The use of immersive virtual reality during robot-assisted walking in healthy adults: a study protocol

Effect of changing the optic flow speed in two different virtual environments on active participation during robot-assisted walking.

Synopsis

The aim of this study will be to investigate the effect of changing the optic flow speed on active participation during robot-assisted walking with the Lokomat-system in healthy adults. Second, the aim is to investigate the effect of two different virtual environments on active participation. The Lokomat is a gait exoskeleton that comprises two actuated leg orthoses and is used in conjunction with a body-weight support and treadmill. 28 participants, divided equally into 2 groups, will be tested in the rehabilitation center TrainM (Antwerp). Participants will perform one virtual-reality (VR) enhanced robot-assisted gait training (RAGT) session under three conditions for 7 minutes each: 1) walking with slower optic flow speed, 2) walking with matched optic flow speed, and 3) walking with fast optic flow speed. The virtual environment will be different for both groups: the experimental group will walk in a more interactive virtual environment such as a park or city street whereas the control group will walk in a virtual environment representing an endless hallway. Active participation will be assessed with the use of electromyography (EMG) and the position and force sensors of the Lokomat.

Key words: Robot-Assisted Gait Training, Lokomat, Virtual Reality, Optic Flow, Stroke

Prof. Dr. Eric Kerckhofs, Brussel 7/12/2017

Corresponding author: emma.de.keersmaecker@vub.be

1. Introduction

1.1 Rationale

The recovery of functional gait is of great importance for neurological patients and is a common goal of their rehabilitation programs [1]. Treadmill training with or without body weight support (BWS) is often used in clinics as a therapeutic approach for improving patients' gait function [2]. A more recent strategy to enhance gait training is robot-assisted gait training (RAGT), combining robotics with BWS treadmill training [1]. Both treadmill training and RAGT have demonstrated improvements in regaining the ability to walk in different neurological populations [3-6]. However, an important problem of using a treadmill for gait training is the incorrect visual information subjects receive during treadmill waking [2].

Controlling our locomotion involves the integration of visual, vestibular and proprioceptive information [7]. An important source of visual information to guide locomotion is optic flow (OF), a pattern of visual motion projected onto the retina of the eye [2, 8]. Optic flow, induced by locomotion, provides us with information about the direction and speed of self-motion [2, 7-9]. However, during treadmill walking, the visual information about the direction and speed of walking is inconsistent with the proprioceptive input of the lower limbs [2]. Subjects are walking on the treadmill and yet, their environment remains static.

It has already been shown that manipulating the OF can induce changes in humans' locomotion. Studies in healthy volunteers and neurological patients have shown that walking speed can be altered by changing the OF speed while walking on a treadmill [7, 9-13]. A negative correlation between walking speed and OF speed has been found, indicating that subjects will walk faster at a slower optic flow speed and vice versa. By manipulating the OF speed, a mismatch will arise between the OF and the proprioceptive information of the lower extremities and gait parameters will be adjusted [2, 7].

This manipulation of the OF can be done with the use of virtual reality (VR) where patients walk in a virtual environment (VE). VR devices and systems can be classified into two categories: (1) Semi-immersive or non-immersive VR systems, who let the user perceive both real world and a part of the VE (e.g. TV-screens, projection screens), and (2) Immersive VR systems, who fully integrate the user into the VE, by blocking out perception of the real world (e.g. head-mounted displays (HMD)) [14].

Although various studies have already investigated the effects of manipulating the OF on gait parameters, all these studies used either overground training or treadmill training to obtain locomotion. None of these studies assessed the effect of OF speed alterations during RAGT. Even more, the majority of these studies used non-immersive VR systems while this study will provide subjects with an immersive VE with the use of a HMD. Since this will be the first study investigating the effect of manipulating the OF during RAGT by means of an exoskeleton, a healthy population will first be tested before performing this on neurological patients. Furthermore, this study is also going to investigate if the type of VE has an influence on the active participation.

1.2 Objective

The aim of this study is to investigate the effect of different OF speeds on active participation in healthy participants during VR-enhanced RAGT by means of an exoskeleton.

The second aim is to investigate the effect of two different VEs on active participation during RAGT.

2. Methods

2.1 Study design

An experimental, 2-group, single-center trial will be conducted in which healthy participants will perform one VR-enhanced RAGT session in which 3 different optic flow (OF) speeds will be presented in a random order: 1) walking with slow OF speed, 2) walking with matched OF speed, and 3) walking with fast OF speed. The VE will be different for both groups. The experimental group will walk in a more interactive VE, whereas the VE of the control group will be a more static environment.

2.2 Participants

2.2.1 Number

Based on a sample size calculation (G*Power 3.0.10) (F-tests, repeated measures ANOVA, within-between subjects) with Cohen's f of 0.25 (moderate effect size), type 1 error probability of 0.05, power of 0.80 for 2 groups and 3 conditions, a total of 28 participants, divided equally in 2 groups, need to be recruited. In case subjects drop out, additional participants will be tested till 14 participants in each group completed all conditions. Participants will be tested in the rehabilitation center TrainM in Antwerp.

2.2.2 Eligibility criteria

Inclusion criteria will be: 1) ≥ 55 years of age, 2) normal or corrected-to-normal vision with glasses or contact lenses, 3) no locomotion impairments, 4) a maximal body weight of 135 kg, and 5) a maximal body height of 200 cm. Limitations regarding body weight and body length are due to the design of the Lokomat gait exoskeleton.

Participants will be excluded if they: 1) have skin lesions that cannot be protected appropriately, 2) have had significant lower extremity injuries during the last two years that might affect their gait, and 3) have any type of vestibular/visual deficiency.

2.3 Instrumentation

2.3.1 Virtual reality

The virtual reality will be provided by a HMD VR system 'Oculus Rift' (Oculus rift, LLC, US) and will assure an immersive virtual environment. The experimental group will walk in a more interactive VE such as a park or city streets, while the VE of the control group will represent an endless hallway where subjects will have to walk through.

2.3.2 Robot-assisted gait training

The Lokomat (version LokomatPro V6) gait exoskeleton (Hocoma AG, Volketswil, Switzerland) comprises two actuated leg orthoses and is used in conjunction with a body-weight support and treadmill. It has four degrees of freedom, allowing to control the movements of the hip and knees in the sagittal plane. Foot lifters can be used to assist the dorsiflexion, necessary for foot clearance during the swing phase. Furthermore, the Lokomat has force and position sensors in each hip and knee joint to measure the interaction torques between orthosis and participant and the range of motion, respectively.

2.4 Procedure

Participants will be tested during one VR enhanced RAGT session at the rehabilitation center TrainM (Antwerp).

Prior to the start of the experiment, surface electrodes will be placed bilateral on the Mm. rectus femoris and Mm. biceps femoris to measure muscle activity. Electrode placement will follow as closely as possible the guidelines of SENIAM [16]. The skin underlying the electrode will be shaved and cleaned to improve electrode–skin contact and reduce impedance.

At the start of the session, participants will be habituated to walking in the Lokomat without the virtual reality. During this habituation trial, the appropriate settings to walk comfortable in the exoskeleton will be determined. To make sure all participants walk comfortable in the Lokomat, subjects will be provided with a body weight support (BWS) of 30%. Guidance force (GF) will be set on 80% for all participants. With lower levels of GF, the biofeedback values will show smaller changes and can become negligible. Lastly, the walking speed (WS) will be set at 2.8 km/h for all participants (setting Lokomat: see Appendix). Preparing and installing the participant and determining the appropriate Lokomat settings will take no longer than 20 minutes. When the Lokomat settings are defined, the Lokomat will be stopped for a moment so that the virtual reality can be added. Participants will put on the HMD and will start walking again for one minute while watching the virtual environment scene expanding at a speed matching their walking speed to get used to the VR. After the habituation trial, participants will walk in the Lokomat with the three different OF speeds [10, 15] that will be presented in a random order for 7 minutes each:

1) slower OF: 0.5 times the individual's comfortable speed,

2) matched OF: same as the individual's comfortable speed,

3) faster OF: 2 times the individual's comfortable speed.

In order to normalize the registered EMG signals, the maximum voluntary isometric contraction (MVIC) test will be used. Each subject carries out the MVIC test 3 times for each muscle. Subjects must reach their maximum strength as quickly as possible and must keep it for 6 seconds. Subjects will perform the MVIC test in the following testing positions: prone with the knees in 30° of flexion (Mm. biceps femoris); seated with the knees in 60°of flexion, and the hips in 90° of flexion (Mm. rectus femoris). The average of the three tests will be taken for each muscle.

Example of a possible VR enhanced RAGT session

Preparation and installation subject + determining settings of the Lokomat	Getting used to the VR	Walking with slower OF	Walking with matched OF	Walking with faster OF	Uninstalling subject
20 min	1 min	7 min	7 min	7 min	3 min
	Total time: 45 min				

Pause the Lokomat to put on the HMD

2.5 Randomization

Subjects who agree to participate in this study will be equally randomized in a 1:1 ratio into 2 groups. For randomization, sealed envelopes will be prepared in advance and marked on the inside with a VE + or VE -. During the intervention, the speed of the OF (slow, matched or fast) will also be randomized. To participants, it will only be said that they will have to walk in the Lokomat with the VR for 21 minutes. They will not know that and when the OF speed will change.

2.6 Materials

Surface EMG electrodes will be used to measure the muscle activity of the Mm. rectus femoris and Mm. biceps femoris. Surface EMG data will be captured with the ME6000 EMG-system (Mega Electronics Ltd) using Conmed Cleartrace electrodes (Ag/AgCl) with an active diameter of 10mm.

The Lokomat has a biofeedback system that measures and displays participants' activity in real-time. Whit the use of force sensors, this biofeedback system measures the force of the Lokomat's drive motors. If the participant actively moves with the programmed gait pattern, the power required from the drives is small. The less active the participant is, the greater the drive force required to move his limbs according to the preprogrammed pattern. With this approach, two values are calculated for each driven joint; one for the swing phase, the other for the stance phase. This provides 8 biofeedback values per step cycle to characterize the degree of activity of the patient. Besides force sensors, the Lokomat also comprises position sensors. These sensors will be used to measure the range of motion (ROM) of the hip- and knee joints.

2.7 Outcome

2.7.1 Biomechanical quantification of active participation

The active participation during RAGT will be measured with the use of electromyography, the force sensors and the position sensors of the Lokomat.

- **Electromyography**: with the use of surface electrodes, muscle activity of the Mm. rectus femoris and Mm. biceps femoris of both legs will be measured. Surface electromyograms of these muscles will be analyzed with the use of the 'mean absolute value' variable. It represents the area under the EMG signal (AUC) once it has been rectified, meaning that all of the negative voltage values have been made positive. The mean absolute value will be measured per minute to compare the amount of muscle activity in time within one OF speed, between different OF speeds and between the 2 VEs.

- **Force sensors:** with the use of the force sensors of the Lokomat, interaction torques between the participant and the orthosis will be measured of the 4 joints (bilateral hip and knee). These interaction torques will be used to quantify how much the participant contributes to the walking movement him or herself. The average of these interaction torques will be calculated per minute to compare the amount of force in time within one OF speed, between different OF speeds and between the 2 VEs.
- **Position sensors:** with the use of the position sensors of the Lokomat, it is possible to measure the range of motion (°) of the 4 joints (bilateral hip and knee).

2.8 Statistical analysis

Statistics will be performed using SPSS (IBM, Chicago, IL). The significance level will be set on 5%. Descriptive statistics will be calculated for baseline participant characteristics. Means and standard deviations will be calculated for continues variables and frequencies and percentages for categorical variables. Active participation will be measured continuously during the session. Data analysis of the average of every minute will be conducted. To investigate the effect of time, the different OF speeds, and the different VEs, repeated-measures ANOVA (within-between subject design) will be done.

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Appendix

Setting Lokomat

Start walking at 100% GF, 30% BWS and 1.5 kmph WS

↓

↑ WS to 2.8 kmph

↓

Visual inspection of the gait pattern (mainly foot clearance, hip and knee angles)
Adapt hip and knee angle, foot straps and/or patient coefficient if necessary
Question participant with respect to pain and comfort

↓

Set GF at 80%

↓

Visual inspection of the gait pattern (mainly foot clearance, hip and knee angles)
Adapt hip and knee angle, foot straps and/or patient coefficient if necessary
Question participant with respect to pain and comfort

↓

If necessary re-adapt WS until comfortable walking in the Lokomat is achieved with visual “normal” gait pattern (e.g. sufficient foot clearance, no knee buckling) and no pain or discomfort