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Dual-task training using virtual reality: Influence on walking and balance in three post stroke survivors

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ABSTRACT

Objective: To investigate the feasibility of using a virtual reality (VR)-based dual task of upper extremity tracking while treadmill walking, to improve gait and functional balance performance of stroke survivors.

Materials and Methods: Three individuals (two males and one female), 66, 64, and 54 years old, respectively, participated in the study. The participants were trained in eight sessions of dual-task walking (DTW) on a treadmill while performing virtual tasks, and eight sessions of single-task treadmill walking (TMW), in a cross-over design. Their walking speed, balance performances, and perceived confidence were measured four times along different stages of the study.

Results: Two participants demonstrated improvements in each of the outcome measures after the DTW intervention and no change after the TMW intervention.

Conclusion: The improvements that were observed in the study demonstrate the potential benefit of DTW using VR while treadmill walking on gait and balance performances of stroke survivors.

Key words: stroke rehabilitation, virtual reality, dual-task training, community ambulation

INTRODUCTION

Loss and impairment of walking ability are two of the major disturbing outcomes of post-stroke sequel. Gait restoration has been recognized as a primary goal in stroke rehabilitation, as well as achieving an optimal level of participation in community activities [1]. It has been reported that nearly one-third of stroke survivors do not go out unsupervised into the community [2]. Environmental factors that determine the challenges and complexity of community mobility are recognized as critical

determinants of mobility limitations in stroke survivors [3].

Common daily activities such as road crossing require the ability to perform two or more cognitive and motor activities simultaneously (i.e., dual tasking), as well as being able to adapt the performance when unexpected events occur. The paradigm of dual tasking and the effect of a secondary task on balance, gait, and cognitive performance have been examined in healthy and clinical populations. It was found that gait and cognitive performance can deteriorate during dual-task performance, especially in people with

neurological deficits [4-6]. Among post-stroke survivors (PSS), dual tasking diminished walking performance [7]. In addition, the high fall risk of PSS [8, 9], challenges researchers to discover innovative ways of improving their gait performance while dual-tasking.

One of the preferred walking retraining methods is treadmill training, which is a whole-task practice under appropriate control of the inclines and speeds, and has shown to improve walking ability in PSS [10-12]. However, the application of dual-tasking while treadmill training with stroke survivors is still in its infancy [1, 13].

One possible method of implementing dual-tasking while walking in a safe and challenging environment is by the use of virtual reality (VR) environments. VR enables an interactive and enjoyable environment, and has shown encouraging results in upper limb rehabilitation of PSS [14], including an improvement of motor functioning of the upper extremity in three adults with chronic hemiparesis [15].

Utilizing video and computer technology, VR creates a virtual scene in which the intensity of practice in a functional task can be systematically manipulated and sensory feedback can be provided, to enable the most appropriate individualized real-life motor retraining [15, 16]. In addition, it was suggested that VR may contribute to positive changes in neural organization and associated functional ambulation [17].

Walker and associates [18] utilized a VR system that generated a virtual environment on a television screen in front of the treadmill to give the six participating PPS the sensation of walking down a city street, and added visual information for improving postural feedback. Mirelman and associates [19] are currently using a similar protocol that includes a treadmill training program augmented with VR to decrease fall risk in older adults. However, while the latter study includes dual-task conditions, they are based on virtual barriers that need to

be engaged while walking on the treadmill. No dual-task conditions of upper-body activity combined with walking on the treadmill have been encountered so far as a training modality for PSS.

Therefore, the purpose of the present study was to investigate the feasibility of using a VR-based dual task of upper extremity tracking while treadmill-walking, to improve gait and functional balance performance in three PSS.

MATERIALS AND METHODS

Participants

The experiment was conducted within the framework of an exercise training center (ETC), which was part of a community services department of an academic college. The procedure of the study was explained to the participants, and their consent was given prior to addressing the specific training conditions. The content and procedure were approved by the college institutional ethics review board.

Inclusion criteria of the participants were: (a) hemiparetic from stroke occurring at least a year earlier, (b) ages between 50-70 years, and (c) stable medical condition to allow participation in the testing protocol and intervention. Exclusion criteria were: (a) severe heart disease, (b) Mini Mental State Examination score < 25, (c) orthopedic difficulties that do not allow training, and (d) more than three falling incidents during the past year. The participants were members of the ETC, and were experienced in physical exercise and treadmill walking.

Three persons with chronic post stroke, two males and one female, who had been discharged after completing rehabilitation, volunteered to take part in this pilot study. Muscle strength and joint range of motion were assessed manually [20]. Their major demographics and clinical data are presented in Table 1.

	Participant 1	Participant 2	Participant 3
Gender	Male	Male	Female
Age	66	64	54
Time since stroke (months)	32	120	12
Body side affected	Right	Left	Right
Physical symptoms	Full ROM, small functional decline. Normal muscular tone, could maintain balance while standing and walking. Exhibited some dysarthria, and a fair cognitive decline. Had been exercising three times a week in the ETC for three years. In addition, walked once a week for an hour around his neighborhood.	Substantially reduced arm and leg ROM and muscle strength. Exhibited spasticity in the right upper and lower extremities, difficulties in static balance, and slow walking pace with a stick. A left drop-foot, treated with an electronic device. Had been exercising twice a week in the ETC for nine years. In addition, he attended hydrotherapy sessions once per week, and received a Botox injection to both UE and LE every six months.	Limited right shoulder ROM due to pain. Reduced tone in right UE and increased tone in right LE with right drop-foot, treated with an electronic device. Slightly reduced superficial sensation in the right foot. Normal standing balance, but reduced balance while walking with a stick. Had been exercising twice a week in the ETC for a year and a half, and received no other treatments.

INTERVENTION

VR Instrumentation

The SeeMe system, which has been documented previously in another feasibility study [21], is a projected video-capture VR system that works with a standard PC and a single, standard web video camera. Participants are located in a demarcated area viewing a large monitor that displays an environment that includes functional tasks such as touching virtual balls. The video camera, mounted on the television screen directly in front of the user, captures the user's image and projects it onto the screen. The user's on-screen video image corresponds in real time to his/her movements, so that it appears as though the user is part of the virtual environment, leading to engagement in the simulated task.

Study Design

This was a multiple case-crossover study with an A B C time series design, and crossover task conditions across participants. A was the first condition, B a fade-out phase, and C the second condition.

Dual-task Walking (DTW).

Each training session began with 8 min of general warm-up. Then, for safety reasons,

the participants were attached to a harness (Unweighing System, Biodex Medical Systems, USA) on a treadmill (Jonson Fitness T 800, Taiwan). Although the harness was attached to an overhead suspension system, no weight support was provided. The VR was rear projected on a 0.7X0.4 m screen mounted in front of the end of the treadmill. The participants began walking slowly on the treadmill for 3 min, during which the speed was gradually increased to the point equivalent to 60%-70% of their heart rate reserve [22]. In the following phases the participants walked at the same speed, while training with 3 VR games: 1. *SeeMe Ball* – The participant has to hit the virtual balls that approach toward him or her from different directions. In the more advanced levels, distractors are added in the form of an occasional thrown shoe (which should be avoided); 2. *SeeMe React* – In this task, virtual balls appear randomly at fixed distances on both sides of the screen. The task of the participant is to touch the virtual ball within a set amount of time; 3. *SeeMe Cleaner* – The participant is supposed to clean a series of mirrors as quickly as possible, by wiping off the virtual dirt. Each session lasted 3 min, and 3 min of single walking was performed between VR sessions. After the final VR session, 2 min of single-task walking was

performed in order to allow for recovery. The time walked in each trial from the starting point to the destination was kept constant at 20 min.

Single-task Treadmill Walking (TMW).

In this intervention, participants performed 8 min of general warm-up, and then continued to walk for another 22 min on the treadmill at a speed that was equivalent to the intensity of 60%-70% of their heart rate reserve.

Procedure

Participants performed four testing sessions and two intervention periods divided by a fade-out phase, as follows:

Pre-intervention test – Performed one week before the first intervention period

First intervention period – Eight sessions of TMW or DTW were performed twice a week, during four weeks.

Participant 1 completed the first intervention under the TMW condition and participants 2 and 3 under the DTW condition.

Post first intervention test – Performed two days after the end of first intervention period.

Fade-out test – Performed one week after the end of first intervention period.

Second intervention period – This period was made up of another eight sessions of TMW or DTW (crossover), which were performed twice a week during four weeks.

Participant 1 completed the second intervention under the DTW condition and participants 2 and 3 under the TMW condition.

Post second intervention test – Performed two days after the end of the second intervention period.

Outcome Measures

1. The over-ground 10-meter walking speed test (10 mW Speed): Participants were asked to walk at their fastest speed through a 12-m hallway, using their usual assistive devices when needed. To avoid the effects of acceleration and deceleration, measurements were taken from the middle 10-m of the hallway. Walking speed was derived by dividing the distance by the time (in seconds) required to walk the 10 m [23].

2. The number of steps completed during the 10-meter walk (10 mW-Steps): The number of steps performed was counted by the test administrator.

3. Timed up and go (TUG): The individual was seated in a chair with armrests, and the time taken to stand up, walk forward three meters, and return to the seated position was measured [24, 25].

4. Functional Reach Test (FRT): The individual stood barefoot, with his/her feet on the ground, placed adjacent to a wall on which there was a metric tape fixed in the horizontal position. To start the test, the individual placed one upper limb at a 90° shoulder flexion with an open hand and fingers stretched, while the position of the tip of the third finger was marked on the wall. The participant made a maximum forward inclination of the torso, with the upper limb reaching as far as possible, without leaning on the wall, without using the other upper limb as support, and without removing the heels from the ground. The arm moved along the horizontal tape, and the distance in centimeters between the initial annotation of the length of the arm and the final displacement from the trunk to the tip of the middle finger was measured. The test was performed three times and the greatest distance reached was recorded [26].

5. Lateral reach test (LRT): The participant stood with his/her back near but not touching a wall with the feet 10 cm apart between the heels. The participant raised both arms to shoulder height and maintained equal weight bearing while the position of the tip of the third finger on the side being measured was marked on the wall. The arm not being measured was lowered. The participant was instructed to reach sideways as far as possible without overbalancing, taking a step, or touching the wall. The position of furthest reach was measured. Both feet remained in full contact with the support surface, no knee flexion was permitted, and no trunk rotation or flexion was allowed. Three measures were recorded on each side and the means were calculated [27].

6. Activities-specific Balance Confidence (ABC)

Scale: This is a 16-item self-report questionnaire that asks individuals to rate their balance confidence in performing specific ambulatory activities on a numerical rating scale (0 – 100). A score of zero represents no confidence, while a score of 100 represents complete confidence in performing the activity [28].

7. The Berg Balance Scale (BBS): This scale consists of 14 tasks that require individuals to maintain their balance in positions and tasks of increasing difficulty. Items are graded along an ordinal scale ranging from 0 to 4 (with a possible total score of 56), based on either the amount of time an individual can hold a position or the amount of time it takes to complete the given task. Fewer points were given if supervision, cueing, or assistance was required during the task, or if the time or distance requirements were not met. Full points were given if the participant was fully capable of performing the task [29].

Data Analysis

Descriptive statistics were used to describe the individual performance in each of the outcome measures.

RESULTS

All three participants could adapt to walking on the treadmill while performing the VR tasks. No adverse events, such as becoming unstable or requesting to discontinue the training, were encountered. All participants reported having greater interest and fun during the DTW in comparison to the TMW training.

Results along four assessments for each parameter are presented in Figures 1-8.

1. Walking speed and number of steps along the 10 meter walk test.

As can be seen in Figures 1- 2, participant 1 showed almost no change in his walking speed or his number of steps along the four assessment sessions. In contrast, participants 2 and 3 showed improvement in their walking speed and a decrease in number of steps after the DTW intervention.

2. TUG.

As can be seen in Figure 3, participant 1 showed a slight decrease after the TMW intervention and a greater decrease in time after the DTW. Participants 2 and 3 showed a large improvement after the DTW intervention. Participant 2 maintained the improvement through the fourth assessment session. Participant 3 lost her improvement after the second intervention.

3. FRT and LRT (Figures 4-6).

Participant 1 showed some improvements in these parameters along the different assessments, mainly following the TMW training. Participant 2 showed a large improvement after the VR training and maintained it through the rest of the study, however he couldn't perform the LRT to the left side (his non-paretic side). Participant 3 showed some improvements after the DTW training, but lost them after the TMW intervention period.

4. ABS and BBS (Figure 7-8).

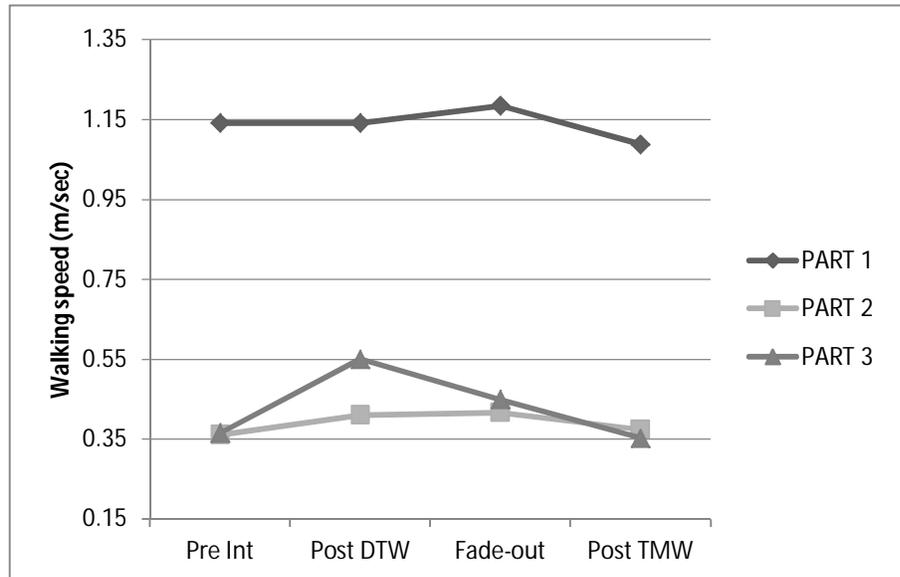
Participant 1 showed almost no changes in these two measurements along the different stages of the study. Participants 2 and 3 showed improvements in both measurements after the DTW intervention, and maintained those improvements almost until the final assessment session.

DISCUSSION

This study showed the potential of using a low-cost VR system to apply dual-task performance conditions during walking. Two participants demonstrated improvements in each of the outcome measures that were measured after the DTW, but no improvements after the TMW.

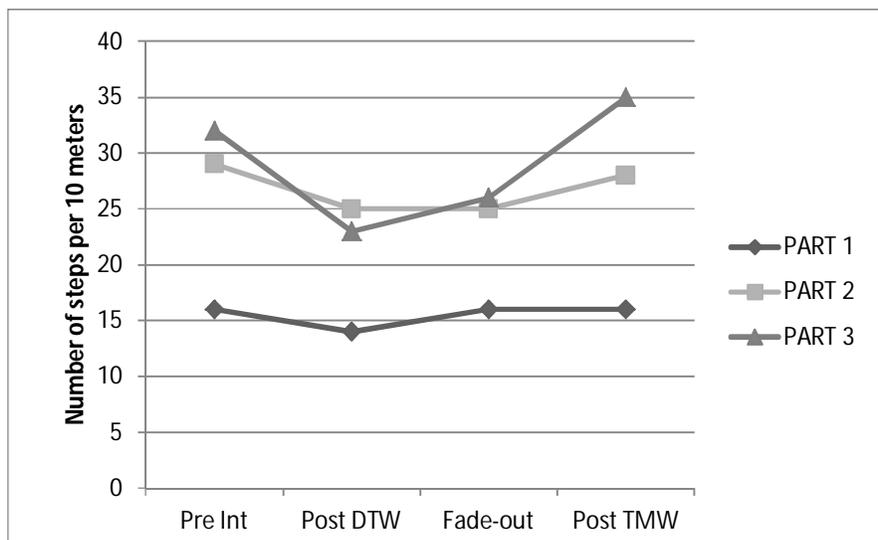
The most important variable that showed improvement was walking speed [2]. Walking speed of participant 2 improved from 0.36 to 0.42 m/s, and that of participant 3 improved from 0.37 to 0.55 m/s (a 49% increase), after the eight sessions of DTW. In addition, it was found for these two participants that the number of steps per 10 m walking

Figure 1. 10-meter walking speed along four assessments



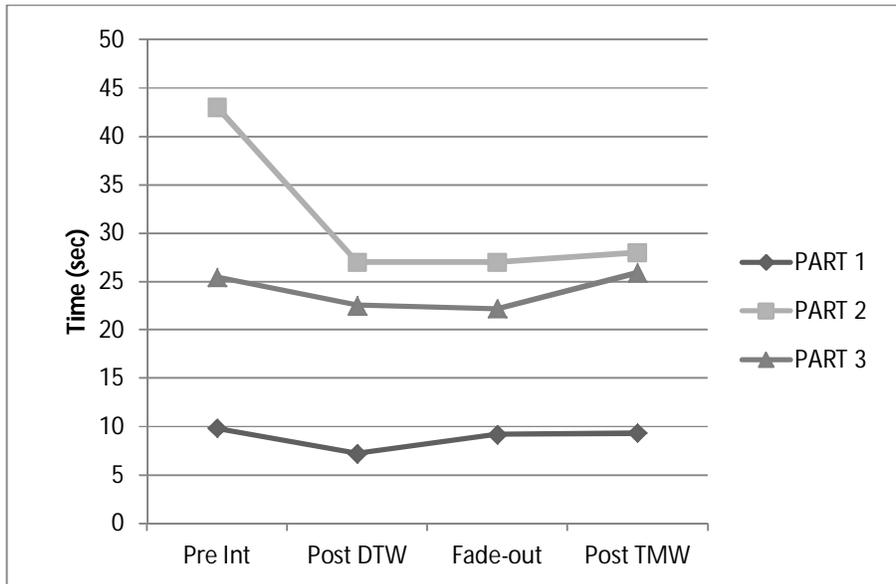
Pre Int – Pre-intervention test, Post DTW - Post- Dual-task walking intervention test, Fade-out - Fade-out test, Post TMW - Post single-task treadmill walking intervention test
Participant 1 completed the first intervention under the TMW condition and participant 2 and 3 under the DTW condition

Figure 2. 10-meter walking number of steps along four assessments



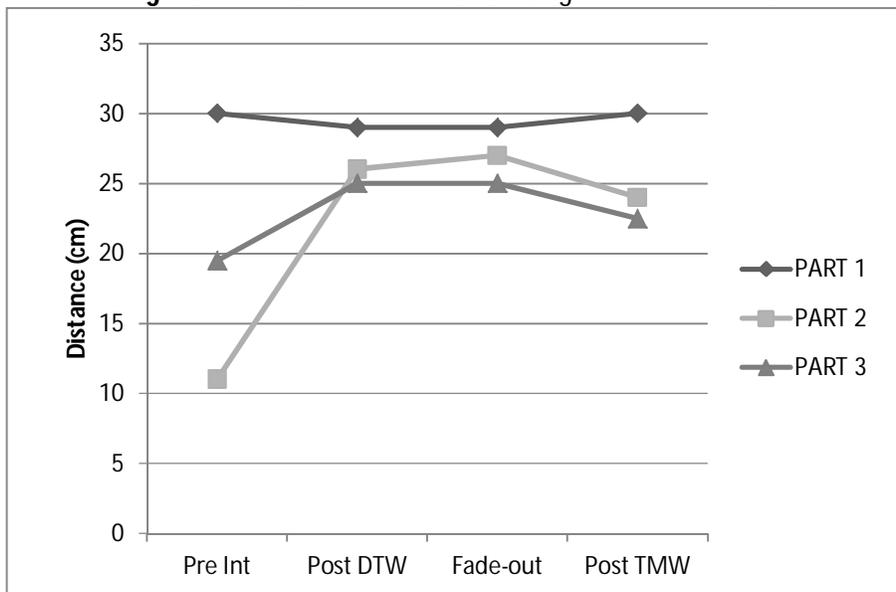
Pre Int – Pre-intervention test, Post DTW - Post- Dual-task walking intervention test, Fade-out - Fade-out test, Post TMW - Post single-task treadmill walking intervention test
Participant 1 completed the first intervention under the TMW condition and participant 2 and 3 under the DTW condition

Figure 3. Timed up and go along four assessments



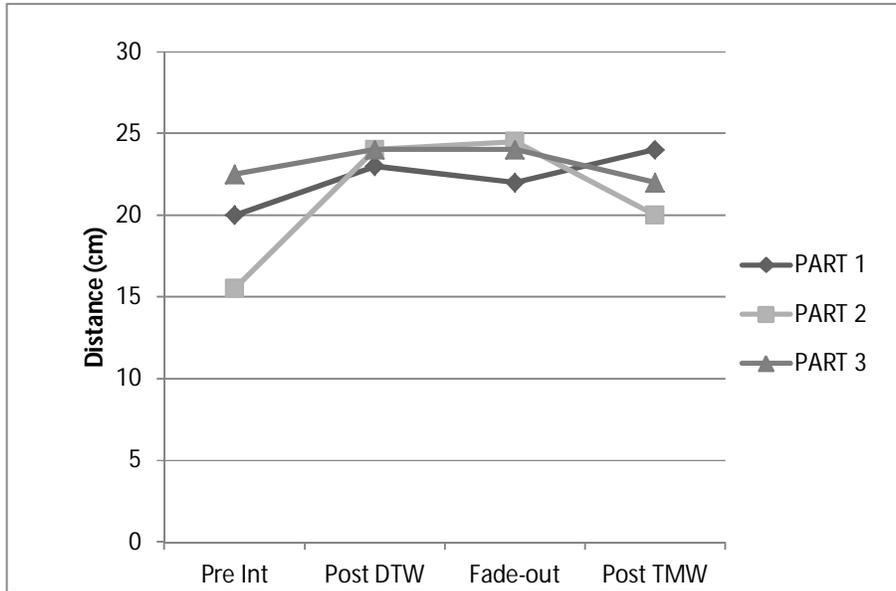
Pre Int – Pre-intervention test, Post DTW - Post- Dual-task walking intervention test, Fade-out - Fade-out test, Post TMW - Post single-task treadmill walking intervention test
 Participant 1 completed the first intervention under the TMW condition and participant 2 and 3 under the DTW condition

Figure 4. Functional Reach test along four assessments



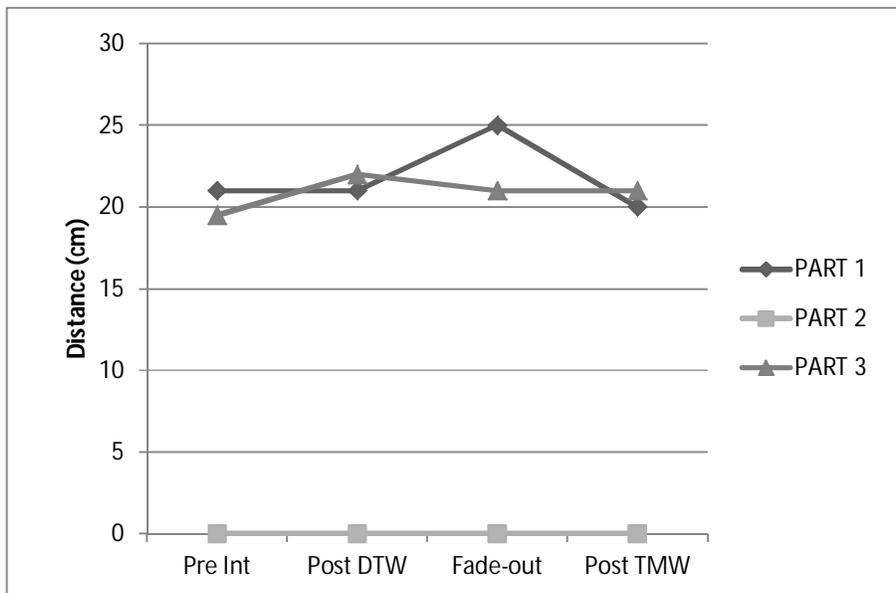
Pre Int – Pre-intervention test, Post DTW - Post- Dual-task walking intervention test, Fade-out - Fade-out test, Post TMW - Post single-task treadmill walking intervention test
 Participant 1 completed the first intervention under the TMW condition and participant 2 and 3 under the DTW condition

Figure 5. Lateral Reach test (right) along four assessments



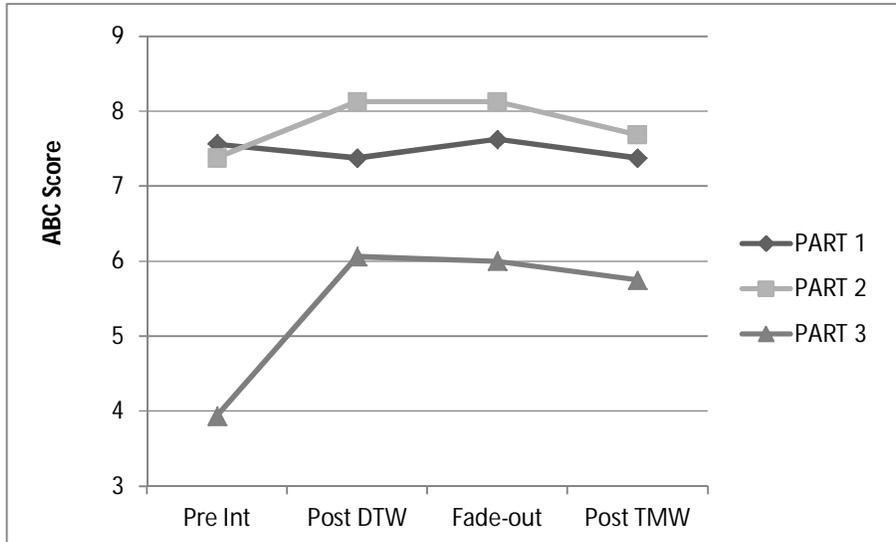
Pre Int – Pre-intervention test, Post DTW - Post- Dual-task walking intervention test, Fade-out - Fade-out test, Post TMW - Post single-task treadmill walking intervention test
 Participant 1 completed the first intervention under the TMW condition and participant 2 and 3 under the DTW condition

Figure 6. Lateral Reach test (left) along four assessments



Pre Int – Pre-intervention test, Post DTW - Post- Dual-task walking intervention test, Fade-out - Fade-out test, Post TMW - Post single-task treadmill walking intervention test
 Participant 1 completed the first intervention under the TMW condition and participant 2 and 3 under the DTW condition

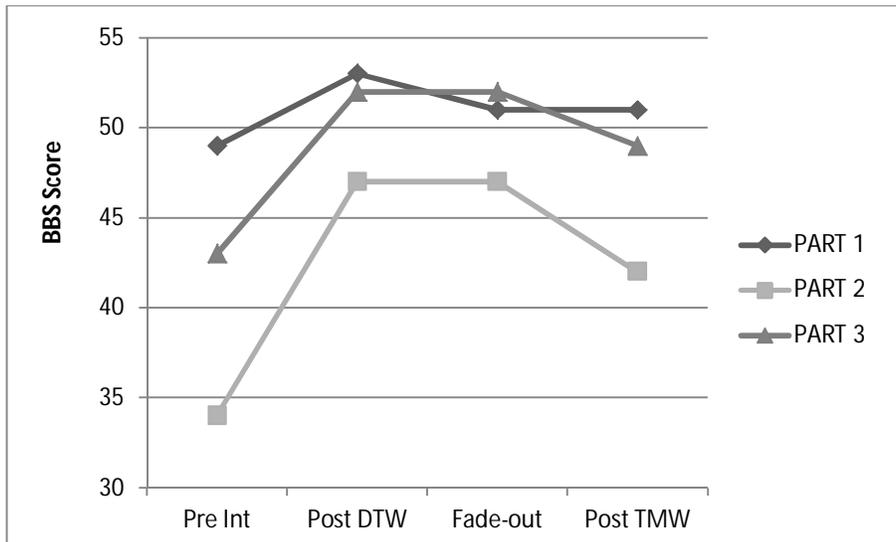
Figure 7. ABC Scale along four assessments



Pre Int – Pre-intervention test, Post DTW - Post- Dual-task walking intervention test, Fade-out - Fade-out test, Post TMW - Post single-task treadmill walking intervention test

Participant 1 completed the first intervention under the TMW condition and participant 2 and 3 under the DTW condition

Figure 8. BBS along four assessments



Pre Int – Pre-intervention test, Post DTW - Post- Dual-task walking intervention test, Fade-out - Fade-out test, Post TMW - Post single-task treadmill walking intervention test

Participant 1 completed the first intervention under the TMW condition and participant 2 and 3 under the DTW condition

decreased after the DTW intervention, implying an increased stride length.

An improvement in gait speed of PPS was found previously using different intervention programs. Combs et al. [30] found improvement in walking speed after 24 sessions of body-weight supported treadmill training. Krishnan et al. [31] found locomotor improvements after 12 sessions of active robotic training. Yang et al. [32] found improvement in walking speed as well as in gait performance after 12 sessions of (non-VR) dual-task training, and suggested that the improvement in gait performance under dual-task conditions may imply improved community ambulation function. The suggestion that in order to ambulate in the community one needs the ability to integrate walking with other tasks, was also mentioned previously [2].

In the current study, the DTW intervention was designed to improve community ambulation, and therefore we integrated walking with upper extremity skills. This integration may be compared to street walking while holding bags or while talking on the phone. The DTW intervention included a significant distractor from the main task that was based on a tracking and reaching task of the upper extremities, and thereby achieved the necessary additional load on the neuromuscular system required for obtaining a training effect.

The use of VR while training a dual-task was studied by Yang and colleagues (2008), who found improvement in walking speed and in community walking time [3]. One mechanism explaining such an improvement may be that while using a dual-task training modality, the participant is engaged in anticipatory control for the VR task, and therefore increases his or her reactive control for the walking task [33].

Another explanation for the improvements found in the current study may be related to the task-oriented program that was used in the VR intervention, as was found previously [32]. The fact that the participants had to react to the changing scenes during DTW,

and to achieve different goals while walking, led them integrate motor tasks in a complex surrounding. It was found by neuroimaging tools that VR intervention can induce cortical reorganization of the neural locomotor pathways [17]. However, the mechanisms induced by VR intervention need to be determined in further studies.

While the improvement in walking speed is considered highly important in the rehabilitation process of stroke survivors [2], it is important to note that this improvement should be transferred to activities of daily living, such as community ambulation and participation in community life. Outcomes in these domains were not directly measured in the current study. However, the improvement in the TUG, the BBS, the FRT, and the LRT scores, may indicate better balance in a variety of mobility tasks that are presented in community life [27, 34].

In addition, the ABC scale [28], a self-efficacy instrument providing the degree of confidence in mobility tasks necessary for community ambulation, was measured. Both participants 2 and 3 demonstrated an increase in their scores on that scale after the DTW intervention. The fact that their stride length was also increased, may also indicate higher confidence in mobility, based on the participants' feeling that they were more stable on each leg.

The fact that participant 1 showed almost no changes in the measurements, besides those of the TUG and the BBS, may be attributed to his higher baseline mobility level. His walking speed, stability measurements, and the ABC confidence scores at the pre-intervention test were considerably higher than those of participants 2 and 3. In accordance with the law of diminishing returns [35], it was expected that the higher the functional status at pre-intervention test, the lower the improvement after the intervention, and *vice versa* [36]. In this respect the results of the

current study are encouraging, in particular given that there were only eight training sessions.

CONCLUSION

This study was designed to address the feasibility of adding VR intervention to treadmill walking, thus it had a small sample size. The improvements that were observed in the study demonstrate the potential benefit of DTW using VR while treadmill walking on gait and balance performances of stroke survivors. A larger randomized controlled clinical trial is needed to confirm and expand the benefits of the DTW intervention.

Conflict of interest

The authors declare having no conflicts of interest. The work was not funded.

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