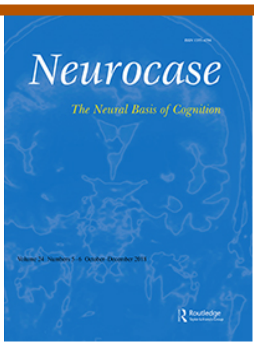

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Effect of kinesthetic illusion induced by visual stimulation on ankle dorsiflexion dysfunction in a stroke patient: ABAB single-case design

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ABSTRACT
The purpose of this study was to investigate the effect of simultaneous intervention with the kinesthetic illusion induced by visual stimulation (KiNvis) and voluntary exercise on ankle dorsiflexion dysfunction in a patient with right-sided stroke hemiparesis. Within an ABAB single-case design, we conducted two phases each lasting five days. Phase A represented the baseline during which only voluntary ankle dorsiflexion (VAD) was performed. Phase B involved simultaneous performance of VAD and KiNvis. We measured the angle of ankle joint dorsiflexion (AJD), and the 10 m maximum walking speed (10MWS). AJD and 10MWS were significantly improved in phase B.

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Kinesthetic illusion induced by visual stimulation; ankle dorsiflexion dysfunction; ABAB single case design; hemiparesis

Introduction

The kinesthetic illusion induced by visual stimulation (KiNvis) is a subjective experience in which there is no actual movement of the body but an individual experiences an illusion of body movement produced by viewing imagery of the subjective experience (Kaneko, Yasojima, & Kizuka, 2007). Previous research in healthy individuals has been conducted to determine whether KiNvis of the fingers occurs, and whether changes in corticomotor excitability are observed following KiNvis. Such studies have reported increased kinesthetic illusions consequent to KiNvis of the hand and increased excitability of corticomotor pathways (Kaneko et al., 2007). Moreover, there have been reports of activity in regions such as the premotor cortex and the inferior parietal lobe measured with functional magnetic resonance imaging (fMRI) during KiNvis of dorsiflexion and palmar flexion of the wrist joint (Kaneko et al., 2015). Furthermore, the kinesthetic illusion has even been observed to occur in the lower limbs with increased corticomotor excitability during KiNvis of dorsiflexion of the ankle or plantar flexion, similar to that observed in the upper limbs (Aoyama, Kaneko, Hayami, & Shibata, 2012).

Reports have confirmed improvement in the range of joint motion and muscle activity resulting from KiNvis of the upper limb, specifically elbow flexion and extension in a patient with stroke hemiparesis (Kaneko, Inada, Matsuda, Shibata, & Koyama, 2016). Meanwhile, our study of patients with stroke hemiparesis who had dysfunction of ankle dorsiflexion confirmed that KiNvis led to improvement in the automatic range of ankle dorsiflexion, as well as improved maximum walking speed (Sakai, Ikeda, Yamanaka, & Noguchi, 2018). These results suggest that the kinesthetic illusion induced by viewing a video can improve motor function.

Although previous studies have demonstrated various effects associated with the performance of KiNvis, the addition of voluntary movement may lead to the effect of ankle joint functions. Gandevia, Smith, Crawford, Proske, and Taylor (2006) investigated the relationship between visual illusion and voluntary movement, and reported that the illusory angle increases with the performance of voluntary movement. This may lead to greater gains in motor function compared with KiNvis alone. Therefore, we sought to examine the effect of simultaneous performance of KiNvis and voluntary ankle dorsiflexion on ankle dorsiflexion dysfunction, and whether the kinesthetic illusion occurred in patients with stroke hemiparesis by using an ABAB single-case design.

Methods

Participant

We recruited a 40-year-old woman diagnosed with left putaminal hemorrhage with right-sided hemiparesis. The patient had a mild sensory disorder with Brunnstrom Recovery Stage (BRS) IV motor paralysis of the lower limbs. The automatic angle of ankle joint dorsiflexion on the hemiparetic side was six degrees. The angle of voluntary ankle dorsiflexion on the non-paralyzed side was 20 degrees, and not restricted. Good function of the lower limb and trunk muscles was observed on the non-hemiparetic side, with a manual muscle test score of 5. The patient's basic movement was assisted by an ankle-foot orthosis and walking was accomplished with the assistance of a T handle cane (Table 1). The purpose of the study was explained to the participant, and written consent was obtained in compliance with the Helsinki Declaration. The study was conducted with the approval of the ethics committee of Hatsudai Rehabilitation Hospital (approval number: H28-62).

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Table 1. Basic attributes.

Variable	N = 1
Age(years)	40
Sex	Female
Type of injury	Hemorrhagic
Region	Putamen
Paretic side	Right
Time since stroke(day)	83
Ankle joint dorsiflexion of paretic side(°)	6
Ankle joint dorsiflexion of non paretic side(°)	20
Lower brunnstrom recovery stage	IV

Study design

In the ABAB single-case design, during phase A (the baseline stage) conventional physiotherapy such as voluntary ankle dorsiflexion was performed. During phase B the same physiotherapy program from phase A was conducted, in addition to a guided 5 min application of KiNvis. Each phase (A1, B1, A2, and B2) was conducted over a period of 5 days, with a total of 20 days for the entire procedure. In phase A, five sets of dorsiflexion movements of the ankle were performed, with each set consisting of 10 repetitions. Voluntary ankle dorsiflexion was performed at a rate of 1 movement per second. Standing, step, and walking exercises were also performed for 60 min daily. In phase B, KiNvis was performed following an explanation of the procedure and confirmation that the participant experienced an illusion of movement of the ankle while viewing the video.

The video used during KiNvis featured ankle dorsiflexion of the patient's non-hemiparetic side, filmed prior to the experiment with a tablet equipped with a camera (iPad pro, Apple). During filming, the patient was seated allowing a first-person perspective. Participants were asked to perform ankle dorsiflexion on the non-paralyzed side at the maximum voluntary dorsiflexion. The video was then transposed, rotated, and flipped horizontally with video reversal software to enable the video to be viewed as ankle dorsiflexion on the patient's hemiparetic side (Figure 1).

During KiNvis, the patient was seated in a chair with her feet covered with a cloth so they could not be seen. The paralyzed leg was positioned so that the ankle joint overlapped with the image of the ankle joint of the non-paralyzed leg shown on the video. To elicit the kinesthetic illusion, we directed the participant to "imagine moving the foot captured on the video as if moving the foot itself and, if possible, move the foot". KiNvis was conducted for 5-min.

Measures

We recorded scores on a visual analog scale (VAS), the angle of voluntary dorsiflexion of the ankle joint, and the 10 m maximum walking speed. VAS scores were used as an index of the level of kinesthetic illusion of movement that occurred during the KiNvis intervention. The participant was asked to point to the position on a 100 mm line that represented the level of illusory movement (0 mm: I do not feel any illusion–100 mm: I experienced a kinesthetic illusion and my leg felt like it was moving).

A goniometer was used to measure the angle of voluntary dorsiflexion of the ankle with the patient seated in a 40 cm chair, with 90-degree knee flexion and a flexion-dorsiflexion angle of 0 degree at the ankle joint. We used the angle formed by a straight line passing through the head of the fibula and the lateral malleolus, and the line passing through the head and bottom of the fifth metatarsal as the point of reference.

We assessed the 10 m maximum walking speed (10MWS) by measuring the maximum speed achieved walking a straight path across a distance of 10 m, measuring the time taken with a stopwatch. Finally, we decided not to use the wand and brace during measurement.

We used the two standard-deviation band method (2SD) for data analysis. We calculated averages and standard deviations from phase A values. Subsequently, the average interval between the upper and lower two standard deviations was calculated and a line was drawn horizontally between them. When phase B values exceeded 2 consecutive standard deviations twice, this was determined as being at a significance level above 0.05 (Ottenbacher & York, 1984).

Results

The kinesthetic illusion during phases B1 and B2 was reflected by an average VAS of 97.9 ± 2.2 mm. Based on self-examination, the participant reported that "I felt that my foot was raised to the same angle as that in the video". Moreover, a significant improvement in the angle of voluntary ankle dorsiflexion was observed in phases B1 and B2 compared with phases A1 and A2. This was reflected in the average values for each phase: A1, 9.2 ± 1.6 degrees; B1, 14.6 ± 3.2 degrees; A2, 9.8 ± 1.4 degrees; and B2, 14.0 ± 2.4 degrees ($P < 0.05$) (Table 2, Figure 2).

We also observed a significant improvement in 10MWS in phase B1 compared with phase A1 ($P < 0.05$) (Table 2, Figure 3). The average values were: A1, 62.4 ± 2.9 m/min; B1, 68.6 ± 1.4 m/min; A2, 67.9 ± 1.1 m/min; and B2, 69.1 ± 1.9 m/min. However, no significant improvement was observed in phase B2 compared with phase A2 ($P > 0.05$) (Table 2, Figure 3).

Discussions

In this study, we implemented voluntary ankle dorsiflexion and KiNvis in a patient with stroke hemiparesis to investigate the effect of the kinesthetic illusion on ankle dorsiflexion function. We observed a significant improvement in 10MWS and voluntary ankle dorsiflexion consequent to simultaneous KiNvis and ankle dorsiflexion, which indicates that the patient experienced a high-intensity kinesthetic illusion.

In a previous study of stroke patients, the average intensity of the kinesthetic illusion during ankle dorsiflexion was 68.8 ± 20.6 mm as measured with a VAS (Sakai et al., 2018). In the current study, the average VAS of 97.9 ± 2.2 mm was higher than that of previous studies. However, previous studies of KiNvis have not included simultaneous voluntary movement of the body during the kinesthetic illusion (Kaneko et al., 2016). We suggest that without performance of simultaneous voluntary movement and the kinesthetic illusion, somatosensory feedback information may not be transferred. Therefore, it is assumed that there is a mismatch between information predicting voluntary movement and information from somatosensory feedback.

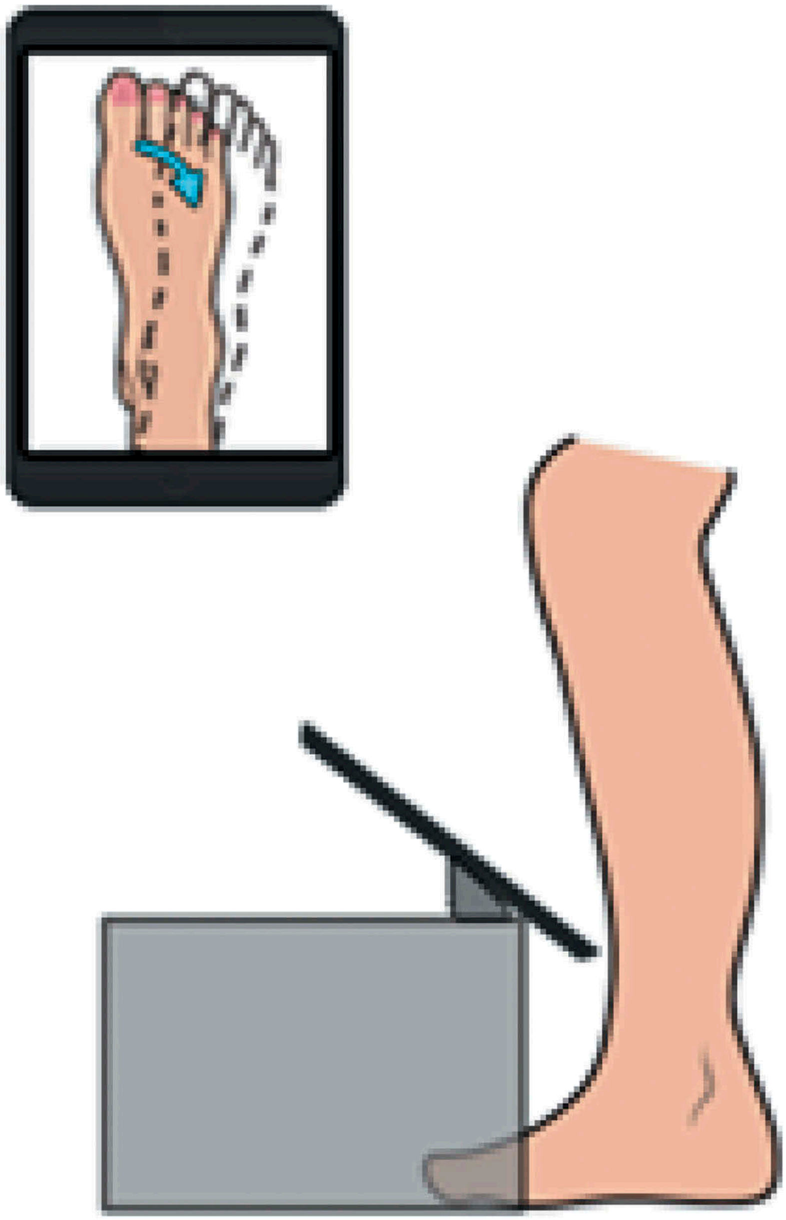

Figure 1. Set of KiNvis.

Table 2. Change of outcomes.

	A1	B1	A2	B2
Ankle joint dorsiflexion(°)	9.2 ± 1.6	14.6 ± 3.2	9.8 ± 1.4	14.0 ± 2.4
10MWS(m/min)	62.4 ± 2.9	68.6 ± 1.4	67.9 ± 1.1	69.1 ± 1.9

Average ± standard deviation
10MWS: 10m maximum walking speed

Previous studies showing reduced corticomotor excitability (Weiss, Tsakiris, Haggard, & Schütz-Bosbach, 2014) and body weight perception (Osumi et al., 2017) suggest that consistency between prediction and feedback information is necessary. We requested that the patient perform voluntary dorsiflexion of the ankle while undergoing the kinesthetic illusion. Therefore, we assume that the high intensity of the experienced kinesthetic illusion was due to the addition of somatosensory feedback information to top-down consciousness alongside visual feedback from the video.

We observed a significant improvement in the angle of voluntary ankle dorsiflexion in phase B, which included KiNvis, compared with phase A, which did not include KiNvis. We hypothesize that improved ability to adjust muscle output was due to congruence between the intention to move, visual information obtained from the video, and somatosensory feedback information. Blanchaed et al. (2013) reported that when there are congruent inputs from different sensations during a visually induced illusion, the illusion is more strongly induced by vision. By observing the image of maximum ankle dorsiflexion on the non-paralyzed side, the illusion is guided by sight and it seems as if the ankle is at maximum dorsiflexion. In addition, as described by Gandevia et al. (2006), it is possible that the level of effort of voluntary movements strongly affects the angle perceived during the illusion. We also surmise that predictive information about the potential movement was modified or supplemented, based on the

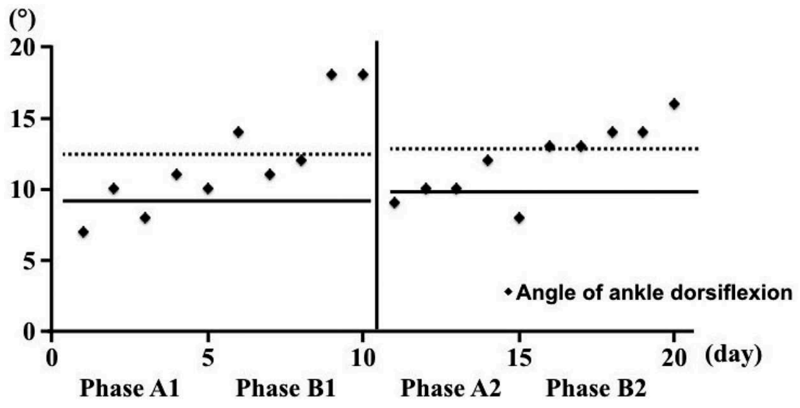

Figure 2. Result of angle of voluntary ankle dorsiflexion.

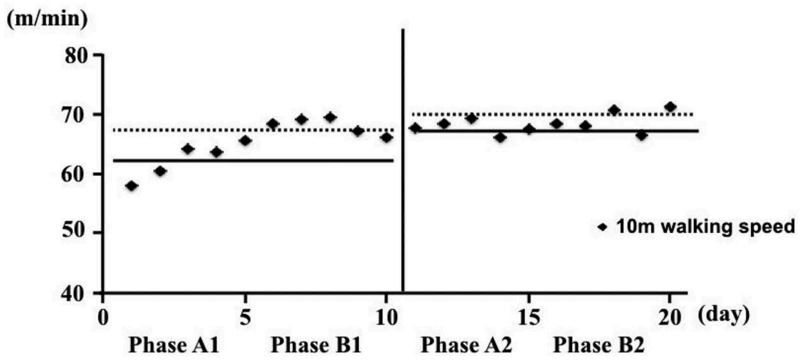

Figure 3. Result of 10 m walking speed.

confirmation of similar brain activity induced by the kinesthetic illusion and images of movement (Naito et al., 2002).

We also observed a significant improvement in the 10MWS during phase B1 compared with phase A1. Previous studies have identified ankle dorsiflexion muscle strength as the biggest contributor to walking speed (Dorsch at al., 2012). Thus, we believe the improved walking speed observed in this study is a consequence of improvements in ankle dorsiflexion function resulting from the intervention. Nevertheless, despite the decreased voluntary angle of dorsiflexion in phase A2, walking speed was similar to that of phase B2. It is possible that this represents a sustained effect of improvements in angle dorsiflexion and walking speed in phase B1. However, this requires clarification in future research.

Mirror therapy (MT) is similar to the method used in the current study. A kinesthetic illusion can be obtained by a reflection of movement of the non-hemiparetic limb onto the hemiparetic limb using a mirror. This study, therefore, is similar to MT because voluntary movement of the hemiparetic limb was required while the KiNvis video was viewed. MT has also been reported to improve BRS scores and ankle dorsiflexion angle in patients with stroke hemiparesis (Sütbeyaz, Yavuzer, Sezer, & Koseoglu, 2007; Wada et al., 2011). However, the difference between MT and the current method is whether the voluntary movement is required of the non-hemiparetic limb or hemiparetic limb. Stroke leads to abnormal inter-hemispheric interactions (Volz et al., 2015). It has been reported that inter-hemispheric interactions develop via overactivation of the upper limb on one side in healthy participants (Avenzino et al., 2011). From this point of view, it is necessary to consider the activity of the non-paralyzed side. Hemispheric imbalance can be selectively improved by raising excitability of the damaged hemisphere (Grefkes & Fink, 2014; Grefkes et al., 2010). Moreover, inter-hemispheric interactions are thought to be involved in recovery from paralysis after a stroke (Auriat, Neva, Peters, Ferris, & Boyd, 2015). KiNvis may, therefore, facilitate recovery as it can selectively induce brain activity of the opposite hemisphere by inducing an illusion (Kaneko et al., 2015).

This study is limited by the inclusion of only a single case. Furthermore, in addition to subjective evaluation, objective evaluations of the occurrence of the kinesthetic illusion would be useful, as assessed with motor evoked potentials and fMRI. Moreover, it is necessary to clarify the neurophysiological mechanisms underlying the intervention and its effects. We aim to investigate the clinical application of the current intervention to restore motor paralysis. Therefore, in future research, we will increase the number of cases and assess objective evaluations of the kinesthetic illusion.

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Disclosure statement

No potential conflict of interest was reported by the authors.

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