficulty in the maze for the VRCZ Group



Figure 2. The second level of difficulty in the maze for the VRCZ Group

The VRCRR are functionally divided into the following zones: Room 1 – for cognitive exercises, Room 2 – for aerobic exercises, Room 3 – for static and dynamic balance exercises, Room 4 – for a scope of dual-task activities. The protocol called for visiting all four VRCRR in the pre-determined sequence, including a 1.5 min rest between accessing the next room (Figures 3–5).

Our study also made use of Carl Zeiss VR ONE plus-ZEISS®, which contains two aspherical biconvex lenses (+32.5 dioptres) that allow the subject to fit onto the smartphone display, which is inserted into the front tray of the head-mounted system at a distance of 44 mm, thus allowing full 3D immersion, and OCULUS Rift S, which additionally contains the sensors responsible for tracking the body movements. Thanks to infrared LEDs and a camera placed on the goggles, it is possible to track rotational movements of the head and pinpoint its position in space.

Procedures and outcome measures

All subjects had been assessed prior to and after the completion of the study protocol, with the aid of the following research tools, i.e. Mini-Mental State Examination (MMSE) [10], Geriatric Depression Scale-15 item (GDS-15) [11], Instrumental Activities of Daily Living (IADL) [12], Timed Up and Go Test (TUG) [s] [13], Timed Up and Go Test Cognitive (TUG_{COG}) [s] and Timed Up and Go Test Manual (TUG_{MAN}) [s] [14], 10 Metre Walk Test (10MW) [15], Berg Balance Scale (BBS) [16, 17], Tinetti Performance-Oriented Mobility Assessment (Tinetti POMA – Test) [18], Single Leg Stance Test (SLS) with eyes open (SLS OP) and eyes closed (SLS CL) [19], Trail Making Tests (TMT) [20], and a 2-minute step test (2MS) methods proposed by Rikli and Jones [21].

Sample calculation and statistical analyses

The sample size was calculated with a sample size calculator, whilst taking into account the subjects' age, average number of free-living older adults who sustain a fall at least once a year, and the possibility of obtaining a static balance test result of twice the standard deviation, assuming 80% test power. Simple randomisation was calculated using the (RAND) command for each subject with the allocation to respective study groups.

Compliance with normal distribution (Shapiro-Wilk test) was considered in the selection of analytical methods. For quantitative variables, basic statistical parameters regarding the central value (mean) and dispersion (standard deviation) were calculated. For qualitative variables, distributions of abundance were determined in relation to the categories of these variables. Comparison of demographic and clinical variables between both groups was made using independent *t*-tests, Mann-Whitney *U* test, or Pearson's χ^2 test. The statistical analysis was based on the significance level $\alpha = 0.05$. The col-

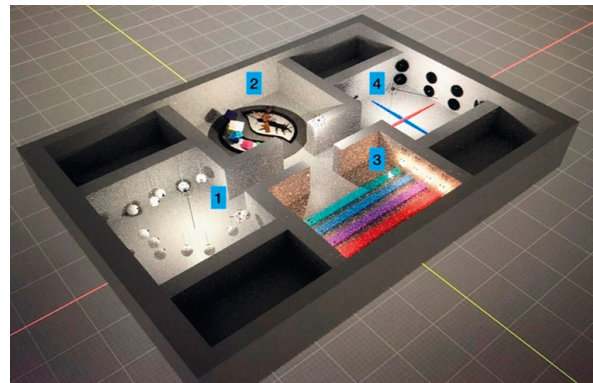


Figure 3. Spatial view of the VRCRR

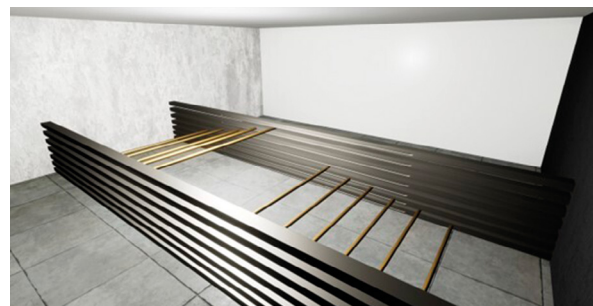


Figure 4. Room 3 – Static balance (golden beams)

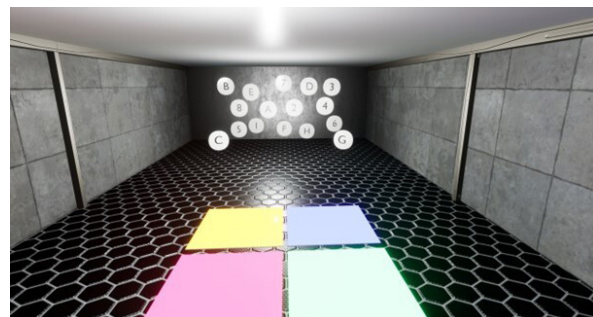


Figure 5. Room 4 – double-task activities and balance

lected research material was statistically analysed using Microsoft Excel and Statistica 13 by StatSoft.

Results

Recruitment process and the size of respective study groups was presented in Figure 6.

Demographic and clinical characteristics

Table 1 addresses detailed demographic data and clinical characteristics of the study subjects. Thirty subjects were assigned to the VRCZ and OCULUS Groups, respectively. The mean subjects' age was approx. 77 years; most of them women (Table 1).

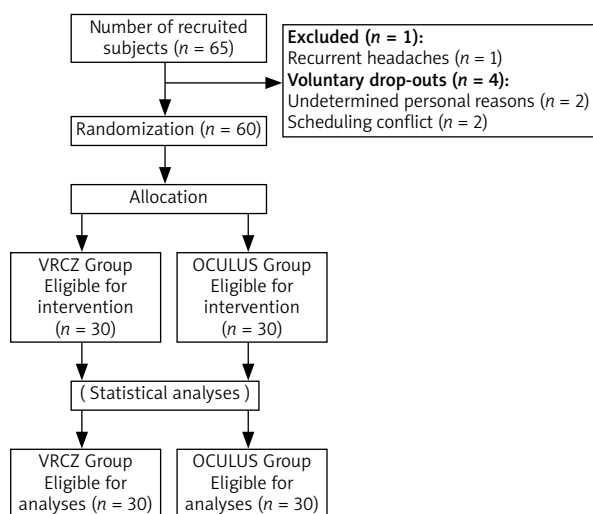


Figure 6. Recruitment process and the size of respective study groups

The effect of VRCZ and OCULUS therapy

Statistical analysis indicated significant differences between respective measurement points in the VRCZ and OCULUS Groups. The VRCZ Group scored significantly higher in the TUG test (by 20.67%) after training, as compared to the first measurement point ($p = 0.001$). The OCULUS Group subjects improved their performance by 23.23% in the TUG_{Man} test ($p = 0.001$), and by 92% on the SLS CL test ($p = 0.005$). There was a significant improvement in TMTB test scores in both groups. The VRCZ Group achieved 13.15% significantly higher scores, as compared to the First Measurement Point ($p < 0.001$). On the other hand, in the OCULUS Group, the analysis showed that the subjects improved their performance in terms of the scores obtained in the test before and after the training, i.e., by 19.93%, which also made them sta-

tistically significant ($p = 0.01$). Functional performance before and after the training is shown in Table 2.

The study subjects reported adverse effects during the first ten training sessions, i.e. dizzy spells, nausea, need for longer breaks, or disorientation (Table 3). Statistically significant differences were observed between the VRCZ Group and the OCULUS Group. Significantly more subjects experienced dizzy spells in the VRCZ Group than in the OCULUS Group ($p < 0.001$). Nausea ($p = 0.05$) and the need to take longer breaks ($p = 0.04$) were also more frequently reported by the VRCZ Group subjects. Confusion was an adverse effect reported in both the VRCZ and OCULUS Groups, although this lacked statistical significance ($p = 0.64$).

Discussion

To the best of the authors' knowledge, this is the first study making use of VR HMD in the individuals over 75 years of age, over a 16-week therapeutic intervention.

The newly proposed solution, i.e. VRCRR, is based on the multi-domain training, covering 4 planes of functional performance, with no need for switching between respective software packages. No statistically significant differences were noted in testing between the two therapies as both yielded satisfactory results in improving functional performance.

The individuals from the OCULUS Group scored significantly better on the TMT B test (by 19.93%), as compared to the scores at the First Measurement Point. The VRCZ Group also improved their scores by 13.15%. Similar conclusions were reached by Thapa *et al.* [22], in whose study the training pursued with VR HMD (spread over 24 sessions) indicated improvement in cognitive function in a group of 34 individuals aged 55–85 years, tested, *inter alia*, with the aid of TMT B.

The VRCRR solution facilitates exploration and motor learning in a more challenging type of envi-

Table 1. Demographic and clinical characteristics of all study subjects

Variable	Total (N = 60)	VRCZ Group (n = 30)	OCULUS Group (n = 30)	χ^2 or Ub	P-value
Age [years] mean (SD)	77.52 (3.02)	77.90 (3.26)	77.13 (2.75)	0.67	0.48
Sex (women), n (%)	49 (81.67)	25 (41.67)	24 (40.00)	0.04	0.83
Education [years] mean (SD)	12.00 (3.69)	12.37 (3.32)	11.63 (4.05)	0.97	0.33
Body weight [kg] mean (SD)	67.58 (11.34)	65.03 (10.24)	70.13 (11.96)	−1.37	0.16
Height [m] mean (SD)	1.66 (0.05)	1.66 (0.04)	1.66 (0.05)	0.21	0.83
BMI [kg/m ²] mean (SD)	24.67 (4.35)	23.68 (3.81)	25.65 (4.70)	−1.25	0.21
Falls within the last year, n (%)	15 (25.00)	10 (16.67)	5 (8.33)	1.80	0.18
Number of medications regularly taken, mean (SD)	4.45 (1.87)	4.07 (2.07)	4.83 (1.60)	−2.10	0.03
MMSE [pts] mean (SD)	27.12 (2.29)	27.50 (2.64)	26.73 (1.84)	1.85	0.06

MMSE – Mini-Mental State Examination, χ^2 – Pearson's chi-square test, Ub – Mann-Whitney U test, SD – Standard deviation.

Table 2. The subjects' functional performance before and after the training sessions

Test	Pre-training mean (SD)	Post-training mean (SD)	Within groups Pre-training vs. post-training	
			U^b	P -value
TUG [s]				
VRCZ ($n = 30$)	13.93 (3.98)	11.05 (1.52)	−3.23	0.001
OCULUS ($n = 30$)	16.05 (3.96)	11.63 (1.32)	−1.32	0.19
TUG _{COG} [s]				
VRCZ	17.41 (4.91)	11.92 (1.49)	1.78	0.07
OCULUS	14.97 (4.31)	12.27 (1.33)	−0.75	0.45
TUG _{MAN} [s]				
VRCZ	17.41 (4.91)	15.42 (3.93)	1.01	0.31
OCULUS	16.66 (8.58)	12.79 (1.69)	3.22	0.001
10MW [m/s]				
VRCZ	1.15 (0.33)	1.16 (0.03)	0.70	0.47
OCULUS	1.14 (0.03)	1.15 (0.03)	1.53	0.12
BBS [pts]				
VRCZ	45.40 (2.77)	45.27 (3.01)	0.05	0.95
OCULUS	45.20 (2.96)	46.30 (2.97)	−1.36	0.17
POMA B [pts]				
VRCZ	11.13 (1.36)	11.47 (1.14)	0.25	0.8
OCULUS	11.17 (1.39)	11.27 (1.23)	1.24	0.20
POMA G [pts]				
VRCZ	10.43 (1.65)	11.00 (1.05)	−0.93	0.33
OCULUS	10.77 (1.76)	11.23 (1.33)	−1.12	0.26
POMA Total [pts]				
VRCZ	21.57 (2.05)	22.47 (1.25)	−0.44	-0.45
OCULUS	21.93 (1.91)	22.50 (1.78)	−0.04	-0.05
TMT A [s]				
VRCZ	53.60 (5.99)	45.27 (2.65)	−1.46	0.14
OCULUS	54.93 (2.53)	44.80 (2.58)	0.83	0.40
TMT B [s]				
VRCZ	147.80 (9.97)	128.37 (11.01)	−3.16	< 0.001
OCULUS	154.57 (4.57)	123.77 (9.8)	2.44	0.01
SLS OP [s]				
VRCZ	7.43 (9.3)	7.8 (2.65)	0.13	0.89
OCULUS	5.03 (2.2)	7.15 (2.4)	0.63	0.53
SLS CL [s]				
VRCZ	2.56 (2.26)	3.63 (1.5)	−0.25	0.80
OCULUS	2.26 (1.37)	4.34 (1.51)	−2.80	0.005
2MS [no of lifts]				
VRCZ	66.43 (14.2)	80.13 (8.48)	0.73	0.46
OCULUS	64.97 (13.45)	83.67 (8.3)	−1.31	0.19

TUG – Timed Up and Go, TUG_{COG} – Timed Up and Go Cognitive, TUG_{MAN} – Timed Up and Go Manual, 10MW – 10 Meter Walk Test, BBS – Berg Balance Scale, POMA B – Balance, POMA G – Gait, POMA Total – Tinetti Performance-Oriented Mobility Assessment, TMT A – Trail Making Test A, TMT B – Trail Making Test B, SLS OP – single leg stance open eyes, SLS CL – single leg stance closed eyes, 2MS – Two Minute Step test, U^b – Mann-Whitney U Test, SD – standard deviation.

Table 3. Adverse side effects in the VRCZ and OCULUS Groups experienced throughout the first 10 training sessions

Variable	Total (n = 60)	VRCZ Group (n = 30)	OCULUS Group (n = 30)	χ^2	P-value
Dizzy spells, n (%)	22 (36.67)	18 (30.00)	4 (6.67)	12.65	< 0.001
Nausea, n (%)	4 (6.67)	4 (6.67)	0 (0.00)	4.01	0.05
Need for longer breaks, n (%)	27 (45.00)	18 (30.00)	9 (15.00)	4.42	0.04
Disorientation, n (%)	21 (35.00)	10 (16.67)	11 (18.33)	0.21	0.64

χ^2 – Pearson's chi-square test.

ronment, as corroborated by Anglin *et al.* [23] who established that VR HMD had the potential to optimise motor learning, consequently enhancing motor/functional performance, as compared to the non-immersive VR. The effect of VR training on individual balance had also been noted in other studies, which highlighted appreciable improvements in TUG, BBS and SLS test scores [9, 24–26].

Some studies claim that immersive VR training may be a viable replacement, a better alternative to a conventional rehabilitation model for the over 75 s. The studies by Dockx *et al.* and Yeşilyaprak *et al.* [27, 28] indicated though that immersive VR balance training failed to bring about any better outcomes than the conventional fall prevention therapies.

Having said that, those findings should by no means be construed in a negative way as the investigators demonstrated that VR therapy had no adverse side effects and was safe to apply. VR solutions may therefore offer a viable alternative for those individuals who are clearly disenchanted with the conventional rehabilitation regimens, or are not particularly keen on attending group activities [29].

The subjects tolerated the HMD very well and most of them offered positive feedback on their experience. They also felt far more relaxed and rather keen on experiencing something novel in their therapy. Approx. 76% definitely wanted to live through their VR experience once again, finding it both exciting and truly inspiring.

Even though most individuals (including those over 75) responded well to VRCRR HMD, there is still an appreciable risk of losing one's balance, whilst carrying out the exercises. In order to resolve the safety issue effectively, it would be prudent to put the subject in a special harness and then have him securely suspended from the ceiling, so as to prevent falling over, should he suddenly lose his balance, whilst executing the assigned scope of rehabilitation exercises [30, 31].

One limitation consisted in the lack of a control group, even though this actually allowed the authors to focus on two study groups attending two different VR programmes.

As the study had no follow-up, there would be no hard data forthcoming on any lasting effects of the in-

tervention in a longer perspective, which might be regarded as another limitation.

Conclusions

Making use of the VR devices fitted with the handheld controllers translated into perceptibly fewer adverse side effects as compared to the ones relying on the head movements alone. The study indicated that immersive VR therapy, as pursued both in the VRCRR and in a virtual labyrinth, may offer a therapeutically viable intervention in the older adults at risk of progressing functional decline. All study outcomes, especially the ones regarding manifest improvement in visuospatial orientation and enhanced sense of balance, offered a tangible contribution to the current body of knowledge on the existing potential for applying the VR-assisted therapy in older adults.

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Ethical approval

Institutional Ethics Committee of Faculty of Medicine and Health Sciences, Jan Kochanowski University of Kielce, Poland, (Ethics Approval Ref. No. 31/2019).

Conflict of interest

The authors declare no conflict of interest.

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