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The effect of Virtual Reality on postural control.

Thesis by
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Preface

This quantitative research was carried out in Fontys University of Applied Sciences, Eindhoven, the Netherlands. It is part of a larger study that aimed to examine the effect of Virtual Reality on postural control and adaptation.

I take this opportunity to express my gratitude to several people for their aid and support.

I am grateful to Sil Kloppenburg, for bringing up the idea to us and inspiring us to work through his motivational feedback. More than that I thank him for supervising, guiding and supporting me during the process of this research.

Thanks are also given to my co-researchers Lennart Driece and Majid Krim for the execution of this research, as well as to my fellow students for screening and helping me throughout the build-up of this report.

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Table of Contents:

1. Personal Data……………………..………………………………….....................4
2. Abstract…………………………………………………………...……………………..5
3. Introduction……………………………………………………………………………6-7
4. Methods…………………………………………………..………................8-11
   4.1 Study Design…………………………………………………..................8
   4.2 Test Subjects…………………………………………………………………8-9
   4.3 Apparatus/ Measurement tools………………………………..……………….9
   4.4 Ethics Statement…………………………..…………………………………9
   4.5 Data collection/ Protocol……………………………………………..……..9-10
   4.6 Data analysis………………………………………………………...............11
5. Results…………………………..………………………………………...12-14
6. Discussion………………………...……………………………………..15-17
7. Conclusion…………..……………………………………………………18
8. Bibliography……………………….……………………………………19-23

9. Appendices………………………………...…………………………..............I-XVIII
   Appendix I- Information Letter………………………………….………………..I-II
   Appendix II- Informed Consent Form……………………………..…………...III
   Appendix III- Questionnaire………………………………………………..… .IV
   Appendix IV- Flowchart of experimental procedure…………...………………….V
   Appendix V- Standardized Patient Instructions…………………….……….…..VI
   Appendix VI- Information of Apparatus and applications used…………..VII-XIII
   Confidentiality Statement. ………………………………………………………XIV
   Conveyance of Rights Agreement………………………………………XV-XVIII

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2. Abstract

Background: Risk of falling is a major problem among the senior population and it results due to poor postural control. Studies have shown the benefit of virtual reality-based training in postural control and adaptation, since it can be used to manipulate visual information. The present study aims to investigate whether changes in optic flow speed and symmetries through a virtual reality application can influence postural control measured in center of pressure excursion.

Methods: Thirty (n=30) healthy participants were asked to stand on a force plate that measured center of pressure excursion in three different conditions of visual stimulus: Normal visual stimulus (eyes open), absent visual stimulus (eyes closed) and a visual stimulus through virtual reality. The virtual reality head mounted device projected a dynamic film of a roller coaster. Twenty-four (n=24) participants were also measured for possible head movements during the three conditions by using an accelerometer placed on their foreheads.

Results: Center of pressure excursion was greatest during the virtual reality visual stimulus in both the medial-lateral and anterior-posterior direction. Participants also had a greater center of pressure excursion in the anterior-posterior direction rather than the medial-lateral direction. Head movement was significantly different in every condition of visual stimulus with the greatest during the virtual reality condition.

Conclusion: The findings of this study suggest that a dynamic virtual reality application with optic flow alternations has an influence on center of pressure excursion. As a result, further research should be conducted to test the effect of a dynamic application on postural control and adaptation, in the aim of enhancing sensorimotor rehabilitation.

Keywords: Virtual Reality (VR), postural control, optic flow, center of pressure (CoP)

3. Introduction

Risk of falls is a considerable health issue that largely affects the senior population. According to World's Health Organization, 23%-35% of seniors aged 65 or over experience at least one fall each year, with an increase in the percentage to 32%-42% for those aged 70 or over (1). Fear of falling and loss of confidence are significant consequences that may lead to a declined activity level and eventually lead to a decrease in strength, balance and mobility, influencing the quality of life of an individual (2–4).

The high incidence of falls makes it essential to search for preventive interventions (5). Research has shown that balance training is fundamental in preventing falls and improving postural control (6). In fact, maintenance of balance requires the integration of a visual, vestibular and somatosensory input (6). In other words, the task of stabilizing involves the synergy and activation of these systems (7,8). The effort from our body to rely on one of these pathways creates postural reactions (9). A study done by Li et al. (2010) proved that postural control was improved in seniors of 70 years old or over after a five-week balance training program that included single-limb support standing with eyes open and eyes closed (10).

Although traditional balance training strategies on the improvement of postural control have been confirmed, participants have characterized them as boring, unable to increase their motivation or not vigorous enough (11,12). Recent technological advances have led to the introduction of new ways of therapy in practice, especially with the use of technology. Researchers observed that Virtual Reality (VR) systems could be integrated in the health care environment since they provide interest and fun while keeping low costs compared to other systems of technology (2,6,7,9,11,13–18). VR can be described as an interactive stimulation within an environment, which is induced via computer interfaces that allow the user to move within a virtual world (11,15,16). A VR environment generates the sense of reality that enables the users to perform various activities and to control movements through immediate feedback mechanisms (7). When experiencing a display of VR, images move across and in the opposite direction of head-movements, thus giving the perception of self-motion (9). Combining this VR display with other features such as a movable platform or vivid sound, a fully immersive environment is achieved. These characteristics of Virtual reality based therapy (VRBT) can be used as a tool to enhance ecological validity in practice.

In fact, VR is useful in many disciplines of healthcare such as in medicine, psychology and rehabilitation (19,20). In the field of rehabilitation, VR is strongly used in neurological rehabilitation. For instance, to treat akinesia in Parkinson's disease patients, to deal with upper and lower extremity impairments, or to practice gait in stroke survivors and even to restore neural function through sensorimotor training (8,11,21,22).

More than that, recent studies have been conducted to test the effect of VR in postural adaptation since it can be used to manipulate visual feedback to generate conflicts between visual, somatosensory and vestibular information (22). In the previous years, postural reactions have been tested through isolating individual control pathways in order to identify their specific contribution (23). In several studies it was noted that older adults depend more on their vision to maintain posture, compared to younger individuals (24). With ageing, there is a decrease in visual acuity that results in problems with depth perception, contrast sensitivity and dark adaptation (25). This suggests that all problems presented by the visual system to detect movement can lead to a reduced ability to react to postural disturbances (25). Consequently, it is of high importance to further see the effect of spatial information from visual inputs on postural control, since postural adaptation is achieved by adapting the visual input to the motor output (26).

Changes in optic flow speed might also provide an effective training method for balance rehabilitation of fallers (27). Optic flow is the pattern generated at the retina of the eye that provides information about speed and direction of self-motion in regard to the surrounding environment (24,28–30). More specifically, when a person is moving towards a forward direction, the optic flow has a radial pattern arising from a central point, named as Focus of Expansion (FoE) (31). The faster an object deriving from the FoE approaches this person, the higher the velocity of the optic flow. Previous studies have examined the effect of optic flow speed using virtual reality on gait patterns (24). They showed that when the optic flow speed is manipulated, adaptation mechanisms are generated to match the proprioceptive information during locomotion (28). Other studies have shown the effect of optic flow asymmetries on locomotor steering (32). Although optic flow is not generated when standing still, VR technology has the power to reproduce an optic flow pattern and to give the perception of self-motion. Consequently, postural reactions can be initiated (33). For this reason, a study that tests the effect of optic flow speed and asymmetries on postural control during stance is needed. This information could be used to control the amount of body sway and thus provide new strategies for postural rehabilitation (33).

The present study aims to investigate the influence of a visual input on postural control by measuring Center of Pressure (CoP) excursion during bipodal support with and without a VR Head Mounted Device (HMD). In order to see whether optic flow speed or changes in its symmetry influence postural control, a dynamic VR application will be used in this study. It is hypothesized that the high velocity and asymmetries of optic flow generated by the film will provoke greater postural reactions. As a result, knowledge will be acquired on the visuo-motor adaptation of our nervous system by manipulating optic flow information when using VRBT.

4. Methods

6.1 Study design:

This study is a cross-over quantitative study in which postural control was measured through CoP excursion in three different conditions of visual information; eyes open, eyes closed and a VR display. Thirty participants (n=30) were measured for their CoP excursion using a force plate (Model: OR6-7-1000)(Appendix VI)(44). In addition, a subgroup of twenty-four (n=24) participants was created in order to determine possible head movements during the three conditions of visual information.

6.2 Test subjects:

Participants were recruited from Fontys University of Applied Sciences or from a personal environment. All participants were invited orally or through email that included an information letter (Appendix I). ***Table 1*** shows the inclusion and exclusion criteria upon which all participants were gathered.

Table 1- *Inclusion and exclusion criteria of participants*

Inclusion Criteria	Exclusion Criteria
Age 18 or above	Neurological Problems
Men and women	Vestibular Problems
	People who had some eye-sight loss
	Recent (<6 months) ankle, foot, knee, hip problem or Lower Back problems
	BMI >30
	People who wore prescription glasses (People who wore eye contact lenses instead will be able to participate in the experiment)

The test subjects were healthy female and male adults aging from 18 years old and over. People with a history of neurological problems were excluded from this study since impaired mobility or brain damage due to a neurological incident can affect postural control (14). Also, people who have experienced vestibular problems (i.e. dizziness, vertigo, labyrinth problems etc.) were excluded, since the vestibular system is responsible in adjusting eye, head and body position in space and therefore posture could be affected (34). In addition, individuals who had recently gone through an ankle, foot, knee, hip or lower back problem were excluded due to possible balance impairments. Increased body mass can negatively affect postural balance (35). For this reason, people who suffer from obesity did not take part in this experiment. People with some or full eyesight loss were excluded from this study since participants had to be able to have a full visual immersion in the virtual reality environment. Last, people who regularly wear prescription glasses that could not be replaced with contact lenses were not able to participate in this study since a VR headset could not be adjusted.

6.3 Apparatus and Measurement tools:

In this experiment a Homido® VR headset (Appendix VI) was used in which a smartphone (LG G3 D855, see Appendix VI) was placed that was projecting a dynamic VR film of a roller coaster (Application used: Dive city roller coaster by Durovis)(45,49). Postural reactions were determined with a force plate (Model: OR6-7-1000), that measured CoP excursion in Newton (N). A force plate determines the force components and force moments applied on a body standing on it in three axes (Fx, Fy, Fz)(Appendix VI)(44). Head movements were measured with an accelerometer (Tringo™ EMG wireless sensor) which was placed anteriorly to the head of each participant, or anteriorly to the HMD (Appendix VI)(50). A stopwatch was used in order to determine with accuracy the participants' initiation of tasks and breaks. In addition, a pair of earplugs was used for every participant to exclude the influence of sound during the measurements.

6.4 Ethics Statement

All the participants were provided with the information letter (Appendix I) through email and then decided on whether they wish to take part in the experiment. Participation was voluntary. A consent form (Appendix II) was signed prior to any measurements. Participants were asked to fill out a questionnaire in order to collect their personal and background information, which answered the inclusion and exclusion criteria (Appendix III). Confidentiality was considered by keeping the information of the participants private and their data anonymous.

6.5 Data collection and protocol

Measurements took place in a gait analysis lab in Fontys University of Applied Sciences, Eindhoven, The Netherlands. Three students of physical therapy were responsible for the process of data collection. A short oral explanation of the experiment was given to the participants upon their arrival (see Appendix V for patient instructions). As soon as participants filled out the corresponding consent forms and questionnaires, they were asked to try on the

HMD in order to adjust the lenses accordingly and to experience a VR film prior to any actual measurement. For the practice session Application I was used (see Appendix VI)(47). After the practice session a 10-minute break was given to each participant in order to avoid the aftereffects associated with VR (36). Postural control was tested by measuring the excursion of the CoP in anterior-posterior and medial-lateral directions using a force plate. Participants were asked to remove their shoes and socks in order to reassure accuracy of CoP displacement. They were given a pair of earplugs to exclude the influence of sound during measurements, since sound can influence postural control (37,38). Subjects were placed in the middle of the force plate - which was marked with a white line - in a two-leg stance position with contact between their medial malleoli. All participants were facing forward. Forward direction was also marked with a cross on the wall. Figure 1 shows the landmarks and the positioning of the participants. CoP excursion was measured in three different conditions of visual input; normal visual input (Eyes open: Task 1), absent visual input (Eyes closed: Task 2) and visual inputs through a VR scene (Task 3). For Task 2, participants were asked to wear the HMD without the mobile phone to reassure that their eyesight was blocked. In order to detect possible head movements, an accelerometer was placed on the forehead of each participant during Task 1. During Task 2 and 3 a second accelerometer was placed on the HMD for the same purposes. The order of the tasks was randomly presented to the participants, by asking them to blindly select sequence papers. Participants were asked to keep their head still for every measurement in order to minimize the influence of the vestibular system through head movement. The measurements lasted for 60 seconds for every visual input, with a 2-minute break after Tasks 1 and 2 and a 10-minute break after Task 3 to avoid the impact of fatigue and the aftereffects associated with VR. All measurements initiated after 20 seconds to reassure standardization. Each participant was measured once for every condition of visual information. The measurements and data of each participant were saved in the computer system of the Gait Analysis lab. A flowchart of the process of this experiment is attached as an Appendix (Appendix IV).

Figure 1: A. Positioning of the participants. *Note*: Medial malleoli touching together and arms are crossed to avoid compensations of the upper body. B. Forward direction marked with a cross (see red circle). C. The middle of the force plate was marked with a white line. Participants were asked to keep the line between their feet.

6.6 Data analysis

Once data were collected, they were transferred to Microsoft® Excel® 2011 in order to define the thirty seconds (first 20 seconds and last 10 seconds were excluded), which were used for further analysis. The standard deviation was calculated for each participant in every task, for both the medial-lateral and the anterior-posterior direction. The standard deviation of the net accelerations of the head movements was also calculated.

All data (including demographic data) were then transferred to the IBM® SPSS® Statistics software (Version 21). Thereafter, the demographic data were tested for their normality, by using the Saphiro-Wilk test. In addition, the same test was used to test the normality of the data collected from the force plate and accelerometers.

To test the differences in CoP excursion for all three conditions of visual stimulus, a One-way repeated measures ANOVA was conducted for the parametric data and a Friedman's test with a Wilcoxon post-hoc analysis for the non-parametric data. A Friedman's test with a Wilcoxon post-hoc analysis was also used for the data collected from the accelerometers (head movements). Last, a Wilcoxon signed rank test with a Sign test was conducted for the direction comparison of CoP excursion in three conditions of visual stimulus.

All data were then represented in Box-plots with non-parametric values. The significance level (alpha level) was defined as $p<0.05$ for all tests.

5. Results

A total of thirty participants were recruited in order to take part in this experimental research. The population (n=30) of the participants consisted of 50% males (n=15) and 50% of females (n=15). A Saphiro-Wilk test was conducted to test the normality of the anthropometric data. The results showed that Age was not normally distributed (p=0.008), whereas BMI, Weight, and Height were normally distributed (BMI: p=0.333, Weight: p=0.272, Height: p=0.813). ***Table 2*** shows the demographic details of the research population.

Table 2- *Demographic data of the participants described in Median, Interquartile range (IQR), Maximum (MAX), Minimum (MIN), Mean and Standard Deviation.*

Demographic Data of the Participants

	Female (n=15)				Male (n=15)				Total (n=30)			
	Median	IQR	MAX	MIN	Median	IQR	MAX	MIN	Median	IQR	MAX	MIN
Age *(Years)*	23	1.5	27	21	22	2.5	28	20	23	2	28	20

	Female (n=15)		Male (n=15)		Total (n=30)	
	Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation
BMI *(kg/m^2)*	22.1	1.9	23.4	2.1	22.8	2.1
Weight *(kg)*	61	7	73.5	7.8	67.2	9.7
Height *(cm)*	165.9	4.9	177	5.7	171.5	7.7

The Saphiro- Wilk test showed that the results were normally distributed for all conditions of visual stimulus in the medial-lateral direction (eyes open (EO): p=0.693, eyes closed (EC): p=0.111, VR: p=0.226). The results from the One-way Repeated Measures of variances (ANOVA) test showed a statistically significant difference in CoP excursion for the medial-lateral direction, for all conditions of visual stimulus (F= 76,992), p=0.000, p<0.005, Wilks' Lambda=0.247, F= 42.684, p=0.000 (p<0.05), η^2= 0.753. Median (Q1 to Q3) CoP excursion for the conditions of eyes open, eyes closed and VR were 0.74 (0.594 to 0.887), 0.91 (0.747 to 1.208) and 2.13 (1.576 to 2.972) respectively. Post- hoc tests using a Bonferroni correction (p=0.017) showed that each pairwise difference was significant (p=0.000, p<0.005) (VR>EC> EO).

The results from the Saphiro-Wilk test for the anterior-posterior direction showed that the data were normally distributed in the EO condition, even though they were not normally distributed for the EC and VR conditions (EO: p=0.485, EC: p=0.001, VR: p=0.030). From a non-parametric Friedman test, it was shown that there was a statistically significant difference in CoP excursion in the anterior-posterior direction for the three different conditions of visual stimulus, p= 0.000 (p<0.05). Post-hoc analysis with Wilcoxon signed-rank test was conducted with a Bonferroni correction, resulting in a significance level of p<0.017. Median (Q1 to Q3) CoP excursion for the conditions of eyes open, eyes closed and VR were 0.91 (0.621 to 1.135), 1.13 (0.814 to 1.359) and 2.238 (1.375 to 3.386) respectively. There was a significant difference between the conditions of eyes open and eyes closed (Z= -3.589, p=0.000, p<0.017), between the conditions of eyes open and VR (Z= -4.782, p=0.000, p<0.017) as well as between the conditions of eyes closed and VR (Z= -4.782, p= 0.000, p<0.017).

In addition, In order to compare the differences between the anterior-posterior (A-P) direction and the medial-lateral (M-L) direction, a Wilcoxon signed-rank test with a Sign test was conducted. The results showed a statistically significant difference in CoP excursion between the A-P direction and the M-L direction. More specifically, there was an increase in CoP excursion in the A-P direction compared to the M-L direction for both the conditions of Eyes open (p=0.000, p<0.05) and Eyes closed (p=0.026, p<0.05). However, this was not the case for the VR condition of visual stimulus; there was no significant difference in CoP excursion between the M-L and A-P direction (p=0.558, p>0.05).

Figure 2 summarizes the results from the analysis of the data in all conditions of visual information in two directions.

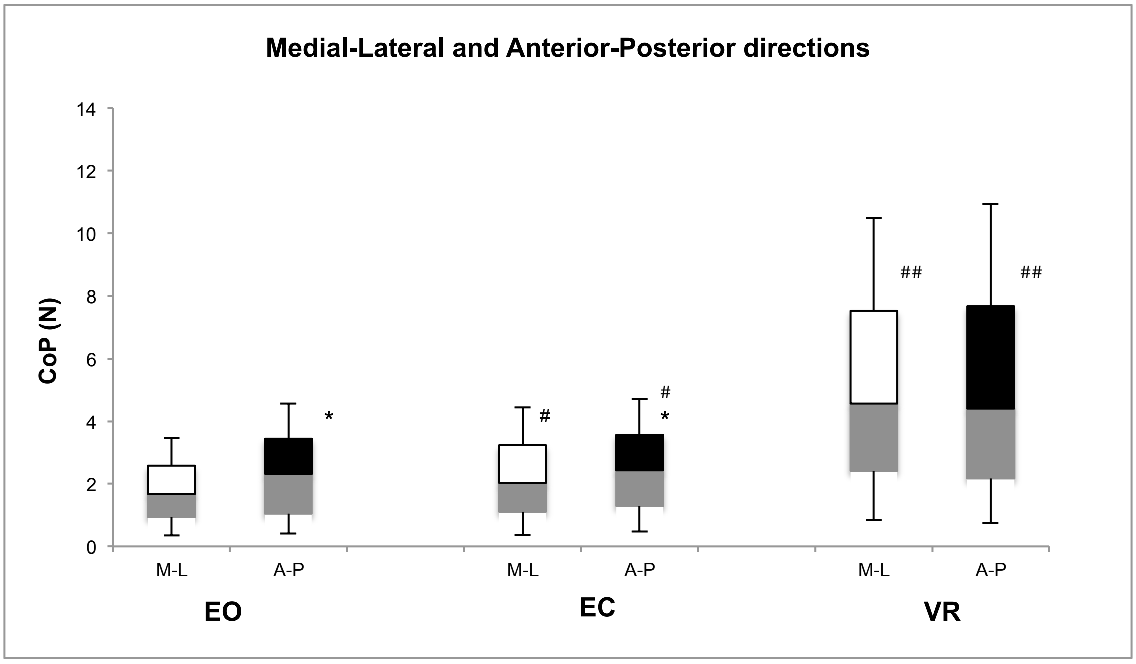

Figure 2*- Differences of CoP excursion for all conditions of visual stimuli (EO, EC,VR) in a medial-lateral (M-L) and an anterior-posterior (A-P) direction.*

** A-P significantly different from M-L*
 # EC significantly different from EO
VR significantly different from EO and EC.

Last, a Saphiro-Wilk test was conducted to test the normality of the data recruited from the head movements. The results showed that the data were not normally distributed for all conditions of visual stimulus (EO: p=0.001, EC: p= 0.000, VR: p=0.000). There was a statistically significant difference in head movements for all three conditions of visual stimulus, p=0.000 (p<0.05), as shown from a non-parametric Friedman test. Post-hoc analysis with Wilcoxon signed-rank test was conducted, with a Bonferroni correction, resulting in a significance level of p<0.017. Median (IQR) head accelerations for the conditions of eyes open, eyes closed and VR were 0.0056 (0.005 to 0.006), 0.009 (0.007 to 0.012) and 0.012 (0.011 to 0.181). The results showed a significant difference between the conditions of eyes open and eyes closed (Z=-4.286, p= 0.000, p<0.017), between the conditions of eyes open and VR (Z= -4.197, p=0.000, p<0.017) and between the conditions of eyes closed and VR (Z= -3,315, p=0.001, p<0.017). These results are represented in ***Figure 3***.

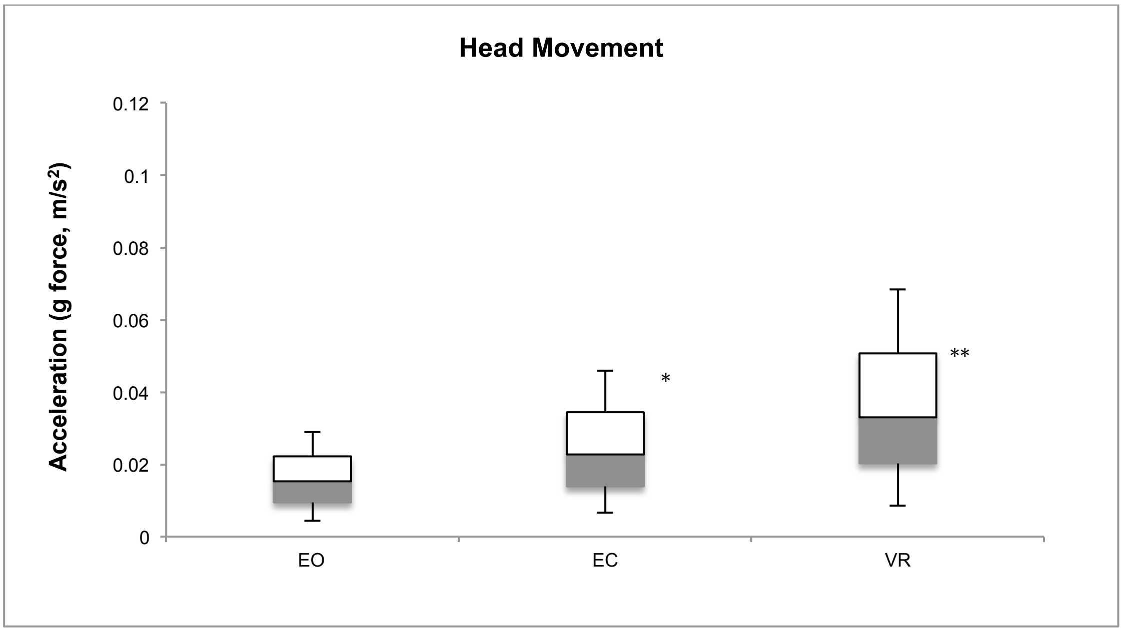

Figure 3 *- Difference of head movement accelerations within three conditions of visual stimulus (EO, EC, VR).*

**EC significantly different from EO*
***VR significantly different from EC and EO*

6. Discussion

The aim of this cross- over quantitative study was to investigate whether there is a difference in CoP excursion between conditions with and without a visual input from a dynamic application of VR. Participants were measured for their CoP excursion in three different conditions of visual stimulus: with their eyes open, eyes closed, and with the projection of a dynamic application through a HMD.

The results showed that there was strong evidence for a significant difference among the tasks, for both medial-lateral and anterior-posterior direction. During the absent visual stimulus (eyes closed) CoP excursion was less than during the VR display, although it did result in a significantly greater CoP excursion than standing with a normal visual stimulus (eyes open). Previous studies that have analyzed postural sways in adults have shown that postural reactions are generated more with eyes closed rather than with eyes open in bipodal support, which meets the findings of this study (25,39). Similarly to Ghiringhelli's study (2011), CoP excursion was greatest when participants were experiencing the VR display, suggesting that postural reactions were greatly generated (39). Although in the literature most studies tested the effect of VR on postural control with a moving surface, in this study postural control was measured during quiet stance. Such fact might burden the comparison among the results.

The dynamic VR application of the roller coaster used for this study can be described as a visual scene with high velocity of optic flow and various asymmetries. A study done by Previc (1993) showed that postural disturbances were greater when participants were presented with a moving visual image consisted of rotation in a rolling pattern (40). This pattern can be compared to the optic flow pattern that a roller coaster exhibits. The same effect was extended in the present study by implementing the perception of self-motion through the VR headset. The strong postural deviations found in this study presume that the preconscious reaction of falling is elicited by allowing an individual's reflexes to push the body towards or opposite to the direction of the stimulus (40). Among other studies, the results from this research confirm that optic flow is involved in the regulation of postural control (31).

An additional finding was that there was a significant increase of CoP excursion in the anterior-posterior direction rather than the medial-lateral direction for both the absent and the normal condition of visual input. These results are comparable to previous studies (41,42). As an example, McClenaghan (1995) showed that displacement in the CoP was greater in the anterior-posterior direction both in young and older adults. It is likely that this difference is due to the different strategies used to maintain posture. More specifically, stability in the anterior-posterior direction is controlled through muscular adjustments mainly at the ankle, whereas in the medial-lateral direction muscular adjustments occur at the hip (41,42). The ankle allows for more degrees of freedom in the sagittal plane, so it might be that subjects depended more on their anterior-posterior mechanisms to keep their posture. Such information is important when it comes to the elderly. It is reported that 90% of hip fractures happened because of a fall, especially in the medial-lateral direction (1). This suggests that when training postural control, attention should be brought to the stability mechanisms in the medial-lateral direction. However, the direction of postural tilt was inconsistent across subjects in the VR condition. In fact, the results showed that there was not a significant difference in CoP excursion between the medial-lateral and the anterior-posterior directions. The reason for these results could be that the strong stimulus generated by the dynamic application forced the participants to depend on more than one stability mechanism. This also suggests that VRBT might be relevant to the enhancement of the medial-lateral stability mechanisms, if optic flow is adjusted accordingly.

In this study, head accelerations were significantly different among the conditions of visual stimuli. Head movements were greater when participants were standing with their eyes closed compared to eyes open. A reason for this result could be the different positioning of the sensors between the tasks. More specifically, during the absent visual stimulus the accelerometer was placed anteriorly to the HMD, which is 65mm further from each participant's forehead (where the other accelerometer was placed during the normal visual input). However, this assumption does not account for the increased acceleration force during the VR stimulus compared to the absent visual stimulus. This finding supports the theory that individuals need the integration of visual, vestibular and proprioceptive pathways to maintain posture. Although these pathways are interrelated to a large extend, it is not unlikely that the magnitude upon which individuals rely on them can vary. Horak et al. (2006) suggested that as sensory conditions change, visual, vestibular and somatosensory stimuli are dynamically re-weighted to help the postural system maintain an upright stance (43). For this study it could be added that the reliability on vision can also produce a re-weighting process resulting for the postural control system to adapt by visual stimuli manipulation (17,33). However, in the future a study should be conducted that examines the extend to which individuals depend on their vestibular, visual and proprioceptive pathways to maintain posture.

There are several strengths noted in this study. Initially, participants were asked to stand on the force plate for 60 seconds in order to have accurate measurements. However, only 30 seconds (20s-50s) of each measurement were used in further analysis in the aim of standardizing the measurements. In addition, standardized protocols and instructions were used among experimenters to ensure coherence during the experimental procedure. In the effort to provide technologically up-to-date but still low cost tools for balance training strategies, this study used an economical HMD that could be easily used in practice (see appendix for HMD characteristics). This does not only provide clinical relevance to the current study but it also brings up new topics of research. In the future, it would be interesting to compare different head mounted devices and test their suitability in real practice.

Certain limitations should be pointed out in relation to this study. To begin with, the aim of this study was to minimize the influence of the sound in order to evaluate the contribution of the visual stimuli on postural control. However, there is a possibility that the earplugs did not fully provide sound protection. As a result, participants were able to hear existing noises generated by the number of people that were in the laboratory room. In future studies, this should be improved by reassuring the quality of the sound protection apparatus, and by managing a quiet experimental environment. Another limitation to this study was that an outlier was detected during the absent visual stimulus, which might have hindered the results. It is hypothesized that the reason for this outlying increase in CoP excursion is due to an external floor perturbation, causing the force plate to measure a greater CoP displacement.

The increased proprioceptive responses generated by the optic flow alternations, confirmed that the application of virtual reality in the context of postural control could be a clinically relevant approach. More specifically, when training postural adaptation, the level of difficulty has to meet the postural abilities of the patient. By using VR, this level can easily be adjusted only by changing the characteristics of optic flow patterns. It would be interesting to see whether an application with less or no optic flow speed and asymmetries would cause less postural disturbances based on the fact that a dynamic application caused great instability in healthy adults. If this is the case, then it would be considered as a less difficult task. In the future, this should be taken into consideration when addressing to a senior population. Rather than enabling researchers to make general remarks about the effects of aging on visual motion perception, literature underlines that these effects are case-specific in that they depend on the visual motions perception (31). According to the findings of this experiment, using a VR application with dynamic characteristics would be very challenging and not suitable to use for the elderly. A reason for that is the decrease of visual acuity that occurs with ageing and results in difficulty to respond to physical disturbances. In addition to that, the connection between the sensorial information and motor action can have an impact on a less stable behavior with time (39).

Although this VR study is still in the laboratory phase, it tried to provide reference values to the use of VR applications in practice. To the author’s knowledge this is the only research that implements the characteristics of a mobile application as a tool to influence postural control. However in order to implement VR into clinical practice, further studies should be conducted as to whether postural adaptation can be achieved with the use of a dynamic VR application, while taking into consideration the present results. Earliest studies suggest that VR offers a suitable visual stimulus for adapting postural reactions over a prolonged period of usage (23,26). However, further consideration should be taken as to the choice of applications used in postural rehabilitation. The adaptive features of the human nervous system, highlights the importance of enhancing the ecology of rehabilitative practice (23).

7. Conclusion

Overall, increased optic flow speed and optic flow asymmetries can generate great CoP displacement, which suggests that a dynamic VR application can cause postural disturbances. This means that postural control is markedly challenged.

Once more, it was shown that VR is a valuable tool for studying postural control. However, in the aim of benefiting more from VR in clinical practice, the effect of VR in postural adaptation should be examined, especially when addressing to those who experience falls. This experiment provided an insight in the context of sensorimotor rehabilitation and can be used as a paradigm for further investigations into postural adaptation.

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9. Appendices

APPENDIX I

Information Letter

Dear Sir/Madam,

We are graduate students of physical therapy in Fontys University of Applied Sciences, Eindhoven, The Netherlands. We would like to invite you to participate in our research experiment, which will take place between the 11th and 15th of April 2016. Before deciding whether you would like to participate or not, we advise you to read carefully the information sheet provided to you in order to have a better view of our experiment.

Goal of the research:
A great number of people suffer from postural instability. Physical therapists are able to help those people by using therapeutic interventions that aim to enhance their balance.
Technology is evolving rapidly and as health professionals it is important to induce it in our practice. The past few years virtual reality technology is being tested to examine whether the filed of rehabilitation can benefit from it.
The aim of this research is to investigate whether people with postural control problems can benefit from a virtual reality training program.

Are you eligible for this experiment?
In order to participate in the experiment you have to meet the following criteria:

- Age 18 or over
- You don’t have a recent (<6 months) foot, ankle, knee or hip problem
- You don’t have any neurological or vestibular problems
- You don’t have any eyesight loss.
- If you wear prescription glasses they should be replaced with eye contact lenses.
- You don’t have a BMI >30

Measurements for this experiment

- Changes in balance will be measured with a force platform
- Body and head movements will be measured with kinematic acceleration sensors

Experimental procedure:
You are going to be asked to remove your shoes, socks and shirt prior to the measurements. We will place a sensor between your shoulder blades and on your lower back that will record the acceleration of any upper body movements. A sensor will also be placed on top of your head, which will record any head movements. Then you will be placed on a force plate, which will record the forces applied on your body at that time. You will be asked to stand on the force plate with your ankles touching together, first with your eyes open for 1 minute, then with your eyes closed for 1 minute. Each participant will have 2 minutes of break between each measurement. After that you will wear a Virtual Reality headset in two different conditions while standing on the platform. Each Virtual Reality display will last 1 minute and you will have 10 minutes of break between each VR film. The order of the tasks will be randomly presented to you, by blindly selecting sequence papers. The experiment is then finished.

What are the risks of taking part in this research?
There is a possibility that you lose your balance while trying to stand on the force plate, therefore a researcher will always stand next to you to avoid possible falls.

What happens if you do not wish to participate in the study?
Participation in this study is voluntary; therefore you are free to decide whether you wish to take part in this experiment. If at any time you are not willing to continue with this experiment, you are allowed to cancel your participation.

What is expected from you?
If you are interested in participating in out study you should arrange an appointment with one of the researchers through email or orally. You are expected to show up on the day of the experiment in MART-lab 0.410. The procedure of the experiment will last 40-50 minutes.

In case you need to cancel the appointment, we would appreciate if one of the researchers is informed about it on time (24-hours before the appointment) in order to arrange for a replacement.

Ethics
The Fontys Ethics Committee has approved the experiment. All your personal data will be kept confidential and anonymous. Your data will only be collected for the purposes of this research. Note that your name will not be linked to your personal data.

Questions?
In case you have any questions about the experiment please contact any of the researchers in the contact information below.

After you have read all the information provided to you, you may review the given questionnaire. A consent form will have to be signed prior to any measurements.

Yours sincerely,

The researchers

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APPENDIX II

Certificate of consent

I have read the foregoing information, or it has been read to me. I have had the opportunity to ask questions about it and any questions that I have asked have been answered to my satisfaction. I consent voluntarily to participate as a participant in this research.

Print Name of Participant ____

Signature of Participant ____

Date
Day/month/year ____________________

If illiterate
A literate witness must sign (if possible, this person should be selected by the participant and should have no connection to the research team). Participants who are illiterate should include their thumb-print as well.

I have witnessed the accurate reading of the consent form to the potential participant, and the individual has had the opportunity to ask questions. I confirm that the individual has given consent freely.

Print Name of Witness ____

Signature of Witness ____

Date
Day/month/year ____________________

VR Thesis (Majid Krim, Marianna Veriki, Lennart Driece)

(Source: World Health Organization, http://www.who.int/rpc/research_ethics/informed_consent/en/)

APPENDIX III

Questionnaire

Dear participant,
Please answer the following questions. We would like to gather some of your personal and background information that are of high importance for the experiment. Confidentiality will be taken into account and all your information will be kept anonymous.

Personal Information

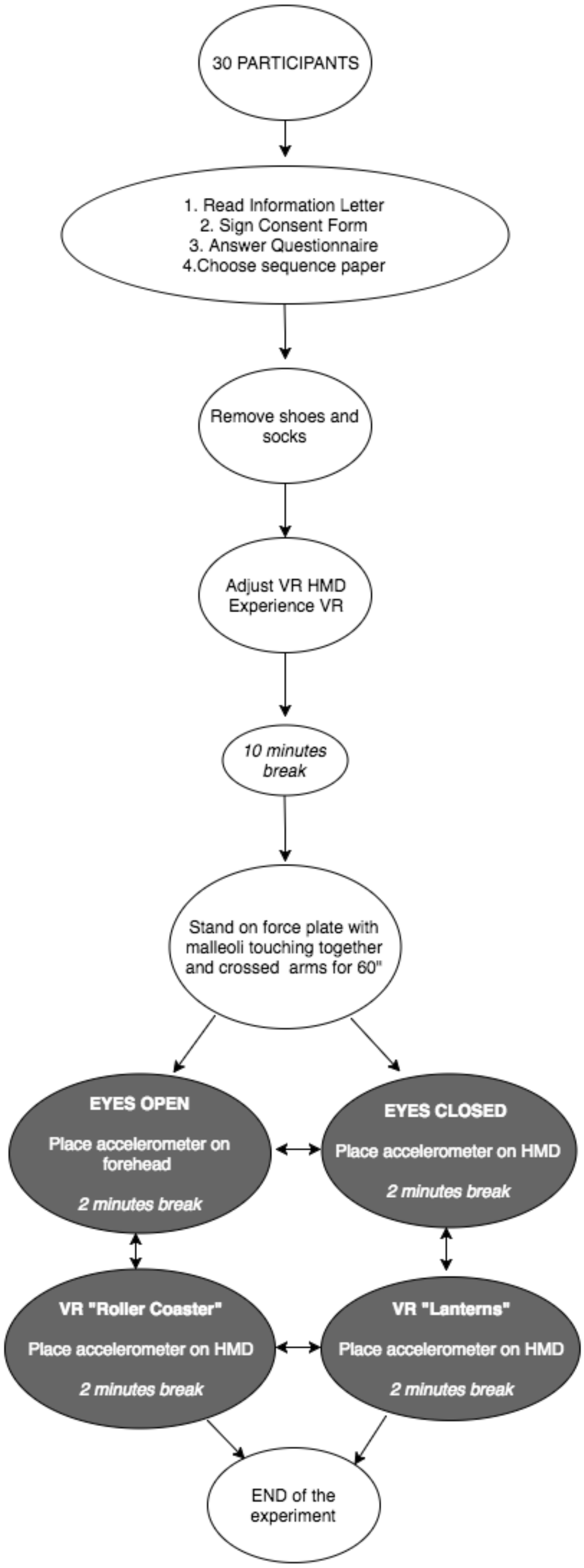
1. Name:
2. Age:
3. Gender: M F
4. Weight:
5. Height:

Background Information

	YES (if yes please Describe)	**NO**
Do you experience any difficulties with your balance?		
Do you have any vision problems?		
Do you wear glasses?		
Do you wear eye contact lenses?		
Have you experienced any recent (less than six months) problems with your hip, knee, ankle or foot?		
Do you experience any symptoms of dizziness?		
Do you have any health problems?		

Thank you for filling in the questionnaire.

APPENDIX IV


30 PARTICIPANTS
1. Read Information Letter
2. Sign Consent Form
3. Answer Questionnaire
4.Choose sequence paper
Remove shoes and socks
Adjust VR HMD
Experience VR
10 minutes break
Stand on force plate with malleoli touching together and crossed arms for 60"
EYES OPEN
Place accelerometer on forehead
2 minutes break
EYES CLOSED
Place accelerometer on HMD
2 minutes break
VR "Roller Coaster"
Place accelerometer on HMD
2 minutes break
VR "Lanterns"
Place accelerometer on HMD
2 minutes break
END of the experiment

APPENDIX V

STANDARIZED PATIENT INSTRUCTIONS

- Welcome to our experiment we are students of Fontys Physiotherapy of Applied Sciences.
- Have you read the information letter? Do you have any questions concerning the experiment?
- Please fill in the questionnaire about your personal data.
- Please sign the consent form and after that choose a paper for the sequence of the tasks.
- Please wear the goggles in order to adjust them. You will now experience a virtual reality film.
- Now you will have a break for 10 minutes before the initiation of the measurements.
- Please remove your shoes, socks and shirt to proceed to the measurements. We are now starting with the experiment
- We are going to start with the first task. We will place a sensor that measure acceleration on your forehead. Try to keep the white line between your feet. Make sure the ankles are touching each other. Keep your eyes open and look straight. You will stay in this position for 60 seconds. You may wear the earplugs and we will start with the measurements. You can step off now. You will now have 2 minutes of break before the next task
- Please step on the force plate again. Try to keep the white line between your feet. Make sure the ankles are touching each other. For this task you will have to close your eyes. You will wear the HMD to make sure that you don't see anything. You will stay in this position for 60 seconds. You may wear the earplugs and we will start with the measurements. You can step off now. You will now have 2 minutes of break before the next task.
- The last task will start now. We will place sensors that measures acceleration on your upper and lower back. Please put on the virtual reality glasses. Do they fit well? Please step on the force plate again. Try to keep the white line between your feet. Make sure the ankles are touching each other. You will stay in this position for 60 seconds. We will place the phone on the goggles and will start with the Virtual Reality scene. While you experience the VR film you are going to wear the earplugs again. You can step off now. You will now have 10 minutes of break before the next task.
- Please step on the force plate again. We will place sensors that measure acceleration on your upper and lower back. Try to keep the white line between your feet. Make sure the ankles are touching each other. You will stay in this position for 40 seconds. We will place the phone on the goggles and will start with the Virtual Reality scene. While you experience the VR film you are going to wear the earplugs again.
- You can step off now. You will now have 10 minutes of break before the next task. Please step on the force plate again. Try to keep the white line between your feet. Make sure the ankles are touching each other. You will stay in this position for 40 seconds. We will place the phone on the goggles and will start with the Virtual Reality scene. While you experience the VR film you are going to wear the earplugs again.
- The experiment is now over.

APPENDIX VI

Information about apparatus and Applications used for this experiment

1. “Homido” Virtual Reality headset

Description:

Homido® is a Virtual Reality headset that works with iPhone™/ Android™/ Windows™ smartphones. Firstly, the “Homido Center” application is downloaded in a smartphone, which includes a variety of virtual reality applications. Once a virtual reality application is installed, the smartphone can be inserted into the headset aligned horizontally. Sharpness can be manipulated by an adjustment wheel in the center of the headset. In order to adjust Homido® according to each individual’s vision, conical lenses are included in the Homido® package. By setting up all the adjustments, a virtual reality immersion begins. ***Table 1*** below summarizes the characteristics of the Homido® VR headset.

Table 1- Characteristics of Homido® VR headset.

Custom made VR lenses: 100° FOV
Farsightedness and nearsightedness settings
Compatible with most recent smartphones (Android & iPhone)
Optical settings: IPD and immersion adjustment
Interchangeable face contact foam
Wireless
Dimensions: 19.5x 13.4 x 1.27
413 G

Figure 1: *Homido Virtual Reality headset (Source: Homido Virtual Reality Headset)(48)*

2. Force Plate

Name: OR6-7-1000 by AMPTI force and Motion

A force plate is a measuring instrument that determines the ground reaction forces initiated by a body standing on it. It can be used to quantify balance, gait or other biomechanical features. Force components are measured in a Fy, Fx and Fz axis, where Fy and Fx are horizontal axes and Fz the vertical axis. Data measured in these three axes can be used to calculate the position Center of Pressure (CoP) relative to the force plate.

In this study, CoP will be measured in an anterior-posterior and medial-lateral direction (Fy, Fx). ***Table 2*** shows the characteristics of the platform used in this experiment.

Table 2: *Characteristics of OR6-7-1000 force plate.*

Features:			
Dimensions (WxLxH)	464 x 508 x 83 mm	**Mounting hardware**	Recommended
Weight	28.18 kg	**Sensing elements**	Strain gage bridge
Channels	Fx, Fy, Fz, Mx, My, Mz	**Amplifier**	Required
Top plate material	Aluminum	**Analog outputs**	6 Channels
Temperature range	-17.78 to 51.67°C	**Digital outputs**	None
Excitation	10V maximum	**Crosstalk**	< 2% on all channels
Fx, Fy, Fz hysteresis	± 0.2% full scale output	**Fx, Fy, Fz non-linearity**	± 0.2% full scale output

***Figure 2**: OR6-7-100 force plate (Source: AMPTI force and motion) (44)*

3. Accelerometers

Name: Trigno™ Wireless System, Delsys©

The Trigno™ Wireless is an accelerometer that measures proper acceleration (g-force, $g=m/s^2$). It has an EMG wireless system with a triaxial accelerometer (F(x), F(y), F(z)) and it is used to detect and monitor movement and vibrations. ***Table 3*** below shows some of the features of Trigno™ Wireless EMG System.

***Table 3**: Characteristics of Tringo Wireless System.*

Features:
Transmission range of 20m
Inter-sensor latency < 500us (< 1 sample period)
Self-contained rechargeable battery • EMG signal bandwidth 20- 450 Hz
EMG signal sampling rate of 2000 samples/sec
EMG baseline noise of <750 nV RMS • CMRR > 80dB
16-bit EMG signal resolution • integrated triaxial accelerometer
Software selectable accelerometer sensitivity of ± 1.5g or ±6g
LED User feedback
Battery charge monitoring and status indicator
Environmentally sealed device
proven parallel bar electrode technology
Contoured sensor-skin interface for maximum signal stability
Auto shutoff

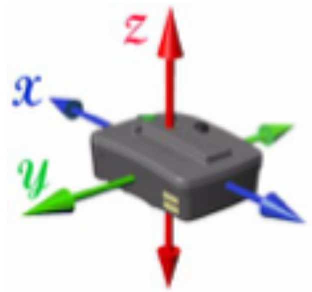


***Figure 3**: Tringo Wireless System (Source: Tringo EMG Systems)(50)*

4. Applications used in this experiment

a. Application I: A time in space VR Cardboard.

Offered by: Creanet 3D Version: 1.0.33

"A time in space VR Cardboard" is an application that allows the user to experience a ride on space. It combines a dynamic and a static environment of VR, with transitions of speed. The user can experience this application in a sitting position. This application will be used for the practice session of the experiment.

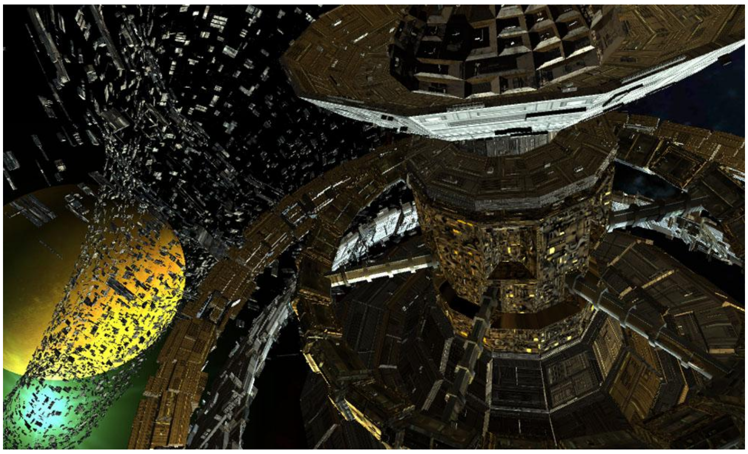


***Figure 4:** "A time in space, Application". (Source: A time in space VR-Cardboard- Android Apps on Google Play) (47)*

b. Application II: Dive City Roller coaster Offered by: Durovis

Version: 1.7

“Dive City Roller Coaster” is an application that allows the user to experience a roller-coaster ride in the city. City scenes move across and in the opposite direction of head-movements allowing the user to experience a real roller coaster ride. This application was chosen since due to the rapid changes in the velocity and symmetry of the optic flow.

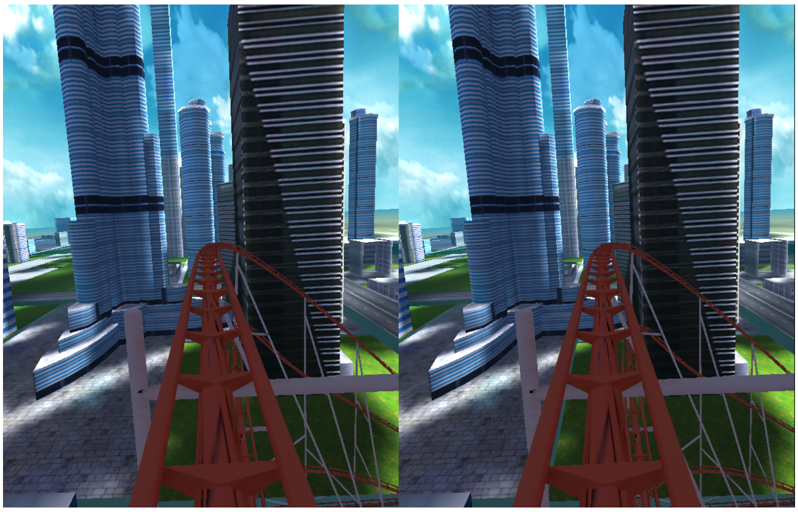


Figure 5: *“Dive city Roller Coater” application. (Source: Dive City roller coasters- Android Apps on Google Play) (45)*

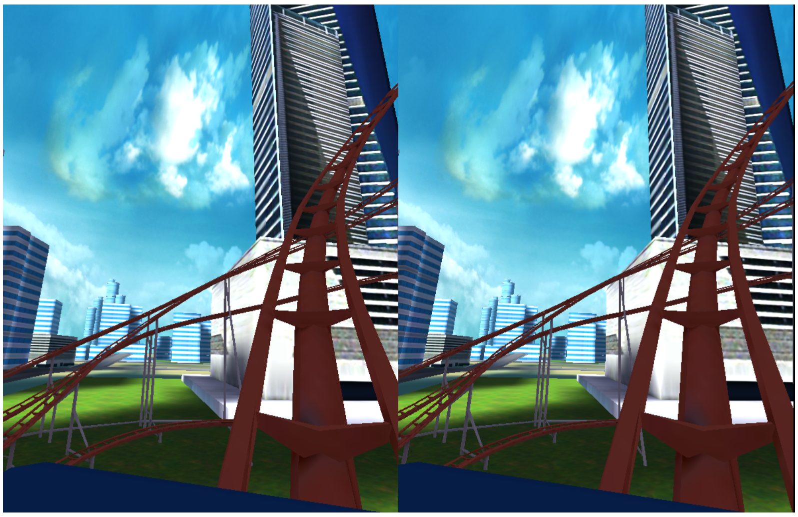


Figure 6*: “Dive city Roller Coater” application. (Source: Dive City roller coasters- Android Apps on Google Play) (45)*

c. Application III: Lanterns for Google Cardboard Offered by: Oleksandr Popov

Version: 2.9

“Lanterns for Google Cardboard” is an application that allows the user to experience a typical night view of Lantern festival celebration. The natural scenery of the mountains and the river gives a realistic character to this application.

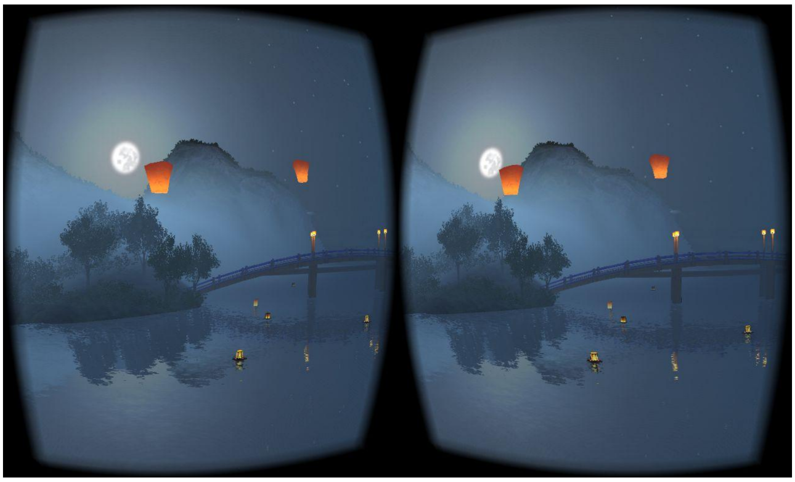


Figure 7: *"Lanterns for Google Cardboard" application. (Source: Lanterns for Google Cardboard- Android Apps on Google Play) (46)*

5. LG smartphone

"LG G3 D855" is a smartphone that allows to the user to have access to the open-source platform Android and download various applications. ***Table 4*** shows the characteristics of LG smartphone.

Table 4*- Characteristics of LG smartphone.*

Model	: LG G3 D855
Type: **RF Band:**	Bar phone 2G (GSM/EDGE), 3G (HSPA+42Mbps/HSPA+21Mbps), LTE (SVLTE, CSFB, CA, VoLTE RCS, MIMO)
OPERATING SYSTEM:	Android 4.4 (KitKat)
CHIPSET:	Qualcomm® SnapdragonTM with 2.46 GHz Quad-Core Processor

Figure 8: *LG G3 D855 (Source: LG Mobile Phones) (49)*

Fontys Paramedische Hogeschool

B8. Confidentiality statement

Name: Student No°:

Title:
The effect of Virtual Reality on Postural control

Content (description):

1. By signing this Statement, the Fontys Paramedic University of Applied Sciences in Eindhoven commits itself to keep any information concerning provided data and results obtained on the basis of research of which is taken cognizance as part of the above practical research project and of which it is known or can be reasonably understood that said information is to be considered secret or confidential, in the strictest confidence.
2. This confidentiality requirement also applies to the employees of the Fontys Paramedic University of Applied Sciences, as well as to others who by virtue of their function have access to or have taken cognizance of the aforesaid information in any way.
3. The above notwithstanding, the student will be able to perform the practical research project in accordance with the statutory rules and regulations.

Student:

Name: Marianna Verikis

(signature) Date: 5/6/2016

Supervisor:

Name: Sil Kloppenburg

(signature) Date: 31/05/2016

Coordinator: for receipt

Name: Steven Onkelinx

(signature) Date 31/05/2016

Manual Practice-based Research Graduation Phase 2013 – 2014 - FPH 1

Fontys Paramedische Hogeschool

B9. Conveyance of Rights Agreement

AGREEMENT

Pertaining to the conveyance of rights and the obligation to convey/return data, software and other means

The undersigned:

1. Mr/Ms Marianna Veriki

[full name as stated in passport], residing at Eindhoven 5625AB, Netherlands *[postal code, place of residence]* at the Winkelcentrum Woensel 13 *[street and house number]*, hereinafter to be called "**Student**"

and

2. Fontys Institute trading under the name Fontys University of Applied Sciences, Rachelsmolen 1, 5612 MA Eindhoven, hereinafter to be called "**Fontys**"

CONSIDERATION

A. Student is studying at the Fontys Paramedic University of Applied Sciences in Eindhoven and is performing or will perform (various) activities as part of his/her studies, whether or not together with third parties and/or commissioned by third parties, as part of research supervised by the lectureship of Fontys Paramedic University of Applied Sciences. The aforesaid activities will hereinafter be called "**Lectureship Study Activities**". At the time of the signing of this Statement, the Lectureship of Fontys Paramedic University of Applied Sciences supervises in any case the studies listed in Appendix 1, but this list is not an exhaustive one and may change in the future.

B. It is of essential importance to Fontys Paramedic University of Applied Sciences that (the results of) the Lectureship Study Activities can be further developed and applied without any restriction by Fontys Paramedic University of Applied Sciences and/or used for the education of other students. Fontys wishes in any event – but not exclusively – (i) to be able to share with and/or convey to third parties (the results of) the Lectureship Study Activities, (ii) to publish these under its own name, where the Student may be named as co-author providing that this is reasonable under the circumstances, (iii) to be able to use these as a basis for new research projects.

C. In case intellectual ownership rights and/or related claims on the part of Student will be/are attached to (the results of) the Lectureship Study Activities, parties wish – taking into account that which was mentioned under (B) – Fontys Paramedic University of Applied Sciences to be the only claimant with regard to said rights and claims. The Student therefore wishes to convey all his/her current and future intellectual property rights as well as related claims concerning (results of) the Lectureship Study Activities to Fontys, subject to conditions to be specified hereafter;

Fontys Paramedische Hogeschool

D. Student furthermore wishes to enter into the obligation – again taking into account that which was mentioned under (B) – to convey all data collected by him/her as part of the (results of) the Lectureship Study Activities to Fontys and not to retain any copies thereof, and also to return all data, software and/or other means previously provided by Fontys as part of (the results of) the Lectureship Study Activities, such as measuring and testing equipment, to Fontys without retaining copies thereof, all the above being subject to conditions to be specified hereafter.

AGREE THE FOLLOWING

1. *Conveyance of intellectual property rights*

1.1 Student herewith conveys to the Fontys Paramedic University of Applied Sciences all his/her current and future intellectual property rights and related claims concerning (the results of) the Lectureship Study Activities, for the full term of these rights.

1.2 Intellectual property rights and/or related claims are understood to refer to, in any case – but not limited to – copyright, data bank law, patent law, trademark law, trade name law, designs and model rights, plant breeder's rights, the protection of know-how and protection against unfair competition.

1.3 The conveyance described under 1.1 shall be without restriction. As such, the aforesaid conveyance shall include all competences related to the conveyed rights and claims, and said conveyance shall apply to all countries worldwide.

1.4 Insofar as any national law requires any further cooperation on the part of Student for the conveyance mentioned under 1.1, Student will immediately and without reservation lend such cooperation at first request by Fontys Paramedic University of Applied Sciences

1.5 Fontys accepts the conveyance described under 1.1.

2. *Waiver of personal rights*

2.1 Insofar as permitted under article 25 'Copyright' and any other national laws that may apply, Student waives his/her personal rights, including – but not limited to – the right to mention Student's name and the right to oppose any changes to (the results of) the Lectureship Study Activities. If and insofar as Student can claim personality rights pursuant to any national laws notwithstanding the above, Student will not appeal to said personality rights on unreasonable grounds.

Fontys Paramedische Hogeschool

2.2 In deviation from that which was stipulated under 2.1, the Fontys Paramedic University of Applied Sciences may decide to mention the name of Student if this is reasonable in view of the extent of his/her contribution and activities.

3. *Compensation*

Student agrees that he/she will receive no compensation for the conveyance and waiver of rights as described in this Statement.

4. *Guarantee concerning intellectual property rights*

Student declares that he/she is entitled to the aforesaid conveyance and waiver, and declares that he/she has not granted or will grant in future, license(s) for the use of (the results of) the Lectureship Study Activities in any way to any third party/parties. Student indemnifies Fontys from any claims by third parties within this context.

5. *Obligation to convey/return data, software and other means*

5.1 At such a time as Student is no longer performing any Lectureship Study Activities and/or is no longer a student at Fontys, Student is obliged to convey to Fontys all data, in the widest sense of the word, collected by him/her as part of (results of) the Lectureship Study Activities, including – but not limited to – studies and research results, interim notes, documents, images, drawings, models, prototypes, specifications, production methods, process descriptions and technique descriptions.

5.2 Student guarantees not to have kept any copies in any way or form of the data meant under 5.1.

5.3 Student is obliged to return to Fontys all data, software and other means provided to him/her by Fontys as part of the Lectureship Study Activities, and guarantees not to have kept copies in any way or in any form, of the provided software and/or other means.

5.4 Student agrees that if he acts and/or proves to have acted contrary to the obligations mentioned under 5.1 up to and including 5.3, (a) he/she shall be liable for all and any damages incurred or to be incurred by Fontys, and (b) that this will qualify as fraud and that Fontys can apply the appropriate sanctions hereto. The sanctions to be applied by Fontys may consist of, among other things, the denying of study credits, the temporary exclusion of the Undersigned from participation in examinations, but also the definitive removal of the registration of the Undersigned as a student at Fontys.

Fontys Paramedische Hogeschool

6. *Waiver*

Student waives the right to terminate this Agreement.

7. *Further stipulations*

7.1 Insofar as this Agreement deviates from the Student Statute, this Agreement shall prevail.

7.2 This Agreement is subject to Dutch law. All disputes resulting from this statement will be brought before the competent judge in Amsterdam.

Student:	Fontys Institute trading under the name Fontys Hogescholen Supervisor:
Name: MARIANNA VERIKIS	Name: Sil Kloppenburg
(signature)	(signature)
Date: 5/6/2016	Date: 31/05 2016
Place: Eindhoven	Place: Eindhoven

I, Ms. M.H. de Waard, sworn translator for the English language registered at the Court in Groningen, the Netherlands, and registered in the Dutch Register of Sworn Translators and Interpreters (Rbtv) under nr. 2202, herewith certify the above to be a true and faithful translation of the attached Dutch document into the English language.

Groningen, 23 May 2012,

[M.H. de Waard]