Feasibility and Acceptance of a Virtual Reality System for Gait Training of Individuals with Multiple Sclerosis

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Feasibility and Acceptance of a Virtual Reality System for Gait Training of Individuals with Multiple Sclerosis.

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Abstract

The aim of this study was to evaluate the feasibility and participants' acceptance of a novel virtual reality-based gait training for multiple sclerosis individuals.

Ten patients with multiple sclerosis participated in a six-week virtual reality-treadmill training program, which required participants to negotiate obstacles, while engaged in dual tasking. Outcome measures included system performances, training progression and participants' acceptance.

Results showed that the system was durable and highly adaptable to participants' abilities.All participants enjoyed the intervention and improved their performance. Moreover, the technology was well accepted and the multisensory feedback was found to be very useful.

This study demonstrated the feasibility of a virtual reality-based system for gait training in multiple sclerosis. It provided a basis for further development of the rehabilitation intervention and demonstrated that virtual reality treadmill intervention is feasible in such a cohort.

Keywords: virtual reality, gait training, inertial sensors, multiple sclerosis, dual task, treadmill.

1. Introduction

A motor rehabilitation intervention aims at improving the independence and the quality of life of treated subjects, by maximizing their functional abilities in everyday life (American Occupational Therapy Association, 2002; World Health Organization, 2001). Daily activities frequently require performing cognitive and motor tasks simultaneously (dual tasking) and adapting strategies of movement when unexpected events occur (Kizony*et al.*, 2010). Unfortunately, dual task training is difficult to achieve, as it requires multi-model approaches with high intensity of training. Virtual reality (VR) has been proposed in rehabilitation since it allows running intensive and repetitive training programs in a safe and motivating environment. VR environments provide controlled stimuli and multi sensory feedbacks, while engaging the participant in dual task activities (Mirelman*et al.*, 2011). Moreover, classical rehabilitation, often does not afford the intensity that is needed for motor learning and can be perceived as boring and repetitive, affecting the patient's motivation. VR allows tracking and registering the subject's motor performance and achievements, providing challenging and engaging exercises accordingly.VR, being perceived as fun, novel and interesting, shifts the focus from the person's efforts to that of interaction with the VR environment (Thornton*et al.*, 2005).

Various VR tools have been successfully developed and used for the motor rehabilitation of patients with neurological impairments, such as post-stroke(Cameirão*et al.*, 2008;Holden, 2005;Jaffe *et al.*, 2004;Mirelman*et al.*, 2009), traumatic brain injury (Sveistrup*et al.*, 2003) and Parkinson'sdisease individuals (Mirelman*et al.*, 2011) and elderly subjects (Bisson*et al.*, 2007).

A limited number of studies applied VR to subjects affected by multiple sclerosis (MS). Leocani et al. (Leocani*et al.*, 2007) used an electromagnetic sensor to record the movement of the index finger of twelve MS subjects while tracking a target projected on a screen. The authors stressed the need of tailored rehabilitation strategies, considering the patient's specific motor and cognitive skills. Baster is and colleagues (Basteris*et al.*, 2011) asked six MS subjects to control a virtual tool, under the effect of a resistive force that, along with the task difficulty, was automatically adjusted to the patients' performance at the beginning of each session, gradually increasing task demands. Results suggested that subjects improved their performance and retained it across the sessions.

Since MS is a chronic, neurodegenerative disease and its motor symptoms (sensory impairment, muscle weakness, spasticity, balance deficits and fatigue)(O'Sullivan, 2001) often lead to gait disturbances (Weinshenker, 1994), such training would be expected to have a positive impact. In spite of this, there is limited literature on VR applications for gait rehabilitation of subjects with MS(Fulk, 2005;Baram&Miller, 2006).

Moreover, the success of a rehabilitation intervention relies on the patient's engagement, motivation and satisfaction (Lewis*et al.*, 2011;Cardoso*et al.*, 2006;Maclean*et al.*, 2000;Maclean*et al.*, 2002; Chen*et al.*, 1999). Despitethe fact that VR showed promising results in rehabilitating MS individuals, there is a lack of structured information on the users' acceptance of such approach that could be useful in the development of future successful VR interventions (Lewis*et al.*, 2011).

The aim of the current study was to develop a VR-based system to train gait in MS individuals and test its feasibility during a six-week program. Secondly we assessed the participants' acceptance of such intervention. The effects of the training program on balance and gait have been reported in previous publications (Aiello*et al.*, 2012; Peruzzi*et al.*, 2013).

2. Materials and methods

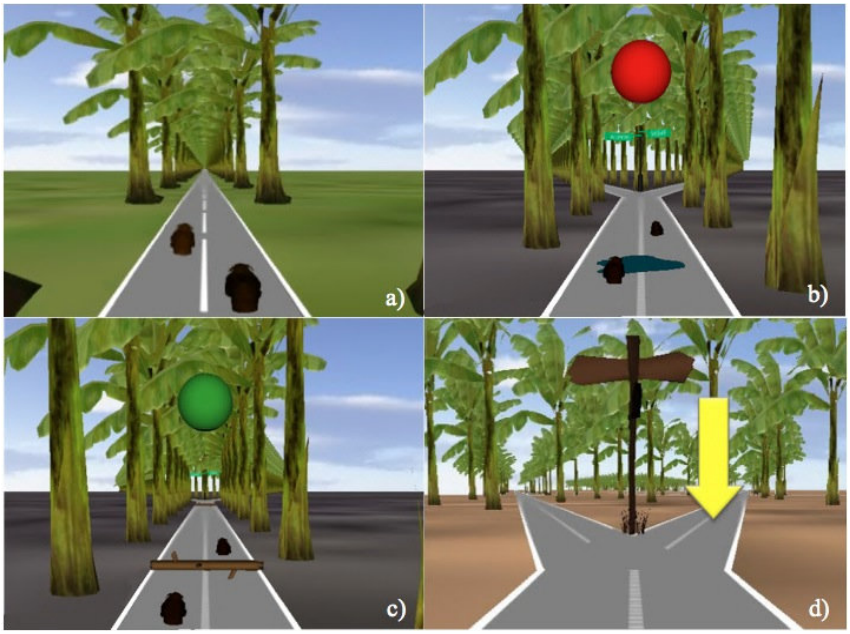
2.1 Hardware

The following equipment was used to administer the proposed gait training program: a conventional treadmill (TM), a harness suspended from a metal frame (the harness was used for safety but did not provide body weight support), three inertial measurement units (IMU – MTx Xsens, Enschede, The Netherlands) and a Head Mounted Display (HMD - Z800 Emagin, Bellevue, WA, USA) – or alternatively a large screen. The TM allowed controlling the patient's walking speed. Participants wore the harness to guarantee a safe experimental setup. The HMD was used to deliver the specifically designed VR environment. Two IMUs were attached to the patient shoes and the data recorded during the walking trails were used to generate in real time, the motion of a pair of shoes in the VR environment. An additional IMU was placed on the patient's head to monitor its rotation in the horizontal plane.

2.2 The VR environment

The software platform implementing the VR environment was based on Python (Python v2.4). The orientation data extracted from the IMUs were streamed in real time into the VR environment at the sampling rate of 50 Hz. The VR environment was generated with the Vizard software (WorldViz, Santa Barbara, CA, USA) and consisted of a tree-lined road upon which two types of obstacles were presented (Figure 1a).While walking on the TM, the patient was expected to negotiate the virtual obstacle without colliding with it. This required motor abilities as well as cognitive function, specifically planning and information processing. In addition, to challenge decision-making, attention and problem solving, road bifurcations were added featuring street signs indicating both the pre-assigned destination and alternative destinations.

FIGURE 1



Environmental changes were also introduced as distracters in order to challenge divided attention. These included different modalities in the form of auditory (chirping birds, barking dogs, ambulance sirens, etc.) and visual stimuli (change in weather conditions or animals and vehicles crossing the walkway).

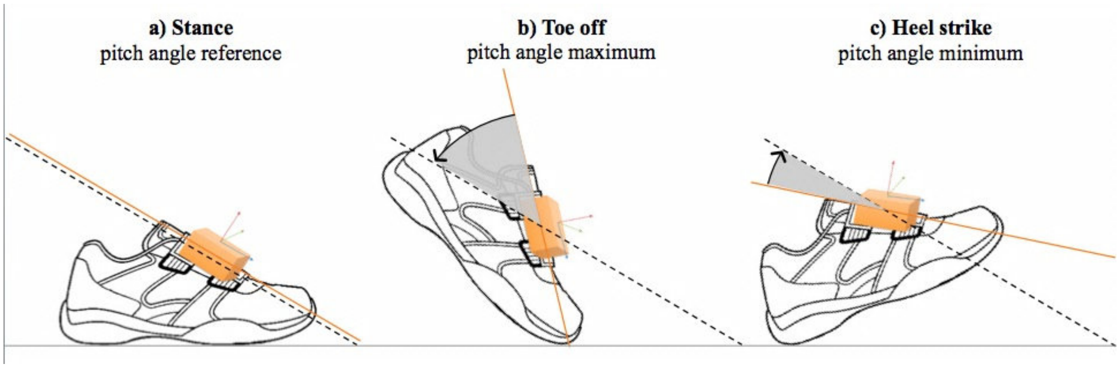
The VR environment had five levels of complexity. These were determined by the number of bifurcations, density of trees and road width.The level of complexity of the VR environment was raised when the clinician considered the patient ready for a more intensive cognitive task.

To promote motor learning, visual and auditory feedbacks were provided to the participant upon motor and the cognitive success or failure (Schultheis& Rizzo, 2001;Fung*et al.*, 2004; Levin*et al.*, 2010). A score, expressed as the amount of passed obstacles, was shown on the display at the end of the training trial.

Gait replication

The identification of gait cycles was obtained from IMU pitch angle data: heel strikes and the toe off corresponded to IMU pitch angle minima and maxima values, respectively (Figure 2).

FIGURE 2



The pitch angle data were used to reproduce the patient's shoes movement in the VR environment, which was made to move toward the patient's point of view depending on the TM speed. The velocity of the patient's shoes in the VR environment during the swing phase was set under the assumption that when walking on a TM, the distance traversed during the stance phase was equal to the distance traversed during swing.

Obstacles and bifurcations

Obstacles (puddles or logs) along the walkway appeared at variable intervals of time, while their number, size and orientation were adjusted by the trainer on a trial-by-trial basis. Patients had to raise their foot, when encountering a log, and lengthen their step, when encountering a puddle. In both cases the duration of the swing time was used as an indirect measurement for discriminating successful tasks and, accordingly, an audio/visual feedback was generated (Figure 1b and 1c).

When in the proximity of a bifurcation, participants were instructed to express the chosen destination by turning their head accordingly. A blinking arrow pointing at the chosen direction, identified from the recording of the head mounted IMU, appeared just before encountering the bifurcation to allow a direction change if needed (Figure 1d).If successful, a positive audio/visual feedback was provided immediately after the turn.

2.3 Participants and gait training protocol

Ten subjects affected by relapsing remitting type of MS according to McDonald et al.'s criteria(McDonald*et al.*, 2001),were recruited from the Operative Neurology Unit at the Sassari University Hospital and participated in this pilot study(9 females, mean age: 44.3 ± 8.1years). Participants were moderately impaired as assessed by the Expanded Disability Status Scale (EDSS)–(Kurtzke, 1983)–score (range: 3 - 5.5) and Ambulation Index–(Hauser*et al.*, 1983)–(range: 3 - 6). All participants provided an informed written consent prior to the beginning of testing.

The training consisted of twelve sessions of thirty-minutes each (two sessions per week for six weeks).Sessions consisted of three trials of ten minutes of walking followed by five minutes of rest, for a total time of about 45 minutes (30 minutes of training and 15 minutes of resting).The Borg Rating Scale of Perceived Exertion Scale– Borg Scale (Borg, 1982)– was administered at the beginning and end of each session to assess and monitor the level of physical effort.

Training progression was based on an earlier study protocol of intensive progressive individualized TM training with VR in patients with Parkinson's disease (Mirelman*et al.*, 2011)and allowed adjustment of training parameters to fit the patient's needs.

During the first session the TM speed was set at low values in order to let people to familiarize with the training. In the second session TM speed was set at 20% lower than the patients over-ground walking speed, measured during the six-minute walk test (ATS Committee on Proficiency Standards for Clinical Pulmonary Function Laboratories, 2002). In the following sessions, the TM speed was adjusted based on their performance during previous trials. Orientation, size, frequency of appearance, and shape of the obstacles were manipulated according to individual needs, following the guidelines for training progression designed to achieve a success rate of 80% in clearing the obstacles.

All participants started the training program, holding both hands on the TM handrails. Balance during walking was challenged by remove one, and then, both hands from the handrail. This was an additional progression level, which was manipulated at the discretion of the clinician.

2.4 Evaluation of setup and administration of the gait training program

The setup and administration of the proposed gait training program were evaluated in terms of feasibility and acceptance.

- Feasibility: a) number of subjects completing the training program, b) number of unexpected events or accidents during the training, c) number of system crashes, d) number of uncompleted trials,e) TM speed progression associated with exertion, balance challenge and VR environment complexity levels.
- Acceptance: a questionnaire based on previous studies (Cameirão *et al.*, 2010;Zimmerli*et al.*, 2009; Girone*et al.*, 2000; Deutsch*et al.*, 2001) was administered (Table 3). The questionnaire included aspects such as the ease and understanding of the task (statements 1-4), attitudes relating to the technology (statements 5-7), the subjective performance (statement 8-10) and enjoyment from the training (statements 11-14). Responses were recorded using a 5-point Likert scale with "strongly disagree", rated as a 1, to "strongly agree", rated as 5.

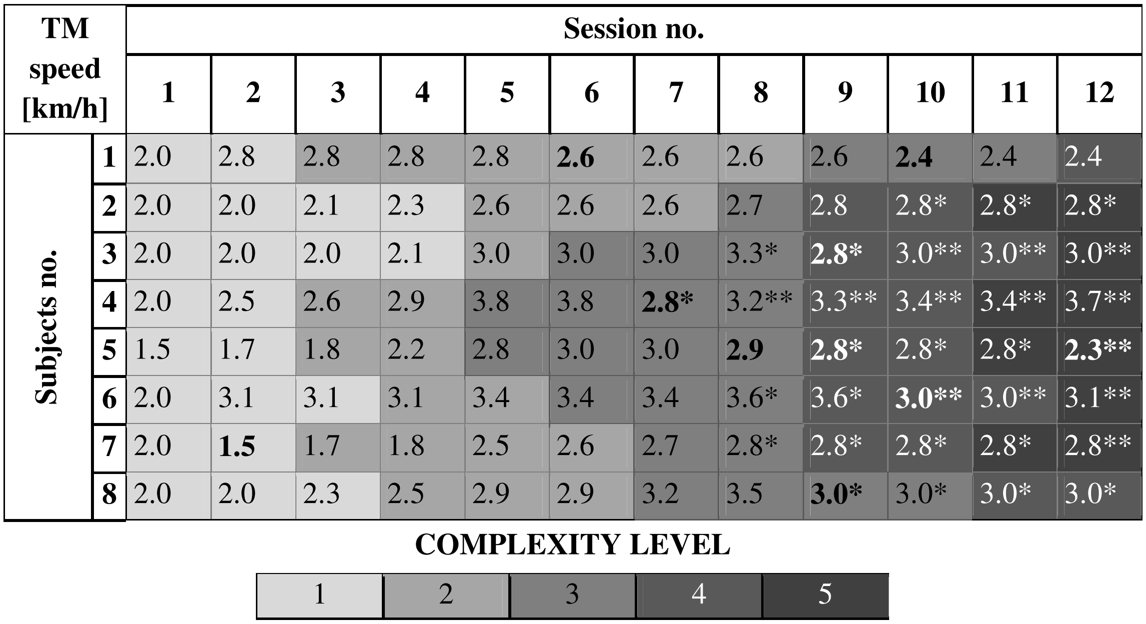
3. Results

Feasibility

All participants completed the training, except for two who dropped out after the first session because of personal reasons.No crashes and adverse events or complications occurred during the entire training period.

TM speed progression for all training sessions and for all participants is reported in Table 1. The table also reports the VR environment complexity levels and the training sessions carried out without using the handrails.

TABLE 1



TM speed [km/h]		Session no.											
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Subjects no.	**1**	2.0	2.8	2.8	2.8	2.8	**2.6**	2.6	2.6	2.6	**2.4**	2.4	2.4
	2	2.0	2.0	2.1	2.3	2.6	2.6	2.6	2.7	2.8	2.8*	2.8*	2.8*
	3	2.0	2.0	2.0	2.1	3.0	3.0	3.0	3.3*	__2.8*__	3.0**	3.0**	3.0**
	4	2.0	2.5	2.6	2.9	3.8	3.8	__2.8*__	3.2**	3.3**	3.4**	3.4**	3.7**
	5	1.5	1.7	1.8	2.2	2.8	3.0	3.0	**2.9**	__2.8*__	2.8*	2.8*	__2.3**__
	6	2.0	3.1	3.1	3.1	3.4	3.4	3.4	3.6*	3.6*	__3.0**__	3.0**	3.1**
	7	2.0	**1.5**	1.7	1.8	2.5	2.6	2.7	2.8*	2.8*	2.8*	2.8*	2.8**
	8	2.0	2.0	2.3	2.5	2.9	2.9	3.2	3.5	__3.0*__	3.0*	3.0*	3.0*

COMPLEXITY LEVEL

1	2	3	4	5

Table 2 reports the mean (and standard deviation) of the Borg Scale scores at the beginning of each training session (B_0) and their increments at the end of the training session (□B=B_f-B_0) averaged over subjects. The percentage of uncompleted trials due to exertion in each training session is also reported in the table.

TABLE 2

	Session no.											
mean (std)	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
B_0	8 (3)	8 (2)	8 (2)	8 (3)	8 (2)	9 (3)	8 (3)	8 (3)	9 (3)	9 (3)	8 (2)	9 (3)
□B	7 (3)	5 (2)	4 (2)	3 (2)	4 (3)	3 (2)	4 (3)	3 (3)	2 (2)	3 (3)	3 (2)	3 (3)
□□incomplete	21	0	8	4	4	8	0	4	4	4	0	0

Acceptance

Table 3 reports the results of the satisfaction questionnaire. The number of subjects who provided the same score to each of the statements is reported in the last columns of the table.

TABLE 3

Statement/Score	1	2	3	4	5
I had no trouble understanding what to do in the training	-	1	1	1	5
It was easy for me to learn how to move my feet and the head in the VR	1	-	3	1	3
It was easy for me to learn how to pass the obstacles	1	-	3	1	3
The visual and the audio feedbacks were helpful	-	-	-	-	8
Wearing the HMD was comfortable	-	-	-	3	5

Wearing the IMUs was comfortable	-	-	-	1	7
Wearing the harness was comfortable	-	-	-	1	7
The exercise was simple	3	2	3	-	-
The exercise was not tiring	1	2	1	2	2
. I made few mistakes	-	-	3	3	2
. I have noticed some improvements in my daily life performing the training	1	-	3	1	3
. I enjoyed the training	1	-	-	1	6
. Participating to the training was important for me	-	-	1	2	5
. I would like to participate to the training again	1	-	1	1	5

4. Discussion

The first aim of this study was to develop a system and a VR environment to be used in a gait training program by MS individuals. The feasibility of both the system and the VR environment has been verified by their safe and intensive use, which lasted six weeks, without the occurrence of adverse events.

The acceptance of the experimental set up and administration of a novel VR-based gait training program on MS individuals has also been evaluated through a questionnaire. In the past, several VR-based tools used in rehabilitation training program have shown a high level of acceptance. Cameirão et al.(Cameirão*et al.*, 2010) used a questionnaire to assess the usability and acceptance of a VR-based neurorehabilitation system for controlling two virtual limbs in individualized tracking tasks. They evaluated the enjoyment in performing the task, the understanding and ease of the task, and the subjective performance, concluding that the acceptance of the system was very high. Similar questionnaires have been used to assess enjoyments and level of challenge during VR training as well as self-confidence and demonstrated high levels of satisfaction of these systems (Lewis*et al.*, 2011; Schwickert*et al.*, 2011).

In our study, findings revealed that subjects tolerated the technology without major difficulties and demonstrated a high level of acceptance throughout the adherence to the training program. Participants were able to complete all training sessions without complications. The protocol allowed to effectively tune the TM speed based on: 1) the level of the VR environment complexity, 2) the amount of challenge of the patient's balance when asked to remove hands from handrails, and 3) the increase exertion level after each training session. TM speed was generally kept constant or reduced when handrails were not being used. The average Borg Scale scores reported at the beginning of each session had limited variability across sessions (average B_0 between 8 and 9 and std between 2 and 3 – Table 2) signifying that, overall, training sessions begun at a similar level of exertion. More importantly, the values of the average increments of the Borg Scale scores were almost constant across sessions (average varied between 2 and 5 except for the first session – Table 2) with a limited variability across subjects (□B std between 2 and 3 – Table 2), showing that an appropriate choice of the TM speed can also keep the exertion increase at the end of the training session within a limited range. Moreover, the limited percentage of uncompleted trials due to exertion in every training session (between 0 and 8% – Table 2), except for the first one, could be seen as the result of the combination of properly tuned TM speed and level of complexity and increased patients' endurance.

The results obtained from the administration of the questionnaire revealed that the highest ratings were obtained for the usefulness of feedbacks and the acceptance of technology (Table 3). High ratings were also found for the ease and enjoyment from the use of the system and the training: all subjects found the training easy to learn and, with the exception of one, enjoyed it and would have liked to continue it.

This aspect is very important, since rehabilitation is a long process and may not be successful if the patient is not committed. Indeed, motivation is an important factor in rehabilitation, stimulating and encouraging the individual to participate in the intervention (Mihelj*et al.*, 2012), and is frequently used as a determinant of the rehabilitation outcome itself (Maclean*et al.*, 2000).Consequently high adherence to a rehabilitation program is seen as indicative of motivation (Maclean*et al.*, 2002) and is essential to achieve successful rehabilitation results (Colombo *et al.*, 2007). Moreover, few studies on MS reported that perceived self efficacy, feelings of fun or enjoyment, sense of accomplishment and pride contribute to engage participants in motor rehabilitation intervention (Motl*et al.*, 2006; Stroud& Minahan, 2009).

Numerous studies on VR-based rehabilitation interventions have already highlighted the importance of motivation, enjoyment and participation of patients involved in VR-based training. Zimmerli and colleagues (Zimmerli*et al.*, 2009) showed that augmented feedback applications for gait training (a VR environment and a Lokomat - Hocoma, AG, Switzerland), increased the subject's motivation and activity level. In a second work they showed that the presence of a virtual opponent in a VR environment produced higher participation and enjoyment of children with gait impairment (Koenig*et al.*, 2008; Brütsch *et al.*, 2010). In Girone et al., (Girone*et al.*, 2000) subjects with ankle disorders responded favorably to a training combining a VR environment with an ankle rehabilitation device. Ease of use of the device and perception of limited exertion during the training resulted in high acceptance and satisfaction (Deutsch*et al.*, 2001).

Finally, the questionnaire reported a high variability in the subjective responses relating to performance, confirming the differences among subjects in terms of task execution and perception of exertion.

A limitation of this study is that no control group was included. Its inclusion would have allowed comparison of proposed approach and subsequent subject acceptance with other interventions.

5. Conclusion

In this pilot study we evaluated the feasibility and acceptance of a gait training setup including a TM and a VR environment created for MS individuals. The results have shown a high level of feasibility and acceptance of the VR system and the gait training program.

The training allowed for some flexibility (setting the TM speed and increasing level of complexity in the VR environment), which was shown to be highly important for providing tools for customizing sessions and engaging the subjects whilst enhancing motivation and acceptance.

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FIGURE AND TABLE CAPTIONS

Table 1. Progression of the TM speed across the training sessions. The asterisks indicate trials in which participants took off one (*) or both (**) hands from the handrails. The gray tone of the cells indicates the complexity level. Bold numbers highlight the occasions when the trainer decided to lower the TM speed (when starting a higher level of complexity, or asking to remove hands from handrails or when exertion increase was assessed as excessive.

Table 2. Average and standard deviation over subjects of the Borg Scale score at the beginning of training sessions (B_0) and difference between Borg Scale scores at the end (B_f) and at the beginning of each training session (□B = B_f- B_0). In the last row of the table the percentage of the incomplete trials due to exertion is reported for each training session.

Table 3. The administered questionnaire with the responses given by the participants. The questionnaire includes statements regarding the understanding of the task, the acceptance of the technology, the subjective performance and the enjoinment of the training. Subjects' responses were recorded using a 5-point Likert scale from "strongly disagree", rated as a 1, to "strongly agree", rated as 5.

Figure 1. (a) A screen shot of the VR environment: a tree-lined road presenting obstacles and road bifurcations. The movement of the shoes reproduces in real time the patient's feet movement. (b) A positive visual feedback (green circle) is returned when the patient successfully passed an obstacle (a log) and (c) a negative visual feedback (red circle) is returned when the patient unsuccessfully negotiated an obstacle (a puddle). (d) A bifurcation as seen by the patient: the road sign shows two directions. The patient chooses a direction by turning her/his head towards it. The head rotation is captured by an IMU and a blinking arrow appears pointing at the selected direction just prior to the turn.

Figure 2. Gait cycles were identified from IMU pitch angle data: heel strikes and toe off instants corresponded to the instants of pitch angle minima and maxima, respectively. The gray solid line represents the longitudinal axis of the IMU, whereas the black dotted line represents the pitch angle reference of the IMU defined by the foot flat on the ground.