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Feasibility of VR exergames for gait training in post-stroke patients

Master's thesis in Human Movement Science
Supervisor: Beatrix Vereijken
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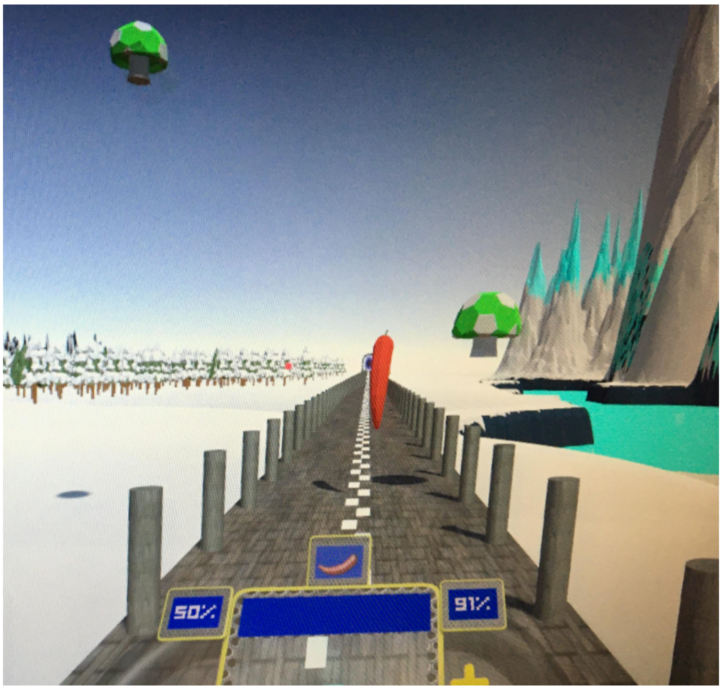

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NTNU
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Abstract

[Purpose] This study aimed to investigate the feasibility of a virtual reality (VR) gait training game targeting gait symmetry in stroke survivors. [Subjects and Methods] The study was conducted with 10 post-stroke participants, each playing three different VR-game conditions on a treadmill, in one session of approximately two hours. The conditions were: step on tiles, step over stripes, and step on tiles while doing a cognitive task. Foot placement on the side of the body with the shortest step length was influenced to take gradually bigger steps, through a dynamic gait adjustment game, in order to make both sides have similar step lengths, thereby improving the body symmetry ratio. The order of the 2 first game conditions was counter-balanced between the participants, while all played the tiles + cognitive condition as the last one. Video recordings were made with the participant walking on a treadmill without virtual reality (reference condition), with virtual reality but without game conditions (VR reference), and in the 3 different game conditions, totaling 5 recordings situations. A 3D motion capture (MoCap) system was used to record the participants' movements by the use of 22 reflective markers and a 7 infrared cameras system. A VR headset (HTC Vive) was used with 2 stations to enable an immersive virtual reality. Walking speed, stride length, step width, double and single stance phase, length and number of steps per minute (cadence) were calculated. The spatiotemporal gait variables step length and step width were chosen to examine gait symmetry. [Results] All 10 participants managed to complete all conditions. Furthermore, gait symmetry was not significantly different between the five conditions, as analyzed by repeated measures ANOVA on step length asymmetry and step width asymmetry variables. However, there was a tendency in each participant towards a better symmetry ratio. [Conclusion] These findings indicate that it is feasible for post-stroke individuals to use a virtual reality game with dynamic gait adjustment. Although there were trends towards improved gait symmetry, the games were likely played too short to find significant improvement. Further studies should be done with a larger sample and longer playing time, to investigate whether adjustment in virtual reality games can lead to improvements in gait symmetry and gait function.

Key Words: stroke, virtual reality, feasibility, gait symmetry

Sammendrag

[Hensikt] Denne studien hadde som formål å undersøke gjennomførbarhet av et virtuelt reality (VR) gangtreningsspill rettet mot gangsymmetri hos personer etter hjerneslag. [Deltakere og metode] Studien ble utført med 10 deltakerne etter hjerneslag, som hver deltaker gikk på en vanlig tredemølle imens spilte tre ulike VR-spill oppgaver, og deltakelsen tok omtrent 2 timer. Oppgavene i VR-spillet var å treffe fliser, å unngå lister og å treffe fliser og samtidig finne og skyte spesifikke objekter i lufta. Fotplassering på kroppssiden med de korteste steglengder ble påvirket til å ta gradvis større steg, gjennom et dynamisk gangtilpassingsspill, for å ha steglengde som ligner på den andre siden og deretter forbedre gangsymmetri. Rekkefølgen på de to første spilleoppgavene var balansert mellom deltakerne, og alle spilte fliser + kognitiv oppgave som den siste aktiviteten. Videoopptak ble laget med deltakerne på tredemølla uten virtuell virkeligheten (referanseopptak), med virtuell virkeligheten, men uten spilleoppgave (VR-referanse), og i de 3 forskjellige spilleoppgaver, i et totall av 5 videoopptaker. Et 3D-bevegelsesfangst-system (3D MoCap) ble brukt til å registrere deltakernes bevegelser ved bruk av 22 reflekterende markører og kamerasystem med 7 infrarøde kameraer. En VR-briller (HTC Vive) med 2 basestasjoner ble brukt for å skape en virtuell virkelighet. Ganghastighet, steglengde, stegbredde, dobbelt- og enkeltstandsfase, lengde og antall steg per minutt (kadens) ble beregnet.
Spatielle gangvariabler (steglengde og stegbredde) ble brukt for å undersøke gangsymmetri. [Resultater] Alle de 10 deltakere klarte å fullføre aktivitetene. Symmetri var ikke statistisk forskjellige mellom de fem oppgavene, som ble analysert ved repeterte målinger av ANOVA, med steglengde asymmetri og stegbredde asymmetri variabler. Imidlertid var det mulig å observere en tendens hos hver deltaker til å oppnå bedre symmetri. [Konklusjon] Resultatene viser at det er mulig for personer med hjerneslag å bruke et virtuell reality-spill med dynamisk gangtilpasning. Selv om det viser en tendens til en bedre gangsymmetri, ble spillene sannsynligvis spilt for en kort tid til å finne betydelige forbedringer. Fremtidige studier bør gjøres med et større utvalg og med lengre spilletid, for å undersøke om justering i virtuell reality-spill kan føre til forbedringer i gangsymmetri og gangfunksjon.

Nøkkelord: hjerneslag, virtuell virkelighet, gjennomførbarhet, gangsymmetri.

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Andréa S Souza

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Table of Contents

1. Introduction

Stroke is a serious cardiovascular health problem which affects around 17 million people globally per year (1) and the number of cases has increased substantially over the past few decades. It is the second largest cause of death worldwide and remains an important cause of disability (2).

Stroke can result in impaired sensation, motor disturbance and cognitive disorders (2). Hemiparesis, a weakness of one side of the body, can be observed immediately after a stroke in more than 85% of the cases (3). Resulting gait impairment often manifests as an asymmetric walking pattern, since compensatory gait strategies such as a decrease in knee flexion during stance phase, can lead to postural imbalance (4). Furthermore, an increase in weight bearing towards the non-paretic side is often observed, leading to overuse of the nonparetic leg (5). This often results in functional limitations and disabilities, which again can affect daily-life activities and social life (2). Therefore gait restoration is often the primary goal in stroke rehabilitation, with focus on returning to community ambulation (6).

In healthy adults, there are three general joint movement strategies for maintenance of anteroposterior stability: the ankle, hip and stepping strategies. The ankle strategy is mostly used in response to small balance disturbances, while the others are larger and faster strategies, used to recover balance after a sway, or after the center of body mass has changed its position considerably (7). In stroke patients, excessive pelvis tilt can be observed in stance and swing phase, which increases instability (4). A recent Cochrane review (8) concluded that people after stroke who are able to walk independently can have their walking capacity and speed improved through treadmill training with or without body weight support. Furthermore, a body-weight support treadmill training (BWSTT) ensures safety during activities (9).

However, this combination or even treadmill training alone was not better to improve independently gait ability when compared with other conventional physiotherapy gait-training interventions (8). More functional activities should be included to contribute to improve overall independence (10), and regarding this, virtual reality (VR) appeared as a promising approach, as it allows users to interact with a multisensory and stimulating environment which requires active participation. Furthermore, it permits better self-correction as it provides real-time feedback on performance (11).

Rehabilitation with virtual reality has a high rate of adherence and shows to be flexible and safe (12). It produces positive effects on attention and reduces the perception of exertion, keeping patients more motivated throughout the training sessions, allowing longer and more intense training sessions (11, 13-15). Although VR is not necessarily more effective than conventional interventions (15), it is a good alternative rehabilitation tool for neurological disabilities. Virtual walking programs, for example, when associated with treadmill training, lead to improvement in gait parameters like cadence, velocity and walking balance (5).

In VR training, a wide variety of different activities with varying levels of difficulty can be offered. When deciding which activity to offer to a patient, the purposes that are aimed to be achieved must be taken into account (16), as it can produce training-specific effects depending on the activity (17). One of the typical difficulties after stroke is to perform time-critical tasks, which requires continuous attention. The typically slow gait speed as well as the altered gait pattern often hinder the execution of these activities (18). In case of cognitive deficits, fewer attentional resources are available for simultaneous activities (19). Post-stroke patients also have difficulties in managing tasks which normally are done automatically (20). Therefore, to increase such abilities, dual or more simultaneous task training should be considered, as they can improve complex walking skills (17).

Although many studies exist on virtual reality in stroke rehabilitation, most of these aimed to compare conventional therapy to virtual reality, or conventional therapy in addition to virtual reality to just conventional therapy. There is a lack of knowledge regarding how to achieve more efficiency in virtual reality using different game components, like different types of activities, variation in the level of difficulty or analysis of possible feedbacks. The effect of different virtual motor activities and the impact of VR-based motor-cognitive training in stroke rehabilitation, requires further investigation. Likewise, it is still underexplored whether it is possible to have dynamic difficulty adjustments during immersive VR game activities and whether VR tasks can be used by post-stroke patients in order to help them improve their walking pattern.

The current study aims to assess the feasibility of using virtual reality exergames to instruct post-stroke patients where to place their feet on a treadmill, and whether this results in improved gait symmetry and gait ability during a single training session.

For this purpose, three different versions of a gait-training VR game were used, two motor tasks and one motor-cognitive task, each presenting gradually more symmetrical targets for foot placement. It was hypothesized that this VR training would be feasible for stroke patients, and that there would be signs of decrease in gait asymmetry and improvement in functional walking. Furthermore, it was expected that the gait performance would be different between the three activities, with the motor-cognitive task being the most difficult to perform, as it mobilizes more complex control reactions.

2. Methods

2.1 Study design

The performed study was observational and cross sectional in design and aimed to look at potential differences in gait parameters, characteristics and quality of movements depending on game difficulty when exposed to different tasks. Each participant attended one session in a laboratory with a duration of approximately 120 minutes. All the procedures were done in the Norwegian language, as all patients were native Norwegian speakers.

The study was approved by the Regional Ethical Committee of Medical and Health Research Ethics, number 50926, date 18/11/2019.

2.2 Participants

Ten stroke participants with unilateral stroke (hemorrhagic or ischemic) in the chronic stroke phase, 7 men and 3 women, were recruited and participated in this project. Written consent was given and signed by all of them before data collection started. The average age was 60.29 ±7.740 for men and 62.67 ± 6.807 for women. This and other information about the participants can be seen in *Table 2* in Results section.

The recruitment for the study was done by an associated physiotherapist researcher at the St. Olav Hospital, Clinic of Physical Medicine and Rehabilitation, Department of Acquired Brain Injury. The inclusion criteria were stroke patients at least 3 months after stroke who have experience walking on a treadmill after the stroke and were more than 18 years old. The exclusion criteria were epilepsy and other conditions that might affect the ability to walk safely with VR on a treadmill.

All participants completed the experiment and no physical injuries or symptoms occurred which required interruption of the testing procedures. To avoid potential problems related to aphasia, all the instructions were verbally explained, as were the items of an applied questionnaire. In order to help them with the questionnaire's answers, a drawn scale with images was used allowing them to point on the desired value. All participants were able to understand the study procedures and answer the questionnaire.

2.3 Protocol and equipment

The participants received oral and written information regarding the study before they arrived in the laboratory. At arrival, they were welcomed and introduced to the testing procedures. Detailed information about all activities and procedures which would be done were given in the lab, using photos, illustrations, and video.

The protocol was divided in 4 stages:

1) short interview and physical examination

2) 4-meters walking test (reference gait)

3) placement of markers, warm up on the treadmill and test of virtual reality glasses

4) gameplay.

Interview and physical examination

In the first stage, a short interview was conducted to collect information about how long ago the stroke took place, the affected side, type of stroke, possible pain during walking, treadmill training experience, and previous experience with VR glasses. Additionally, participants' height and weight were measured using a measuring tape and a SECA 761 Analog-weighing Scale, see *Figure 1*.

Then, a kinesthetic sensation test from the Nottingham Sensory Assessment (NSA) standard tool (27) was performed by a physiotherapist. The following movements were assessed: knee extension and flexion, hip external and internal rotation, plantar flexion and dorsiflexion. Three aspects of these movements were tested simultaneously: sensation of movement, direction and accurate joint position sense. The limb on the affected side of the body was supported and moved by the examiner, one joint at a time. The patient observed the movement made on his paretic leg and was asked to mirror it with the other leg. Then, the physiotherapist repeated the movement and the patient tried again with closed eyes. In case the movement was not carried out or was performed in the wrong direction or angulation/ height, the physiotherapist conducted two more trials of the same movement before evaluating. The score assigned to each test ranged from 0, absent movement, to 3, mirrors the test movement within 10° of the aimed position. Score 1 refers to a movement in an incorrect direction and score 2, correct direction but with more than 10° difference from the aimed position.

Following this, goniometric and anthropometric measures were taken, using STANLEY Tape Measure and TRIDENT Goniometer, see *Figure 1*.

The kinesthetic sensation test and clinical measures were taken with the objective to check possible and previous conditions that could influence the patient's gait and performance of the game, especially when game difficulty was increased. Such conditions could be spasticity, contracture, abnormal muscle contraction, abnormal weakness, coordination or cognitive problems, etc.

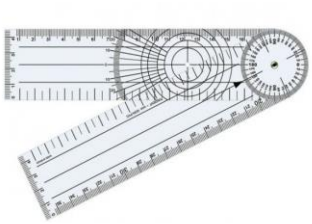


Photo: www.magazineluiza.com.br

Trident Goniometer

Photo: www.seca.com

SECA 761 Analog-weighing Scale

Photo: www.clasohlson.com/no

AZAKLITT Professional Stopwatch

Photo: www.ffx.co.uk

Bosch PLL360 Self-Levelling 360° Line Laser

Photo: Andrea Souza

Clinical and physical evaluation room

Photo: www.thetapestore.co.uk

STANLEY Tape Measure

Figure 1. Illustrations of equipment used during the testing procedure.

Walking test

In the second stage, the walking test, the patient was invited to walk 4 meters over ground at a comfortable velocity, for three times. An AZAKLITT Professional Stopwatch was used for taking the time, see *Figure 1*.

This allowed calculation of the average speed patients had in comfortable over ground gait which would be the starting speed on the treadmill. Thus, if the participant deemed it necessary, the speed was reduced to a more comfortable one and maintained the same during the following five activities on the treadmill.

Motion capture system (MoCap)

In the third stage, reflective markers and 7 infrared cameras (OQUS mx400, 100Hz, Qualisys AB) were used to record participants' movements to calculate walking speed, stride length, step width, double and single stance phase, length and number of steps per minute (cadence). The markers were placed on 18 anatomical points according to the Plug-in-Gait marker placement guide (22): on the thigh, knee, tibia, ankle, heel, toe, anterior superior iliac, posterior superior iliac on both the right and left sides, see *Figure 2*. Black fabric shoes were used for all participants in order to facilitate the identification of shoe markers by the cameras. In addition, a marker was used on the middle of each foot, for game configurations. The markers were attached to the skin on the lower body of the participants with skin-friendly tape (micropore) and with double-sided adhesive tape when placed on fabric (feet markers and iliac markers). These markers reflected the cameras' infrared light which were used by the motion tracking program to identify the segments and calculate the movements. The rigid body models were used as foot models by the QTM system. All other unwanted reflectors on their clothes were hidden with tape, and possible jewelry removed. Then, a Bosch PLL360 Self-Levelling 360° Line Laser was used to ensure their position, see *Figure 1*.

Before the tests started, the researchers calibrated the 3D motion capture (MoCap) system to capture the treadmill area.

The patients were told about the marker positions and asked to notify the researchers if they bumped into them and they changed their position. The researchers were all the time aware that the position of the markers remained placed correctly.

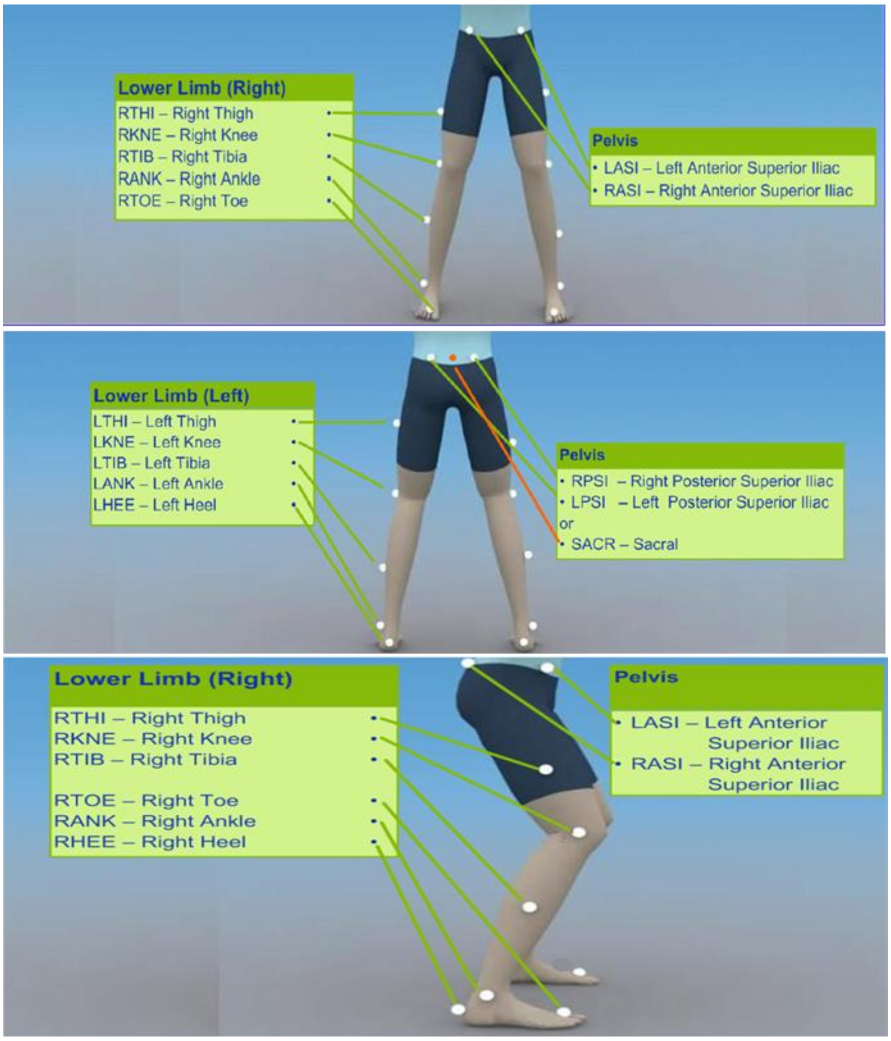


Figure 2. The markers and their positioning on the lower body, represented in three planes.

Digital video (GoPro Hero 3+, 30 Hz, GoPro Inc) was recorded for data quality assurance.

Warming up activities

The test procedure continued with the participants on a standard treadmill (X-erfit 4000 treadmill). They were asked to keep the arms on the handrails to ensure a safe distance from the edge of the treadmill, and to avoid blocking the reflective markers.

First, the patient walked about 3 minutes to warm up. A reference recording was taken to check the patient's walking pattern and find a comfortable treadmill speed the patient deemed possible to maintain during the rest of the test. They started with the average speed from the 4-meters-walking test and adjusted this, if necessary, for the game. Once set, the speed in the three game conditions was the same.

Subsequently, a VR headset (HTC Vive) which tracked the eye gaze was put on the participants to allow them to interact with the game. They learned how to use head movements to select an option during the game. A calibration recording was done for a game reference to the Unity program and for having a reference from virtual reality treadmill walking without game conditions. Two HTC Vive Stations were used to track the position of the VR headset in the Unity program (the game software), see *Figure 3* . The Unity software received information about the patients' step length from the right and from the left foot, cycle length, step width and walking speed. This information was later used in the game conditions to place tiles and stripes.

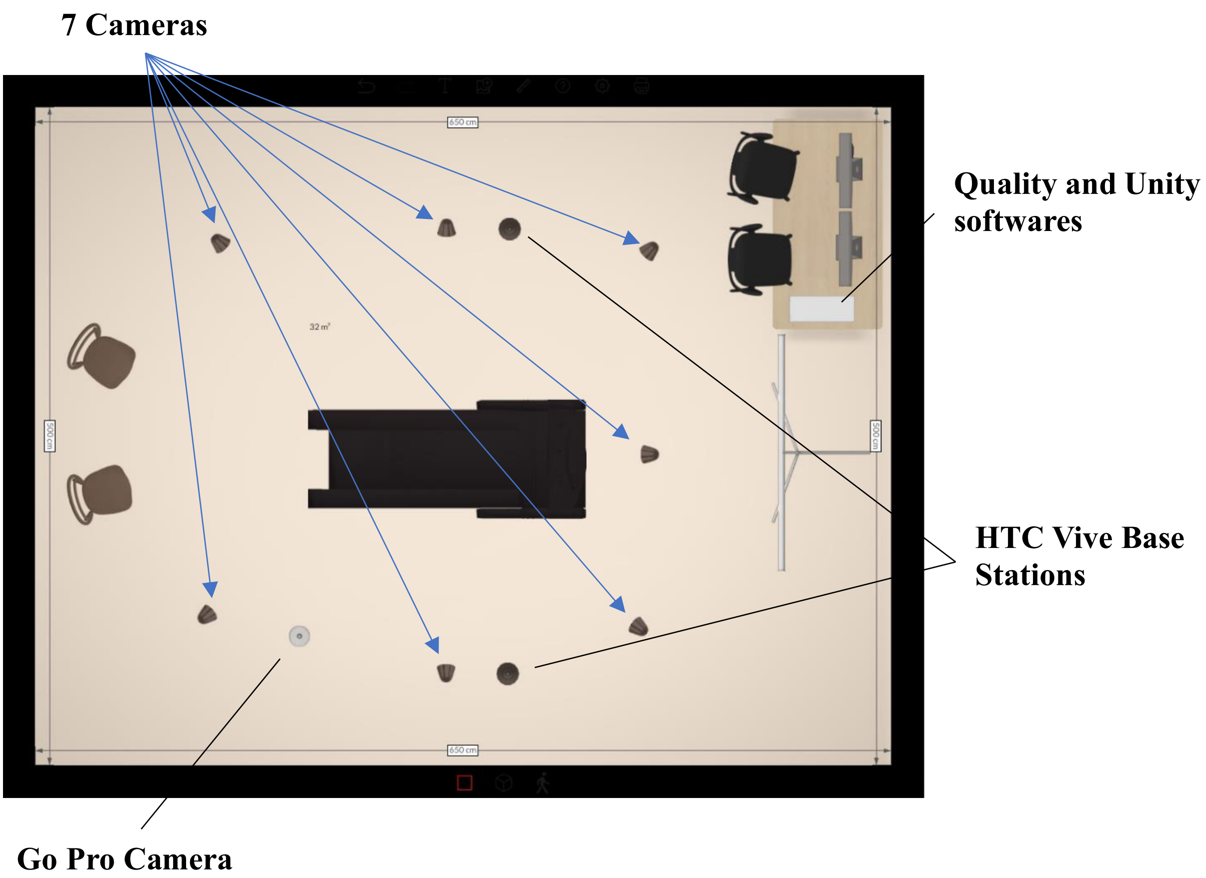


Figure 3. The placement of cameras, treadmill and other materials in the laboratory.

Gameplay

Then the gameplay was started. This was the last part of the testing procedure and was divided in 3 play conditions with a duration of 3 minutes each: step on the white tiles, step over the yellow stripes and step on the white tiles with cognitive matching task (just called cognitive condition here after). The order of the two first conditions was counter-balanced between patients: 5 of them received the hit tiles condition as the first trial, while the others started with stepping over the stripes condition. Each game condition was recorded separately for later analysis.

In the *step on the white tiles* condition, they should place each foot in the middle of the rectangle. They received the maximum score if they stepped exactly in the center. The feedback in this condition was given as shown in *Figure 4*.

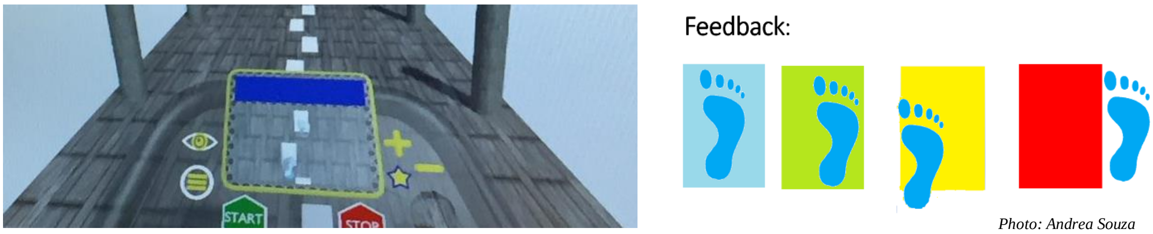
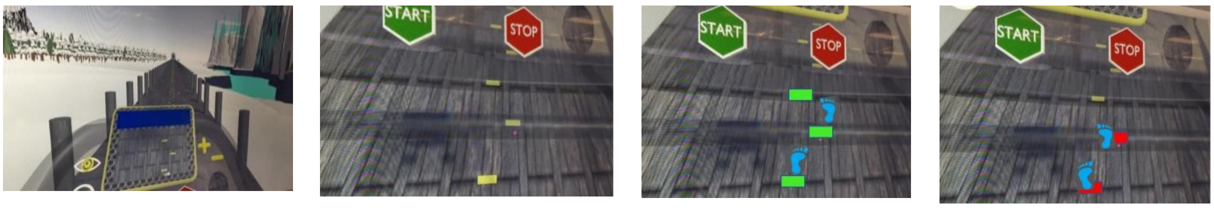


Photo: Andrea Souza

Figure 4. Hit tiles condition, showing the path and the possible types of feedback.

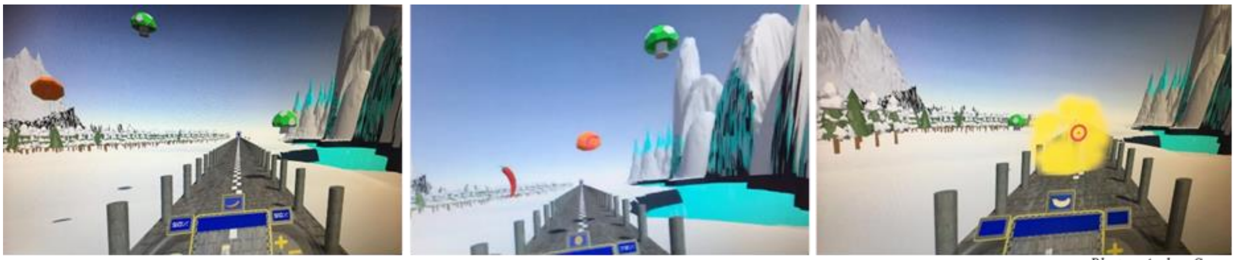
In the *step over the yellow stripes* condition, the activity was the opposite of the previous condition. The patients should avoid stepping on the yellow stripes which appeared, so each foot should be placed between two stripes. The feedback in this condition was a change to green in the stripe color, if they managed to avoid the stripe 100%, or to a red color if they did not, see in *Figure 5* .



Photos: Andrea Souza

Figure 5. The step over stripes condition with the possible feedback.

The third version of the game, cognitive, was the last condition for all participants. They should step on the same white tiles as before, while doing a cognitive activity simultaneously. At the top of the treadmill screen appeared different elements they should focus on with their eye gaze. There were 3 kinds of elements: a chili pepper, a mushroom and a banana, and the way they could catch them was by focusing the red target over the chosen element until the red target was fully charged. The feedback in this condition was fireworks around the object after it was caught, as illustrated in *Figure 6*.



Photos: Andrea Souza

Figure 6. The cognitive condition with the elements, the target, and the feedback.

Table 1 shows the different tasks the patients performed, the measuring equipment used, and the purpose of each task.

Table 1. Activities performed by the patients during the test procedure, with measuring equipment used and purpose of the task.

	TASK	MEASUREMENTS	PURPOSE
A	4 meters walking test on the floor	Timing with stopwatch	Find the participants' preferred walking speed on the floor
B	3-minute reference recording on a treadmill without VR glasses	Digital video, 3D data	Reference footage of walking pattern for use in comparison with walking pattern in the game (starting with walking speed from A)
C	2-minute test round on the treadmill with VR glasses	Digital video, 3D data	Getting comfortable and used to the glasses and VR world. Game calibration in the last 30s.
D	3-minute VR game, stepping on the tiles	Digital video, 3D data, number of hits, types of error, speed, distance, IMI	Implementation of games with gait pattern measurement
E	3-minute VR game, stepping over stripes	Digital video, 3D data, number of hits, types of error, speed, distance, IMI	Implementation of games with gait pattern measurement
F	3-minute VR game, step on the tiles + cognitive matching task	Digital video, 3D data, number of hits, types of error, speed, distance, IMI	Implementation of games with gait pattern measurement with an additional cognitive task

In addition to the changing colors of the tiles and stripes or the fireworks around the object, the participants received feedback about their gait performance during gaming through a percentage score on each side of the dashboard, one for the left foot and other for the right foot, which should help them having better control for each side.

After each game condition, participants completed a short Intrinsic Motivation Inventory (IMI) (21) questionnaire about their subjective experiences of the game. Answered were provided using a 5-point Likert-scale with face drawings which helped them to answer. See *Appendix 1* and *Appendix 2*. Data from this questionnaire will not be analyzed here as it was the focus in another master thesis.

The game adjustment

The objective of the game was to stimulate the poststroke patients to achieve a more symmetric gait in three different conditions. The Unity software calculated average step length on each side. As predetermined by researchers, the longer step length was used as the reference step length during the game trials. Then, the software gradually adjusted and increased the distance of stripes or tiles in 1% every 3.8m, for the shortest side only, to persuade the leg of this side to take longer steps and thereby becoming more symmetric with the other side. On the longest side, this distance appeared always constant and was based on the average step length the Unity program calculated during the game calibration track.

The game pathway was 400m long during a 3-minute trial. The first 10m were without stripes or tiles, with the purpose of the steady-state velocity being achieved before they appeared. The last 10m of the track was also without stripes or tiles, but here to allow the treadmill to reduce its velocity and come to a complete stop. This means that at the end of 390m walking, the gait adjustment would be 100%, and the distance between stripes or tiles would be the same on both sides, in a perfect gait symmetry and equal to the longest step length. Because of how the game adjusted the distance between stripes or tiles, and the fixed duration of the game, patients who walked faster walked a longer distance and thereby received a higher gait adjustment. This procedure is illustrated in *Figure 7*.

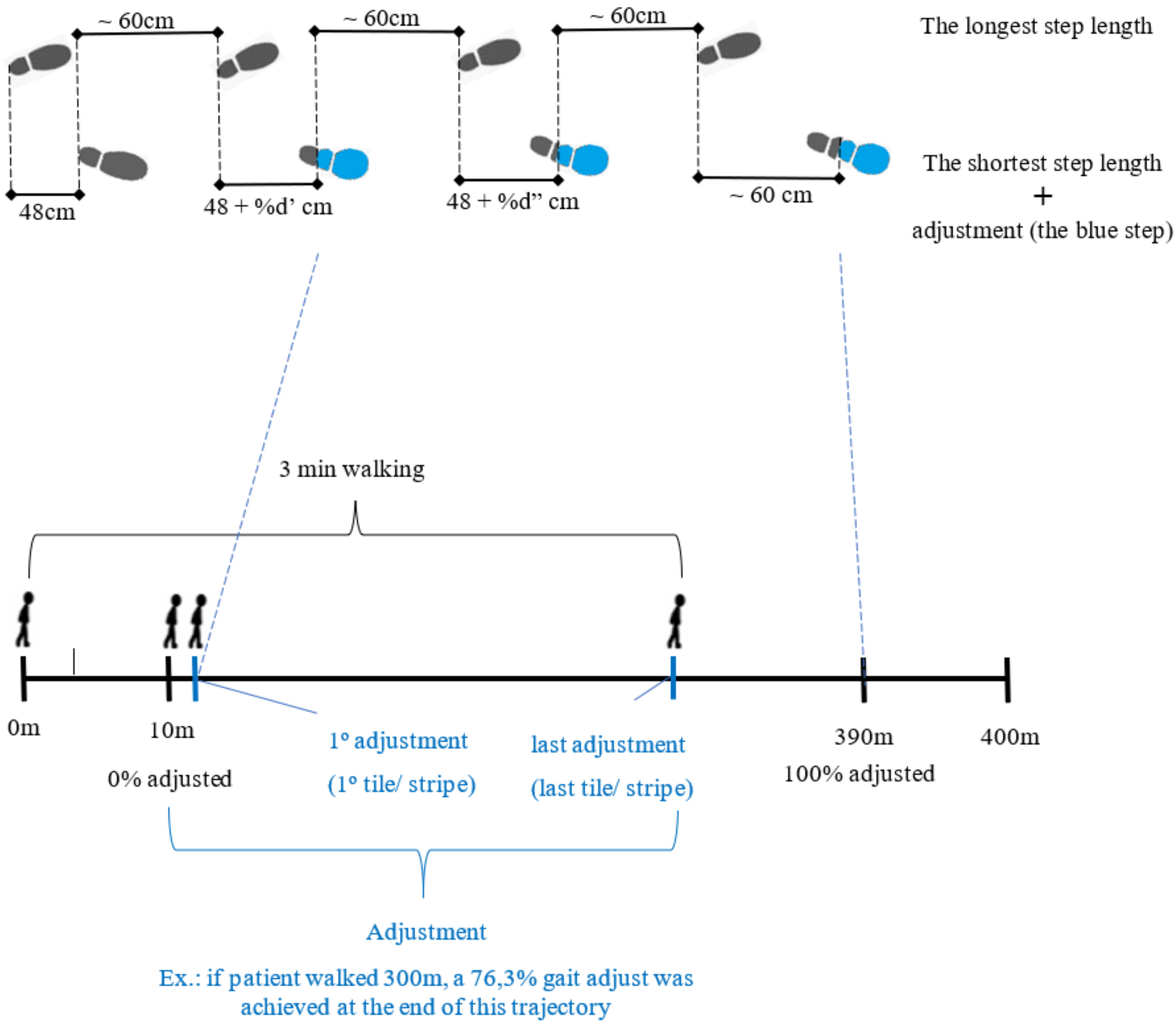


Figure 7. The game adjustment form (d' and d'' are distances walked to these points).

2.4 Data analysis

For the present study, the focus was to follow the process of potential change in gait symmetry. There is no consensus or standardized method to measure gait symmetry in post-stroke gait in terms of discriminative ability or distribution. However, the symmetry ratio calculated by the equation of spatiotemporal parameters from paretic side divided by non-paretic side, is recommended as it is the easiest to interpret (22). Following this recommendation, the present study used the following equation below to calculate symmetry:

$$\textit{Symmetry ratio (ratio)}: \text{ratio} = V_{\text{paretic}}/V_{\text{non-paretic}}$$

where $V_{paretic}$ is the corresponding variable obtained from the paretic side, and $V_{non\text{-}paretic}$ is the corresponding variable obtained from the non-paretic side. When *Symmetry ratio* (*ratio*) equals 1, paretic and non-paretic sides are in perfect symmetry.

The recorded position of the reflective markers was converted into a skeleton model and consecutively filtered and analyzed. Spatio-temporal parameters were calculated using the Plug-in-Gait biomechanical model in Vicon Prozac (version 1.3). The output parameters included the step length, stride length, gait speed, stride time, double support, step width and number of steps per minute, for each body side and for each cycle.

Asymmetric step lengths and larger step widths are typical strategies to compensate for poor balance in a post-stroke gait (23). As step length can give distinct information about temporal symmetry and step width about gait stability (22, 24), the present study selected both parameters to study symmetry ratio. Furthermore, although the game did not have focus on adjusting the step width symmetry ratio, it would be interesting to explore if the changes in step length would be reflected in this time parameter as well. In other words, whether the game itself would be able to cause changes in gait parameters not specifically targeted. First, the step length average for each participant for paretic and for non-paretic side, in each of the five conditions was calculated. For reference and VR reference conditions, all step lengths throughout the entire trial were used to calculate the average, as there was no gait intervention by the game. However, for the three game conditions, only the last five step lengths cycles were taken to calculate the average, since the gait adjustment was dynamic, and the study aimed to analyze the result of this interaction. Outliers which were 3 standard deviations larger or smaller than the average were removed as they were most likely due to errors.

The same procedure was done regarding step width, by replacing the parameters in the equation above with step width values for the paretic and for the non-paretic body side. There were only 3 outliers in step length measures: 2 during VR reference of participant 3 (the last average step length on the paretic and non-paretic side) and 1 during VR reference of participant 10 (the last average step length on the paretic side), and 2 in step width measures: 1 during VR reference of participant 3 (the last average step width on the non-paretic side) and 1 during stripes condition of participant 8 (the last average step width on the paretic side).

Then, the symmetry ratio for each condition was found by dividing the average of the paretic side by the average of the non-paretic side. However, as the present study used the value of 1.0 as perfect symmetry, it followed also the recommendation to have always the numerator with the greater value (22), regardless of the paretic side (which are referred to below as the new variables), so the results would not be skewed by values < 1.0.

Statistical analysis

This study calculated the averages and standard deviations using IBM SPSS Statistic 26 (IBM, USA). All information was processed without exposing the patient's personal data, such as name, ID number or any other directly recognizable information.

Data normality was assessed using the Shapiro-Wilk test and visual inspection of the histograms. Results showed normal or close to normal distribution for all variables, which allowed the use of parametric tests.

Descriptive analyses were performed on the participants’ background data and, on the information regarding the kinesthetic test and goniometry.

To assess potential interactions between Condition and body mass category, hemiparetic body side and first game played, respectively, a series of two-way repeated measures ANOVAs on the symmetry ratios were performed. Separate two-way ANOVAs were chosen rather than a single omnibus four-way ANOVA because of the lack of power due to a limited number of participants. The interactions made were BMI*Conditions, Affected_side*Conditions and First_condition*Conditions. Mauchley’s test of sphericity was used to verify compound symmetry and the assumption of sphericity was not violated in any of the cases. The results indicated neither a main effect of the additional factors (all p’s > 0.141), nor interactions between Condition and BMI (p = 0.253), Condition and Affected side (p = 0.945) or Condition and first game played (p = 0.171) on step length asymmetry. Similar results were found on step width asymmetry. Neither a main effect of the additional factors was found (all p’s > 0.435), nor interactions between Condition and BMI, Condition and Affected side, or Condition and first game played (p = 0.306, p = 0.489, p = 0.636, respectively).

As none of the other factors had significant main effect or significant interactions with Conditions, one-way for repeated measure ANOVAs was used to assess potential differences between the Conditions (reference, VR reference, tiles, stripes and cognitive) on step length asymmetry and step width asymmetry. Mauchley's test of sphericity was used to verify compound symmetry. The assumption of sphericity was not violated.

Significance level was set to $p < 0.05$, while trends $p < 0.1$ are reported as well.

3. Results

The results are presented in 3 parts: participant characteristics, feasibility of the VR gaming conditions, and gait characteristics related to step length and step width. During the analysis of step length variation, a possible relationship between this variable and the body mass index, the stroke affected side and the first game condition used was also studied.

3.1 Participant characteristics

Participant characteristics are presented in *Table 2.* Information about the affected body side, type of stroke, possible pain during walking, previous experience with treadmill training after stroke and previous experience with virtual reality are shown in *Figure 8.* As can be observed, four participants reported walking pain which was associated with their feet, knee, hip, or previous pain in the affected body side (mentioned as a diffuse pain which did not disable walking).

Table 2. Mean, range and standard error (SE) for age, height, weight, BMI and time after stroke for women and men separately, and for all participants

	Women (n = 3)			**Men (n= 7)**			**All (n =10)**		
	Mean	**Range**	**SE**	**Mean**	**Range**	**SE**	**Mean**	**Range**	**SE**
Age (yrs)	62.67	55 - 68	3.93	60.29	47 - 70	2.92	61	47 - 70	2.27
Height (cm)	158.83	155 - 163	2.31	178.85	174 - 187.5	1.91	172.85	155 – 187.5	3.38
Weight (kg)	63.67	62.5 - 65	0.73	84.21	71.5 - 113	5.92	78.05	62.5 – 113	5.12
BMI (kg/m^2)	25.26	23.9 - 26	0.68	26.25	21.12 - 32.14	1.51	25.95	21.12 - 32.14	1.06
Time after stroke (mnd)	205.33	34 - 516	155.61	67.86	9 - 165	19.66	109.10	9 – 516	47.28

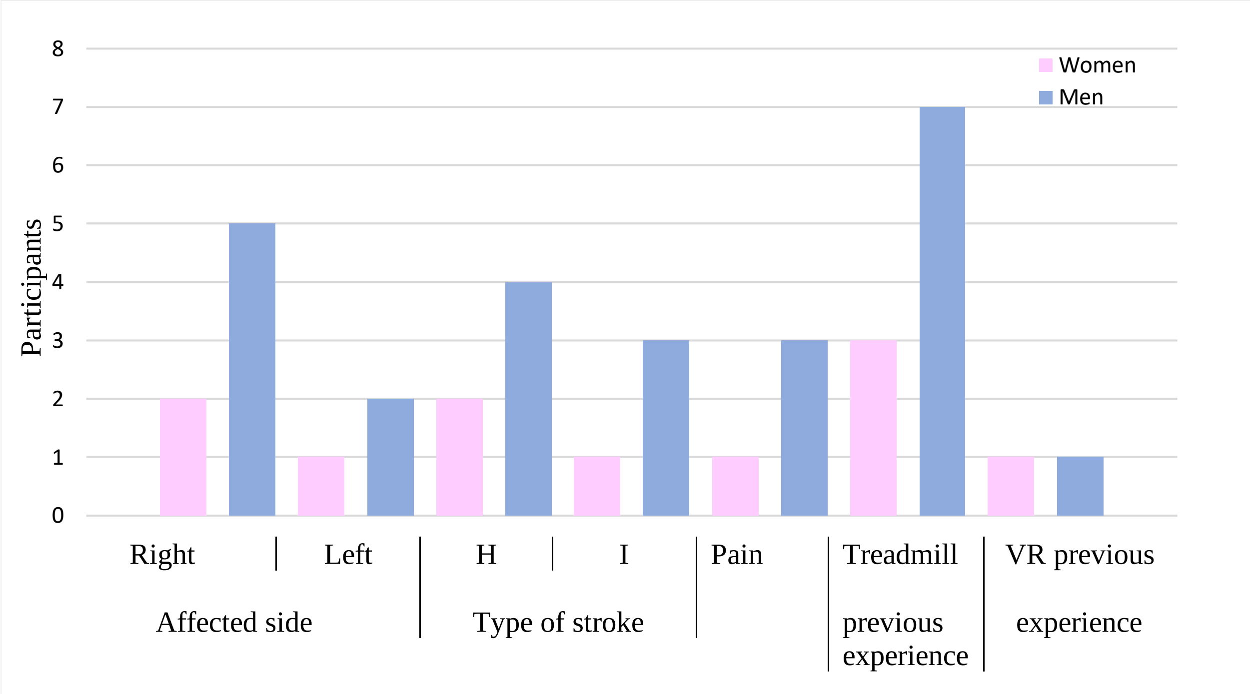


Figure 8. Number of participants regarding affected side, type of stroke (H – hemorrhagic and I – ischemic), possible pain while walking, treadmill experience and virtual reality experience for women and men separately

The kinesthetic sensation test showed no important deviations from normal sensation. The difference between left and right side of body-measures in the anthropometric measures was ≤ 1 cm, which is considered normal (25).

The goniometric measures did not appear to be very different from a healthy population (26) and not very different between paretic and non-paretic sides.

Figure 9 presents the decrease in speed during the study, from the 4m walking test to the 5 conditions on the treadmill. All the participants reduced their gait speed from floor to treadmill, but the amount of reduction was very different between the subjects, ranging from 0.69% to 50%.

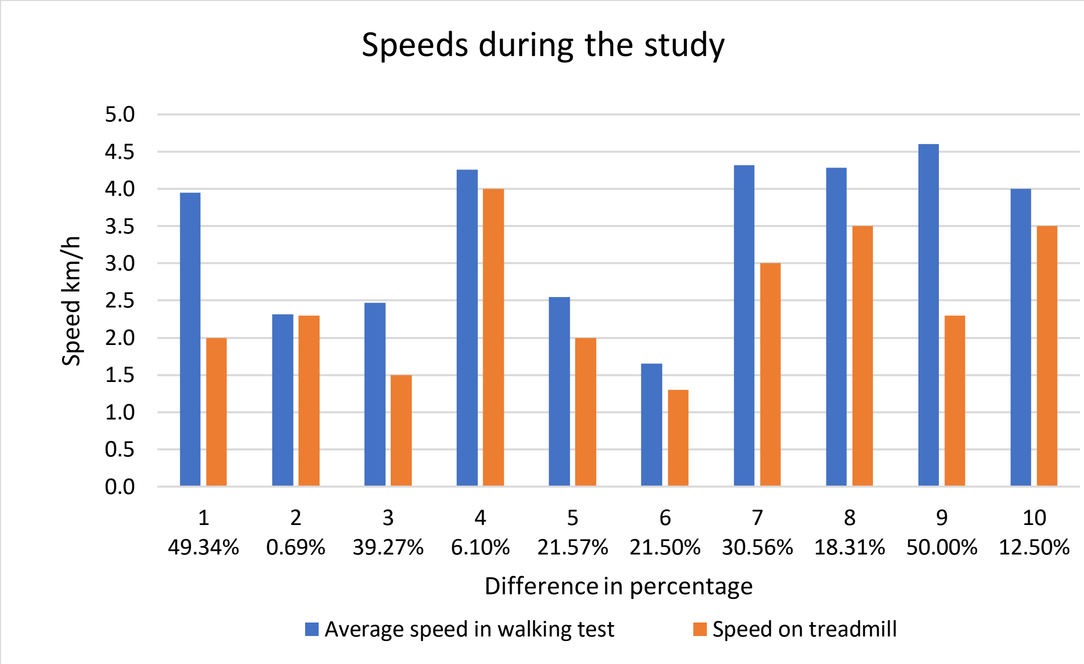


Figure 9. Reduction in speed for each participant in km/h and in %.

3.2 Feasibility of the VR gaming conditions

All 10 participants successfully completed all part of the study. There were no adverse events. However, the following observations were made:

- Some technical issues occurred. The percentage score during the stripes condition did not appeared to participants 1, 2, 3, 8 and it was fixed in 100% all the time during this condition with participant 5. The color of footprints feedback did not change during the stripes condition from participant 7, staying just in green color all the time. On the cognitive task with participant 2, the treadmill shook, and the tiles came a long way. During participant 1 the coordinate system rotated and took some time to be back on the right place. The virtual image of treadmill shook during the tiles condition with participant number 8, and then, was adjusted to the other conditions.
- Some participants experienced some degree of difficulty during the study stages. The cognitive condition was mentioned as too difficult by patients 2 and 3. The first one was tired at the end and the last one was tense in the shoulders throughout the testing. Participant 4 found the instructions to be a little difficult. Participant 5 became tired of following instructions during the game. Participant 6 was rather impatient during the study and was the only one who showed spasticity in all conditions. Participant 9 had

problems to remember the information given in the power point presentation. And finally, participant number 10 found the treadmill speed to be rather slow when the game conditions started but chose not to change the speed. This impression was gradually changing and getting better as soon as the game condition continued.

- Some participants used orthoses: foot orthosis - participant 2, walker - participant 3, arm sling and walking stick - participant 5, and wheelchair - participant 6. Only participants 2 and 5 (just arm sling) continued using their orthosis during the treadmill activities.

3.3 Gait characteristics

Two spatiotemporal gait parameters were used in the analyses: step length symmetry and step width symmetry. The results are analyzed separately and described in detail below.

Step length symmetry ratio

The average step length for all participants in each condition, as well as the symmetry ratio can be observed in *Table 3*. The step length symmetry ratio approached closer to one, which is perfect symmetry, from the two first reference conditions to the game conditions. The stripes and cognitive conditions showed the best results regarding this ratio.

Table 3. Mean and standard deviation (SD) for paretic (p) and non - paretic (np) step length (mm) in each condition and their respective symmetry ratio.

	Paretic (SD)	**Non - paretic (SD)**	**Symmetry Ratio = p/np (SD)**
Reference	481.29 ± 104.96	414.85 ± 93.09	1.17 ± 0.15
Reference VR	480.45 ± 94.60	420.56 ± 96.75	1.17 ± 0.15
Tiles	493.96 ± 115.03	454.47 ± 90.98	1.09 ± 0.17
Stripes	478.24 ± 126.83	442.89 ± 91.88	1.07 ± 0.16
Cognitive	479.21 ± 107.00	448.05 ± 96.53	1.07 ± 0.10

An individual analysis of the participants indicated that only participants 2 and 6 had worse symmetry ratios in the virtual reality tasks than in the reference conditions, see *Figure 10*. All other participants showed at least one condition with better ratio when compared with the reference.

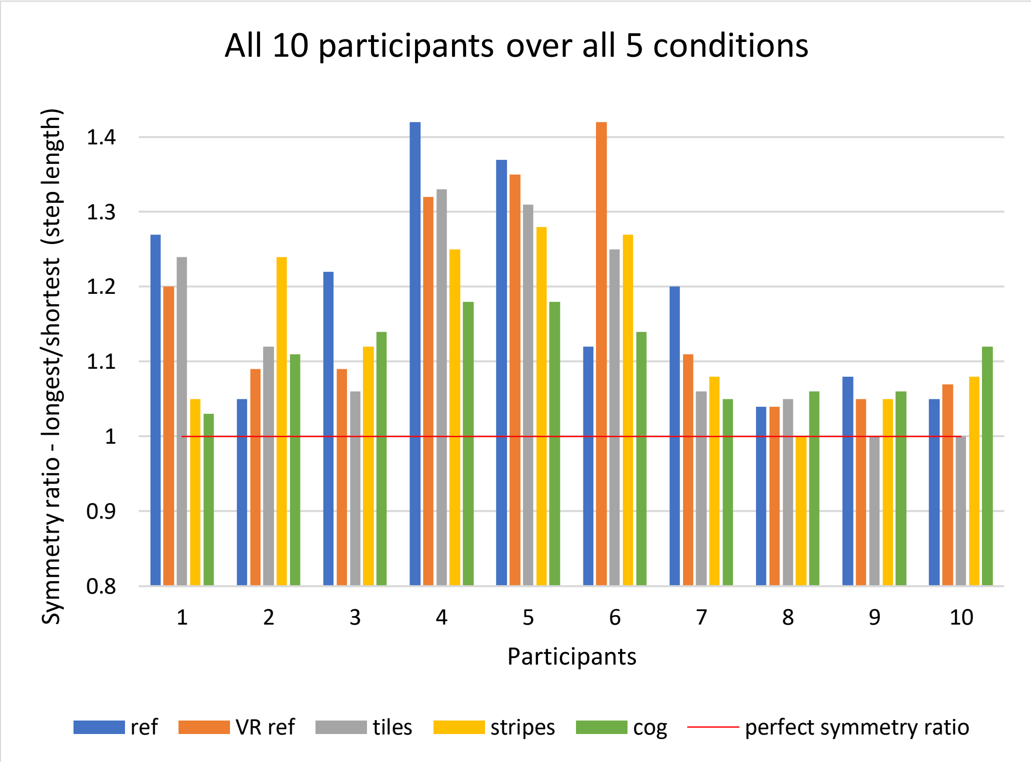


Figure 10. Difference between initial ratio (reference ratio) and the others: VR ratio, tiles ratio, stripes ratio and cognitive ratio in step length.

Moreover, only 3 of the 10 subjects (participants 3, 6 and 8), had the adjustment on the paretic side, as their affected side was also the one with the shortest step length. Despite this common characteristic, a pattern among them was not found, as participant number 3 developed better symmetry ratios in all VR conditions compared to reference ratio, while participant 6 got worse in all VR conditions and participant 8 showed improvement only in stripes, see *Figure 10*.

It was observed that participants with larger differences in symmetry ratio between reference condition and the perfect symmetry, showed better adaptation and improvement with the game from the beginning of the trial, whereas those who had already a rather symmetrical gait, regarding step length, were more variable to adapt to the symmetrical gait pattern. This is illustrated in *Figure 11* and tended to change towards better symmetry ratio over the 3 minutes.

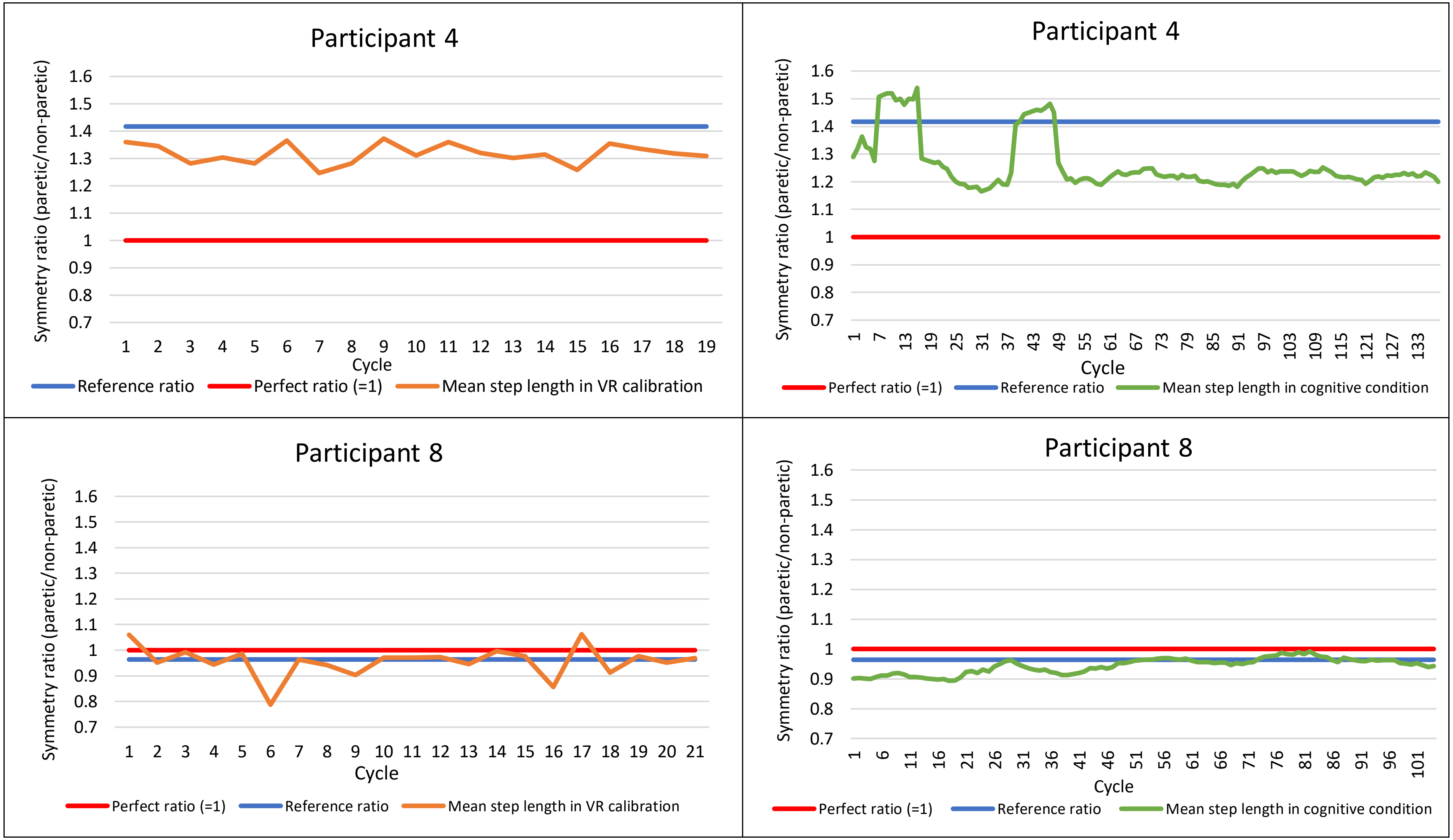
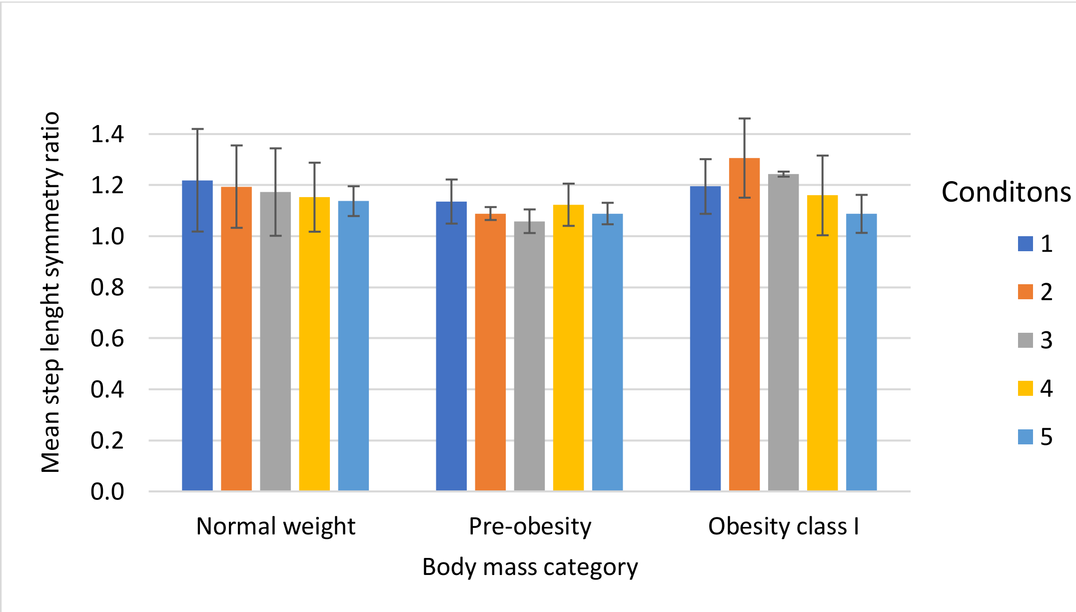
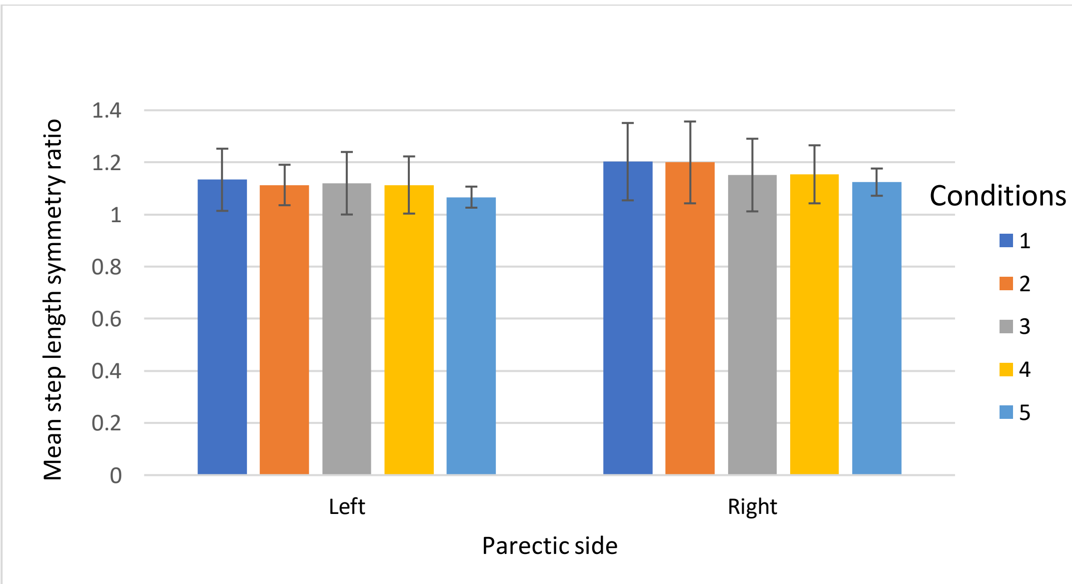


Figure 11. The behavior of game adjustment in a very asymmetric gait participant (participant 4 with difference of 1.41) compared to another with almost symmetrical gait (participant 8 with difference of 0.96), during the VR calibration condition and cognitive condition in step length.

One-way repeated measure ANOVAs were used to access potential differences in the step length symmetry ratio between the five conditions (reference, VR reference, tiles, stripes and cognitive). Despite the observations reported above, the results showed that there were no significant differences between the conditions ($F\ (4,36) = 1.721$, $p = 0.167$, $\eta_p^2 = 0.161$).

As reported in the Methods, the two-way ANOVAs showed no significant main effects of BMI, affected side and first game played, nor significant interactions with Condition. These results are illustrated in *Figure 12*.





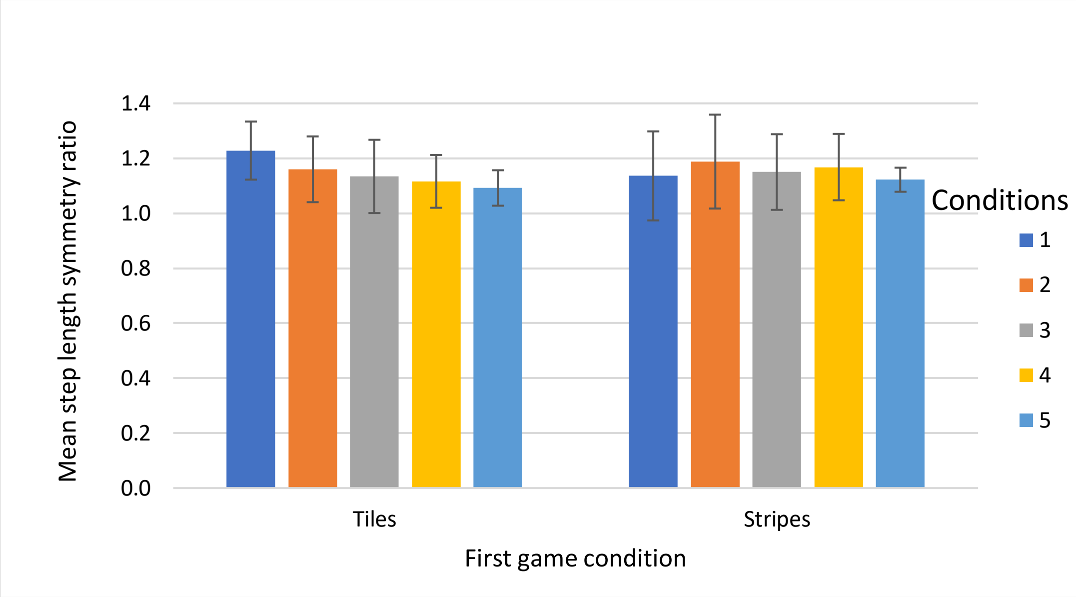


Figure 12. The relationship between body mass index (BMI, top panel), participant's paretic side (middle panel) and first condition during the game (bottom panel), and the 5 conditions of the study in step length.

When observing other characteristics individually, such as age difference between participants, the use of orthoses in daily life, or previous VR experience, no patterns could be detected.

Step width symmetry ratio

In contrast to step length symmetry, the symmetry ratio based on the average step width of paretic and non-paretic side, moved away from perfect symmetry during the trial, *Table 4.*

One-way repeated measures ANOVAs were used to access potential differences in step width symmetry ratio between the five conditions (reference, VR reference, tiles, stripes and cognitive). Despite the observation above, no significant differences between the conditions were showed in results ($F (4, 36) = 0.836$, $p = 0.512$, $\eta_p^2 = 0.085$).

As also reported in the Methods, the two-way ANOVAs showed no significant main effects of BMI, affected side and first game condition played, nor significant interactions with Conditions. These results are illustrated in *Figure 15*.

Table 4. Mean and standard deviation (SD) for paretic(p) and non – paretic(np) step width in each condition and their respective symmetry ratio.

	Paretic (SD)	Non - paretic (SD)	Symmetri Ratio = p/np (SD)
Reference	143.50 ± 50.47	135.25 ± 42.02	1.07 ± 0.21
Reference VR	185.81 ± 106.84	170.61 ± 99.24	1.10 ± 0.23
Tiles	147.44 ± 52.32	132.96 ± 40.98	1.11 ± 0.27
Stripes	176.19 ± 50.13	160.65 ± 47.84	1.11 ± 0.18
Cognitive	160.24 ± 57.75	144.52 ± 46.38	1.11 ± 0.24

However, looking closely at the individual level, there was a great variation between participants with most of them, or maintaining, or improving their gait symmetry. This was verified in 70% of the cases and appeared from reference ratio to the second game condition. However, during the cognitive condition, 50% of the participants developed a very asymmetric pattern (see the second chart of participant 3 in *Figure 14*), even more asymmetric than in the reference situation, and farther from perfect symmetry ratio, see *Figure 13*. Interestingly, 3 of the 4 participants with the best initial symmetry ratio had problems to maintain their symmetry during the cognitive condition of the game, developing a very asymmetric gait pattern. It happened with participant 3, for example, and is showed in *Figure 14*.

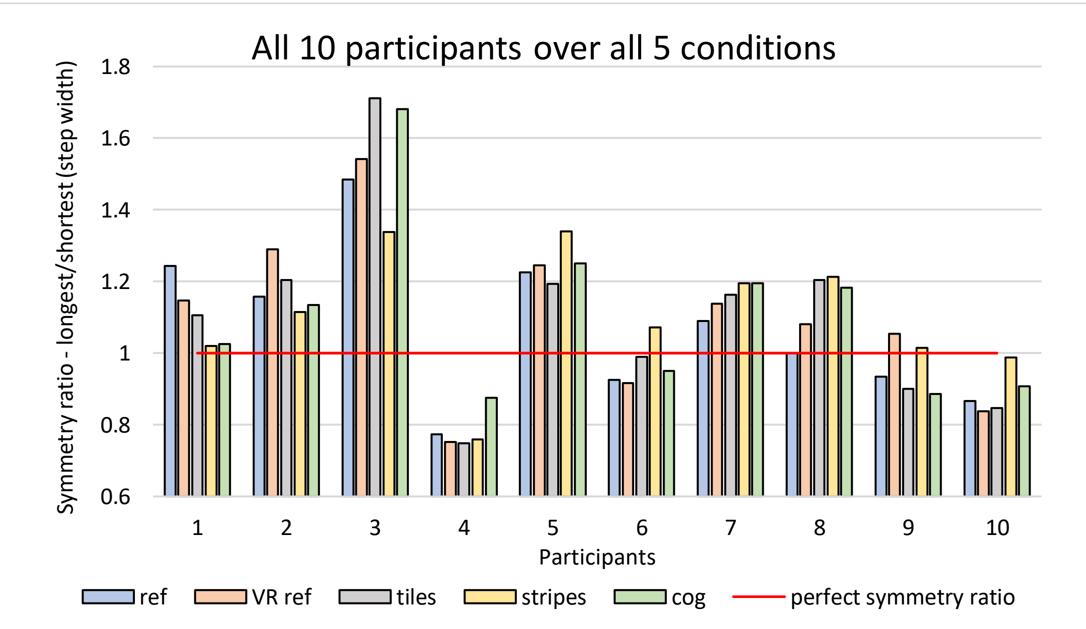


Figure 13. Difference between initial step width symmetry ratio (reference ratio) and the other condition: VR ref, tiles, stripes and cognitive.

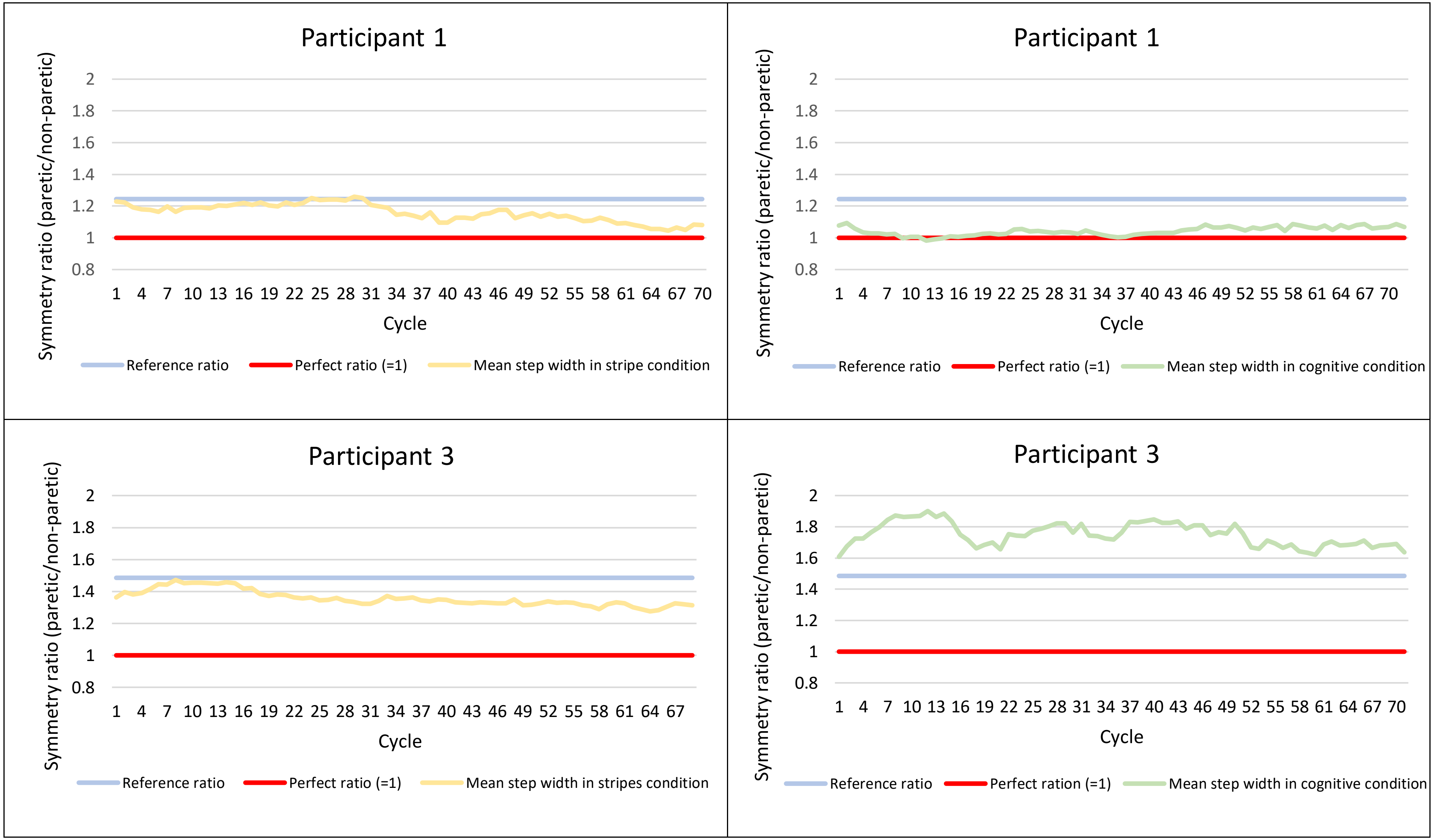


Figure 14. Representative examples of improvement (participant 1' panels and left panel for participant 3) and worsening (bottom left panel) of step width symmetry ratio for two participants in the stripes condition (left panels) and cognitive condition (right panels).

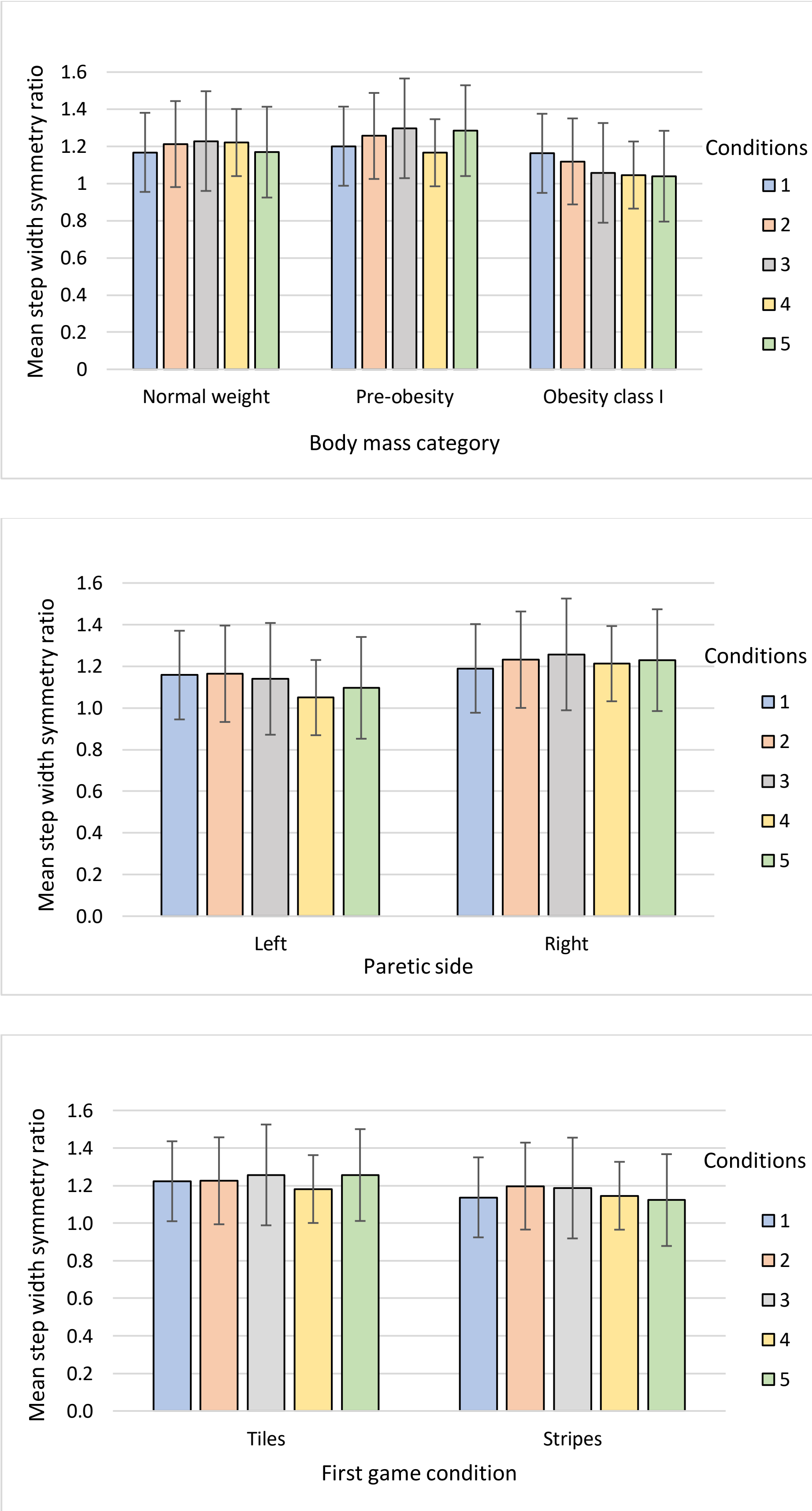


Figure 15. The relationship between body mass index (BMI, top panel), participant's paretic side (middle panel) and first condition during the game (bottom panel), and the 5 conditions of the study in step width.

4. Discussion

In this study the feasibility of using a VR treadmill training game in post-stroke participants was investigated. The game was developed with the challenge of guiding the participant on where to position their feet in 3 different conditions: stepping on tiles, stepping over stripes and stepping on tiles combined with a cognitive task. Step length and step width was the variables chosen to assess whether these different activities would lead to improve gait symmetry. Although the results showed no significant improvement, a trend towards improvement was observed.

The interactions between the three game conditions and body mass index, the participant's paretic body side and the first condition started in game were also assessed, and no significant difference was found.

This section is divided in 5 parts. In the first 3 parts, the results of this study are discussed and compared to previous studies. The last 2 part contains the strengths of this study and recommendations for future studies.

4.1 Feasibility

Chronic post-stroke survivors

This study is, to the best of our knowledge, the first to investigate the feasibility of using a virtual reality training game with real-time adjustment, in post-stroke participants, designed for the purpose of improving their gait symmetry. The results showed that it is feasible even for such a varied group in terms of age and time after stroke as the one in this present research, see *Table 2*. Previous experience with virtual reality could have helped the participants to perform the game, although the specific game used was new for all participants. This result is consistent with the study of Orvis and colleagues (27), that found a link between prior videogame experience and motivation and performance in videogames utilized as instructional tools.

According to Dobkin et al. 2004 (28), the brain activity of post-stroke patients is able to change all the time and the sensorimotor function can be improved, regardless if they are in acute, sub-acute or chronic phase. In chronic post-individuals, for example, gains in residual movement ability can be achieved with well-targeted therapy and practice. This present study showed feasible for individuals in chronic phase to follow a game with dynamic gait adjustment, as all of the participants had stroke more than six months ago.

Game adjustment

- The side of adjustment

During the game, after the first 10m walked and before the last 10m to the end, foot placement on the shortest step length body side was influenced to gradually change toward bigger steps, regardless if it was the paretic or non-paretic body side. The results demonstrated that it does not matter with regard to feasibility. This indicates that a paretic leg can be persuaded to follow different gait patterns, taking bigger step lengths, when the adjustment be done on its side, or sustaining bigger steps lengths from the healthy side, if the adjustment gradually occur on the non-affected side.

- The type of gait adjustment

The game was adjusted to change the distance between tiles or stripes for the leg with the shorter step, with the purpose to make the step length the same as on the other side. The adjustment was 1% of the difference between them, after every 3.8m. It means that the step length changed slowly and gradually, after the first 10m, when the adjustment started. However, although dynamic during the condition, this method was fixed for all participants, regardless of their gait speed and initial step length asymmetry, and therefore might not have been the best choice. Due to this, patients who had a very slow treadmill speed obtained little adjustment percentage after three minutes. Possibly, a fixed game distance for all participants, or a fixed speed, or even, a varying adjustment percentage between participants, could have produced a different result. Although not implemented in the current game play, the game could also have induced more symmetric step width, if the distance in width between tiles, for example, was adjusted. However, it is important that the determined criteria be based on individual's learning capacity with an approach as adaptive as possible for better results in performance (27).

Type of activities

Several participants stated at the end of the study that the cognitive trial was the more challenging. However, the increased complexity of this condition compared to the two first conditions, as it added a cognitive activity, did not hinder the feasibility of this game condition.

With regards to stepping on tiles or over stripes, no difference between these two activities was detected in step length or step width asymmetry. Perhaps because it is possible that the precision required to fit the foot in the middle of the tiles is similar to the motor capacity required to lift the foot and place it again after an obstacle without losing balance. It remains to be tested whether the cognitive condition with avoiding stripes would be challenging in the same way as it was when combined with stepping over tiles.

Hung et al. (11) found that stepping activities in games may increase spasticity and risk of falling. This was not observed in this present study instead, all activities were successfully completed. The only participant who had signs of spasticity during the study, participant 6, presented this in all conditions.

The feasibility of the three conditions proposed can be attributed to the use of an immersive virtual reality which permitted a wide visual field and to the use of a good model of the feet in the game, which provided a good simulation of reality, increasing the sense of presence and the accuracy of foot placement (29).

As demonstrated by Skjæret-Maroni and colleagues (30), the selection of game activities is not irrelevant. It is important to base it on the type of movement that needs to be achieved or changed. Therefore, if the goal is to improve gait abilities, a variety of game activities targeting gait features should continue to be explored.

4.2 Change in symmetry ratio

A symmetric gait is related to the conservation of bone mass density in the paretic lower limb, as well as reduction of injuries associated with the increased strain on the locomotor system. In addition, symmetric gait allows the maintenance of gait efficiency and dynamic balance control (31).

Step length

When it comes to step length, the current study found no significant differences between the five conditions in symmetry ratio. Nevertheless, the findings for individual results indicated that during the game intervention, the gait pattern seemed to move closer to a perfect symmetry ratio (= 1) in most of the cases, see *Figure 10*. Even participants who had very asymmetric first steps, seemed to achieve a somewhat better symmetry pattern along the condition and finished it better than started. Possibly, a longer game playing period, or a game with more sessions over time, could have resulted in clearer and significant improvements.

Step width

The differences between conditions was not significant regarding step width symmetry either, which was expected since the game adjustment did not target this gait parameter. However, interestingly, it could be noted in 7 of the 10 participants that during the 3 first VR conditions, the step width developed an intermediate symmetry ratio which was in between the reference ratio and the perfect ratio, see the behavior for participant 1 in *Figure 14*. This might be because the adjustment applied to the step length was reflected in step width, except during the cognitive task. During this last task, an asymmetric pattern was observed in half of the participants, with an even greater asymmetric ratio than that found in the reference conditions. In addition, two participants with step width symmetry ratio close to 1 had problems to maintain this ratio during the cognitive activities. If these findings would hold up in a larger sample, it could indicate that the current gait adjustment has more benefits for patients with larger asymmetry when compared to those that were not very asymmetrical.

4.3 Reduction in speed

A decrease in walking speed from the 4 meter-walking tests to the activities on the treadmill was observed in all participants, but no clear association could be found between this reduction in speed and change in the symmetry ratio. As demonstrated by Mehrholz and collaboraters (8) treadmill training is able to produce improvements in endurance and walking speed in independently walking post-stroke patients, improving their gait abilities.

Treadmill, body weight support and immersive VR can help maintain the number of steps performed, the training intensity and repetition and preserve the patient's safety and motivation during the activities. The use of these three tools together may ensure that participants walk longer distances, with higher speed, performing challenging activities during longer time, and therefore, must be maintained.

4.4 Strengths of the study

The result of this study is clinically and potentially important. It opens up a range of rehabilitation possibilities to be explored which can help stroke survivors with more option of exercises, increasing their motivation, therapists with greater diversification of rehabilitations forms and society as whole, with increased chances of their return to work.

In this project, 12 healthy people volunteered as pilots that tried the game before the tests with post-stroke participants began. Thus, it was previous confirmed that the game were completed feasible for healthy adults in different ages and in both genders. In addition, it involved a multidisciplinary work with the participation of several professionals, from programmers to health professionals, and two departments of NTNU (Norwegian University of Science and Technology).

Other strengths to be pointed are the exclusivity of the game, developed for the purpose of this study and the inclusion of three different activities, important to mobility life and not commonly studied together in previous literature.

4.5 Suggestions for improvements and future research

As a feasibility study, one of the limitations from the present research is its small sample size. In addition, this study was observational only, without a longer intervention and follow up. Future studies on VR interventions should be considered with larger sample size and longer follow-up to analyze the influence of different game conditions on change in symmetry ratio, its efficacy of the intervention and check whether good results can be sustained over longer time. Another possibility is to have a control group with a different intervention, which could be cognitive activities associated with stepping over stripes, or simple cognitive task on treadmill walking, or even the same activities but without VR on a treadmill.

Three methodological changes might be done to improve the design of the study and potentially the results. Firstly, start with the walking tests and move the physical examination as well as the interview, to the end. The game tasks were performed sequentially and towards the end of the experiment. It means that the virtual reality was used just at the second hour of the study, when some of the participants were getting tired. An immersive virtual reality, like the one used, can be intensive and tiresome. This fatigue can result in loss of focus and therefore, worse performance than that which could be expected before getting tired. Increased fatigue might, in turn, have led to a smaller difference between the symmetry ratios in the different conditions. Secondly, more gait parameters, such as single support can be used in future studies which might help to clarify the kinematic mechanism of any improvements. Thirdly, the game should be more adjusted to the individual participants, with a playing time that can cover the entire adjustment percentage, which could be longer play time or higher frequency of adjustment.

Additionally, visual feedback should continue to be explored during virtual tasks as they motivate participants to complete the activities and contribute to a more normal gait pattern (18). Technical issues must be carefully avoided.

Finally, further investigation should attempt to measure accelerometry, assessed by a lower back accelerometer. As previous research showed, repetitive trunk accelerometry can differentiate the asymmetric measures with higher precision, thereby potentially leading to larger effect size (32).

4.6 Conclusion

The findings of this observational study illustrate the feasibility of a protocol for post-stroke participants that include the use of a VR-game training in a treadmill with real-time gait adjustment. It was observed that even in a very short session with virtual reality game, it is possible to see small signs towards better symmetry in most of the participants. The results support that it is possible to explore the difficulty in the game with dual task activities, for example cognitive tasks coupled with stepping on tiles.

Future studies should have larger samples and longer gameplay time, to investigate whether adjustments in virtual reality games can lead to improvements in gait symmetry and gait abilities. For testing the possibility of use in rehabilitation, interventional studies with longer training time and follow-up are recommended.

It is also recommended that different game activities continue to be tested and that other methods of analysis, like single support and accelerometry, be used.

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Appendix 1

Intrinsic Motivational Inventory

Spilloppgave: treffe fliser

ID nummer: ________________

For hver av de følgende påstandene, vennligst indiker hvor godt dette stemmer for deg, med bruk av følgende skala:

1	2	3	4	5	6	7
Helt uenig			Hverken eller			Helt enig

Fyll ut tabellen under:

	Spørsmål	**Score (1-7, der 1=helt uenig og 7=helt enig)**							**Vet ikke**
		1	**2**	**3**	**4**	**5**	**6**	**7**	
1	Jeg likte denne typen gangtrening godt - Forklaring: spille VR-spill mens du går på tredemølle								
2	Jeg syntes jeg var ganske god på å treffe flisene								
3	Jeg la mye innsats i å treffe flisene								
4	Jeg følte meg ikke nervøs i det hele tatt da jeg prøvde å treffe flisene								
5	Jeg tror at en slik type gangtrening kan være nyttig for meg								
6	Det var gøy å prøve og treffe flisene								
7	Jeg vil beskrive denne type gangtrening som spennende/interessant								
8	Etter å ha holdt på med denne spilloppgaven en stund, følte jeg meg ganske flink								
9	Jeg prøvde virkelig å gjøre det bra da jeg utførte denne spilloppgaven								
10	Jeg var anspent/bekymret da jeg utførte denne spilloppgaven								
11	Jeg er villig til å gjøre dette igjen fordi det har verdi for meg								
12	Jeg syntes det var ganske morsomt å prøve og treffe flisene								

13	Jeg er fornøyd med hvordan jeg gjorde det på spilloppgaven								
14	Det var viktig for meg å gjøre det bra på denne spilloppgaven								
15	Da jeg prøvde utførte spilloppgaven tenkte jeg på hvor morsomt jeg syntes det var								

Spilloppgave: unngå lister

ID nummer: _________

For hver av de følgende påstandene, vennligst indiker hvor godt dette stemmer for deg, med bruk av følgende skala:

1	2	3	4	5	6	7
Helt uenig			Hverken eller			Helt enig

Fyll ut tabellen under:

	Spørsmål	**Score (1-7, der 1=helt uenig og 7=helt enig)**							**Vet ikke**
		1	**2**	**3**	**4**	**5**	**6**	**7**	
1	Jeg likte denne typen gangtrening godt - Forklaring: spille VR-spill mens du går på tredemølle								
2	Jeg syntes jeg var ganske god på å unngå listene								
3	Jeg la mye innsats i å unngå listene								
4	Jeg følte meg ikke nervøs i det hele tatt da jeg prøvde å unngå listene								
5	Jeg tror at en slik type gangtrening kan være nyttig for meg								
6	Det var gøy å prøve og unngå listene								
7	Jeg vil beskrive denne typen gangtrening som spennende/interessant								
8	Etter å ha holdt på med denne spilloppgaven en stund, følte jeg meg ganske flink								
9	Jeg prøvde virkelig å gjøre det bra da jeg utførte denne spilloppgaven								
10	Jeg var anspent/bekymret da jeg utførte denne spilloppgaven								
11	Jeg er villig til å gjøre dette igjen fordi det har verdi for meg								
12	Jeg syntes det var ganske morsomt å prøve og unngå listene								

13	Jeg er fornøyd med hvordan jeg gjorde det på spilloppgaven								
14	Det var viktig for meg å gjøre det bra på denne spilloppgaven								
15	Da jeg utførte spilloppgaven tenkte jeg på hvor morsomt jeg syntes det var								

Spilloppgave: kognitiv

ID nummer: _______

For hver av de følgende påstandene, vennligst indiker hvor godt dette stemmer for deg, med bruk av følgende skala:

1	2	3	4	5	6	7
Helt uenig			**Noe enig**			**Helt enig**

Fyll inn tabellen under:

	Spørsmål	**Score (1-7, der 1=helt uenig og 7=helt enig)**							**Vet ikke**
		1	**2**	**3**	**4**	**5**	**6**	**7**	
1	Jeg likte denne typen gangtrening godt								
2	Jeg syntes jeg var ganske god på å finne objekter samtidig som jeg skulle treffe flisene								
3	Jeg la mye innsats i å finne objekter samtidig som jeg skulle treffe flisene								
4	Jeg følte meg ikke nervøs i det hele tatt da jeg prøvde å finne objektene samtidig som jeg skulle treffe flisene								
5	Jeg tror at en slik type gangtrening kan være nyttig for meg								
6	Det var gøy å prøve og finne objektene samtidig som jeg skulle treffe flisene								
7	Jeg vil beskrive denne typen gangtrening som spennende/interessant								
8	Etter å ha holdt på med denne spilloppgaven en stund, følte jeg meg ganske flink								
9	Jeg prøvde virkelig å gjøre det bra da jeg utførte denne spilloppgaven								
10	Jeg var anspent/bekymret da jeg utførte denne spilloppgaven								
11	Jeg er villig til å gjøre dette igjen fordi det har verdi for meg								

12	Jeg syntes det var ganske morsomt å finne objekter samtidig som jeg skulle treffe flisene								
13	Jeg er fornøyd med hvordan jeg gjorde det på spilloppgaven								
14	Det var viktig for meg å gjøre det bra på denne spilloppgaven								
15	Da jeg utførte spilloppgaven tenkte jeg på hvor morsomt jeg syntes det var								

ID nummer: _______

Tilleggsspørsmål

	Spørsmål	Svar	Vet ikke
1	Hvilke av de tre spilloppgavene likte du best? Treffe, unngå, kognitiv?		
2	Hvilke av de tre spilloppgavene syntes du var mest motiverende? Treffe, unngå, kognitiv?		
3	Var noen av spilloppgavene for vanskelig?		
4	Hvilke elementer i spillet hadde størst påvirkning på din motivasjon? F.eks. feedback fra spillet, den virtuelle verdenen, spillelementene.		

Appendix 2

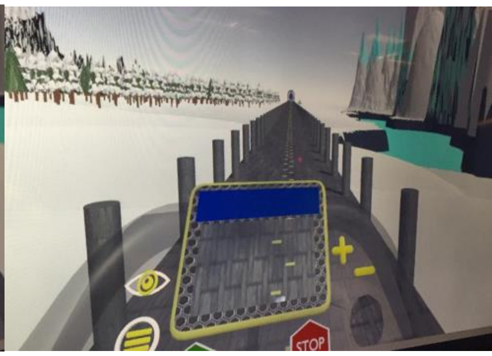
For hver av de følgende påstandene, vennligst indiker hvor godt dette stemmer for deg, ved å peke på følgende skala:

1	2	3	4	5	6	7
Helt uenig 			Hverken eller 			Helt enig 

Tilleggsspørsmål

Treff

Unngå



Kognitiv

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