



Original Article

Immediate effect of video viewing with an illusion of walking at a faster speed using virtual reality on actual walking of stroke patients

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Abstract. [Purpose] The objective of this study was to provide cerebral stroke patients with virtual reality videos of gait occurring at a faster speed than their actual measured gait speed and ascertain the effect on generating errors of gait. [Participants and Methods] The participants were 12 stroke patients. They were given a 2-minute virtual reality presentation of gait occurring at a speed faster than their actual measured comfortable walking speed. Immediately following the presentation, their 10-m walking speed was measured again to observe the immediate effect of the intervention, after which the time required to walk at maximum gait speed was measured. Stride length, cadence, and walking speed before and after the intervention were compared. In addition, heard an immersive feeling. [Results] At a comfortable walking speed, the cadence improved significantly post-intervention. Walking speed and stride length also tended to increase. At the maximum walking speed, there were no significant differences in any parameter. There was no problem with the immersive feeling. [Conclusion] After watching virtual reality videos of gait at a speed faster than the patients' actual gait speed, their walking speed tended to increase in comfortable walking. It was speculated that this technique could be applied to walking training, depending on the device.

Key words: Stroke, Illusion, Virtual reality

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INTRODUCTION

The use of visual stimulation by virtual reality (VR) presentations in the rehabilitation of cerebral stroke patients is increasing¹⁾. VR presentations offer a range of uses, as patients can move freely within the area covered by infrared beams emitted from four points while manipulating a special controller to engage in training, or simply use them to watch videos. The visual stimulation provided by these videos is believed to allow easier induction of physiological changes, such as kinesthetic illusion induced by visual stimulation^{2, 3)} and optical flow⁴⁾.

A number of studies have reported functional improvements by the addition of VR training using VR presentations focused on the arms or legs to conventional exercise therapy⁵⁾. Other studies have found that parameters, such as balance and gait function, are significantly improved by VR training^{6–8)}. However, although there have been reports that experiencing presentations of walking at the same pace as in real life to heighten the sense of immersion improves gait function, few studies have addressed the appropriate walking speed for virtual experience when using VR presentations in training for sequelae of cerebral stroke.

The objective of this study was therefore to give cerebral stroke patients a VR experience of gait images at a faster speed than their actual measured gait speed and ascertain the effect of generating errors on gait.

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PARTICIPANTS AND METHODS

The participants were 12 patients (age: 63.3 ± 10.0 years) who had their first cerebral stroke and who were being treated in the recovery ward of Hirosaki Stroke and Rehabilitation Center from whom written informed consent had been obtained. Patients who would have difficulty understanding instructions during the experiment, those with serious orthopedic disease or pain in the legs, and those judged unsuitable for any other reason were excluded. The participants were all patients who could walk independently within the ward (including only in some zones), with or without the use of a walking aid, such as a brace or cane, or those who could walk under supervision.

Information on height, weight, age, gender, diagnosis, Functional Independence Measure (FIM) motor score, Mini-Mental State Examination (MMSE) score, Berg Balance Scale (BBS) score, Examination of the trunk and lower limbs Brunnstrom recovery stage (Br.stage), and time since the onset of cerebral stroke was collected from the patients' medical record.

The presentations were given to the participants using a head-mounted display (Tepoinn VR Goggles 3D). The walking video was recorded using a 360° camera (Ricoh Theta) at the following six walking speeds: 30 sec, 25 sec, 20 sec, 15 sec, 10 sec, and 5 sec to cover 10 m.

The participants were given the presentation according to the following procedure. To measure the baseline walking speed, they were asked to complete a 10-m walking test at a comfortable speed, and the parameters, including speed, stride length, and cadence, were measured, or calculated. This measurement was conducted once, and the resulting values were used as the baseline values. Each participant was given a presentation at one level faster than their base time required to walk 10 m. To ensure that the environment was familiar, the presentation was filmed at the same location where the participants performed the walking tests. To actually experience the presentation, they were seated in a chair and fitted with head-mounted goggles, and to make the most of the features of VR, the screening time was 1 minute with the patient facing forward in the direction of the video and 1 minute with the chair rotated at an angle of 90° to the right, making a total of 2 minutes.

After the participants had experienced the presentation, they were again asked to walk 10 m at a comfortable speed and the same parameters were measured. After taking a good rest, they were again given the walking presentation, after which the time required at maximum gait speed was measured.

The choice of presentation to give to the participants was determined in a preliminary study, in which 10 healthy young adults walked 10 m at a comfortable speed three times. The mean time required was 7.21 ± 0.90 sec. The standard deviation of 0.90 sec was taken as the possible error range of the walking speed of the participants over a 10-m course. A presentation one level faster than the baseline speed, as indicated previously, was thus considered to be at least 0.9 sec faster; thus, if the time taken for a participant to walk 10 m in the preliminary experiments was 8.8 sec, one level faster was $8.8 - 0.9 = 7.9$ sec. Given that the next level up from 7.9 sec was 5 sec, the 5-s presentation was given to the participant.

After completing the experiment, all the participants were asked to rate the realism, or "sense of immersion", of the presentation on a Visual Analog Scale (VAS) with scores ranging from 0 to 10, where 10 indicated the closest to the actual physical scenery. They were also asked to rate their sense of discomfort on the same scale from 0 to 10, where 0 indicated no discomfort at all while experiencing the presentation.

The difference between pre-intervention maximum walking speed and comfortable walking speed was calculated and referred to as the walking reserve. Changes in the comfortable and maximum walking speeds after the intervention were also calculated, and their associations were investigated.

A statistical analysis was carried out by first checking the stride length, walking rate, and walking speed for normality and then using either a paired t-test or Wilcoxon-signed rank test depending on the result. To investigate the associations of Br.stage, FIM motor score, BBS score, time since onset, and walking reserve with changes in comfortable walking speed and maximum walking speed, Spearman's rank correlation coefficient was calculated for each parameter. SPSS version 22 J (IBM) was used for the statistical analysis, and $p < 0.05$ was regarded as significant.

This study was approved by the Ethics Committees of Hirosaki Stroke and Rehabilitation Center (approval number: 18A004) and Hirosaki University Graduate School of Health Sciences (reference number: 2019-033). Written informed consent was obtained from the participants.

RESULTS

Table 1 shows the patient's baseline demographic data obtained from their medical records.

Table 2 shows the median values (min-max) of stride length, cadence, and walking speed at a comfortable walking speed pre- and post-interventions. Stride length was 0.46 m (0.35–0.56 m) and 0.51 m (0.38–0.59 m) pre- and post-interventions, respectively, showing a non-significant difference ($p=0.56$). Cadence was 101.0 steps/min (88.3–116.0 steps/min) and 103.7 steps/min (87.5–117.8 steps/min) pre- and post-intervention, which showed a significant increase after the intervention ($p=0.05$). Walking speed was 50.3 m/min (33.9–61.2 m/min) and 53.1 m/min (35.76–5.5 m/min) pre-and post-intervention, showing a non-significant difference ($p=0.15$). However, it tended to increase slightly.

Table 3 shows the median values values (min-max) of stride length, walking rate, and walking speed at maximum walking speed pre- and post-interventions. There were no significant differences in stride length, cadence, and walking speed before

Table 1. Participant characteristics (N=12)

Age (years)	63.3 ± 10.0
Gender	male (6/12)
Height (cm)	158.3 ± 8.6
Damaged hemisphere	Right 7 left 5
Brunnstrom stage	III 1, IV 4, V 3, VI 4
FIM-Motor	78 (75–87.2)
MMSE	28 (22–30)
BBS	51.5 (48–56)
Period from onset (days)	111.5 ± 40.9

Brunnstrom stage: Brunnstrom Recovery Stage-lower extremity; FIM-Motor: Functional Independence Measure-Motor point; MMSE: Mini-Mental State Examination; BBS: Berg Balance Scale.

Table 2. Results after VR intervention in comfortable walking conditions

	Pre intervention	Post intervention
Step length (m)	0.46 (0.35–0.56)	0.51 (0.38–0.59)
Cadence (steps/min)	101.0 (88.3–116.0)	103.7 (87.5–117.8)*
Walking speed (m/min)	50.3 (33.9–61.2)	53.1 (35.7–65.5)

*p<0.05.

Table 3. Results after VR intervention in maximum walking conditions

	Pre intervention	Post intervention
Step length (m)	0.54 (0.37–0.67)	0.56 (0.37–0.67)
Cadence (steps/min)	109.5 (98.4–144.0)	111.1 (98.7–150.7)
Walking speed (m/min)	59.1 (42.3–99.1)	61.0 (43.2–103.1)

*p<0.05.

and after the interventions.

The participants' mean score for the realism of the VR presentation on the questionnaire was 7.4 ± 1.2 , and that for strangeness was 1.7 ± 2.6 . Both scores were comparatively good. No participant developed VR sickness from the VR experience. The frequent comments included "It was similar to the scenery I usually walk through", "It didn't feel strange to watch", and "The scenery was presented without lag".

The changes in walking speed and walking reserves were calculated from the results of the 10-m walk at comfortable and maximum walking speeds. At a comfortable walking speed, the change in walking speed was 2.1 m/min (-2.1 – 3.8 m/min). At maximum walking speed, the change in walking speed was 0.9 m/min (-0.2 – 3.7 m/min). The pre-intervention walking reserve, calculated as the difference between the maximum walking speed and comfortable walking speed, was 8.1 m/min (1.7 – 27.6 m/min).

The correlations between the change in comfortable walking speed and Br.stage, FIM motor items, BBS score, time since onset, and walking reserve. Although no significant association was evident at the comfortable walking speed, there were moderately positive correlations found between the change in walking speed and Br.stage, BBS, and walking reserve.

At the maximum walking speed, a significant moderately positive correlation was found between walking reserve and change in walking speed ($p < 0.05$).

DISCUSSION

We gave cerebral stroke patients a VR experience of walking at a higher speed than their own speed and investigated their comfortable and maximum walking speeds. At a comfortable walking speed, both walking rate and walking speed tended to increase after the intervention, and cadence increased significantly. In terms of the changes in gait after the intervention, experiencing the VR presentation brings about physiological changes in the cerebrum, which causes optical flow⁴⁾ and kinesthetic illusion induced by visual stimulation^{2, 3, 9)}. Given that the optic pathway is bilaterally symmetrical within the cerebrum, there may only be a little difference in the optic pathway depending on which hemisphere is damaged. All the

participants in this study had experienced their first stroke, and, given that none had bilateral damage, it was suggested that the optic pathway was activated via the undamaged side. In this experiment, there was no difference in the magnitude of the change in walking speed or walking rate at both the comfortable and maximum walking speeds, regardless of the damaged hemisphere.

Optical flow refers to the movement pattern generated on the retinal surface by moving through space, and provides important visual clues about the directionality of self-motion. The accurate perception of optical flow enables the perception of the temporospatial relationship between self and the external environment¹⁰. Kinesthetic illusion induced by visual stimulation is an illusory phenomenon, whereby a person feels as if he is moving even if his body is not moving either voluntarily or passively⁹. Accordingly, when experiencing a VR presentation, specific areas in the parietal lobe region and the vestibular area are activated symmetrically on both sides.

During the induction of kinesthetic illusion generated by visual stimulation, the excitability of the corticospinal tract increases, and the neural circuits of the premotor cortex, supplementary motor area, inferior parietal lobule, corpus striatum, insula, and occipito-temporal cortex are activated⁹.

The illusion of walking faster than one's own pace induced in this study tended to increase walking speed immediately afterwards, and slightly increased the walking rate. Previous studies have shown that, in specific situations that do not normally occur in everyday life, such as walking backwards or on a treadmill, stride length shortens and walking rate increases so that the double support phase becomes longer, and this is considered to be a strategy for guaranteeing safety. Similarly, walking speed is adjusted by increasing or decreasing the cadence¹¹. The significant increase in walking rate seen in this study was believed to be due to the activation of the supplementary motor area and premotor cortex by watching the VR presentation being immediately reflected in gait, as explained above. Increasing the video speed of the VR presentations has been shown to contribute to the autonomic nervous system, such as increasing the heart rate¹², and as it is well known that autonomic nerves are closely connected to the neural mechanisms of gait, we conjectured that the speeded-up presentation was linked to some sort of trigger. The questionnaire results also indicated that the presentation was realistic, suggesting that the excitation of the cerebral cortex was evoked in a way that is similar to those of previous studies.

Given that the maximum walking speed reflects the participants' maximum performance, eliciting an even better performance is particularly difficult in cerebral stroke patients. However, our results suggest that, even in these patients, a short 2-minute intervention using a VR presentation can have an effect that causes an immediate change in gait dynamics.

Both at comfortable and maximum walking speeds, the better the walking reserve, the faster the patients were able to walk. This "reserve" is the difference between the function exerted under normal circumstances and the maximum function exerted when a greater-than-normal function is required. People with a higher walking reserve were able to respond to the illusion generated by the stimuli in the VR presentation on their actual gait, enabling them to adjust their walking speed. These findings indicate that the assessment of hemiplegia function and balance ability or walking capacity is required in the participants of this study or in cerebral stroke patients undergoing an intervention. Given that individuals with a certain level of function can immediately change their performance, they may be more likely to respond to the intervention.

In terms of study limitations and prospects, increasing the excitability of the optic pathway mentioned in previously is an inference that comes to mind from various previous studies, and, because head-mounted goggles were used in this study, we did not conduct near-infrared spectroscopy or functional magnetic resonance imaging. The excitation of brain activity is thus purely hypothetical. In terms of the intervention period, many previous studies had a long-term observation period, and the immediate effect investigated in this study may be a somewhat disadvantageous condition. However, given that a change in gait, which was believed to be an immediate effect, was observed, reconsidering the conditions and other factors, and carrying out further studies to confirm this immediate effect may be meaningful in terms of future clinical use.

In addition, the small number of samples was one of the reasons why it was difficult to make a significant difference.

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Conflict of interest

There are no conflicts of interest to disclose.

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