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SPTS

Case Study

Effects of kinesthetic illusion induced by visual stimulation on the ankle joint for sit-to-stand in a hemiparesis stroke patient: ABA′ single-case design

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Abstract. [Purpose] The purpose of this study was to investigate the effect of kinesthetic illusion induced by visual stimulation to the paralyzed side ankle joint on the sit-to-stand of a hemiparesis stroke patient. [Participant and Methods] A 33-year-old male with left hemiparesis due to a right putamen hemorrhage participated. This study used the ABA' single-case design. Phase A and A' conducted only conventional physiotherapy. Phase B conducted kinesthetic illusion induced by visual stimulation and conventional physiotherapy. To create a kinesthetic illusion, a video image of the patient's ankle joint dorsiflexion movement on the non-paralyzed side was inverted and placed on the patient's paralyzed ankle. The patient observed this display for 5 min. We evaluated weight-bearing symmetry values during sit-to-stand, duration of sit-to-stand, trunk and ankle joint movement on the paralyzed side during sit-to-stand, active ankle dorsiflexion angle on the paralyzed side, and the composite spasticity score. [Results] The weight-bearing symmetry values, movement of the ankle dorsiflexion during sit-to-stand, active ankle dorsiflexion angle, and composite spasticity score were significantly improved in phase B as compared with phase A and the effect was sustained in phase A'. [Conclusion] Kinesthetic illusion induced by visual stimulation for a hemiparesis stroke patient affected the ankle dorsiflexion function, resulting in an improved asymmetry during sit-to-stand as assessed by weight-bearing symmetry values.

Key words: Visual-motor illusion, Sit-to-stand, Ankle dorsiflexion function

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INTRODUCTION

The Sit-to-stand (STS) is a frequent motion in daily life. A decrease in the STS ability is one of the major problems that impede activities of daily living in hemiparesis stroke patients (hemiparesis patients)[1]. The STS is divided into four periods (i.e., flexion momentum period, momentum-transfer period, extension period, stabilization period)[2]. It has been reported that in the STS of healthy participants, center of gravity (COG) is moved forward from flexion momentum period to the momentum-transfer period[3] because the tibialis anterior muscle is activated earliest and the ankle joint is dorsiflexed[4]. However, previous studies on the STS have reported that hemiparesis patients have reduced the tibialis anterior muscle contraction from flexion momentum period to the momentum-transfer[5, 6]. STS in hemiparesis patients has been reported to

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result in faster triceps surae activity than tibialis anterior muscle activity[7]. Therefore, in hemiparesis patients, the ankle dorsiflexion angle is reduced from flexion momentum period to the momentum-transfer period, which prevents the COG from moving forward and increases the STS duration[8]. It has also been reported that STS is asymmetrical in hemiparesis patients due to decreased load on the paralyzed lower limb caused by decreased activity of the tibialis anterior muscle[9]. Therefore, improving ankle dorsiflexion function during STS in hemiparesis patients may improve the smoothness and asymmetry of the flexion momentum and momentum-transfer periods and affect the STS.

Recently, visual stimuli presented in self-movement video images could evoke kinesthetic illusion[10–12]. These studies reported kinesthetic illusion induced by visual stimulation (KiNvis) as a kinesthetic illusion intervention, evoking kinesthetic perception from visual stimulation and promote reciprocal contraction of agonist and antagonist muscles[13]. In a KiNvis, a monitor showing limb movement is placed at the extremity of the participant's limb. When the participant observes the monitor, the self-movement illusion occurs as though the body is moving, even though it is not[12]. The KiNvis research has been conducted on the ankle joint, and improvements in the dorsiflexion angle of the ankle joint on the paralyzed side and walking ability have been reported in hemiparesis patients[14]. This mechanism may be due to the selective activation of the corticospinal tract involved in the tibialis anterior muscle during KiNvis for the ankle joint[11] and the activation of the premotor area[15], which is the brain region of the motor-related region. Therefore, the KiNvis promotes the reciprocal activity of the tibialis anterior and triceps surae muscles during STS, which requires ankle dorsiflexion, and may affect the smoothness and stability from the flexion momentum period to the momentum-transfer period. However, no previous studies whether KiNvis affects STS. Therefore, the purpose of this study was to explore whether the effect of KiNvis on the ankle joint of a patient with hemiparesis improves ankle dorsiflexion function and affects the STS.

PARTICIPANT AND METHODS

The participant was a 33-year-old male patient (height 175 cm, weight 86.3 kg) with left hemiparesis diagnosed with right putamen hemorrhage. The time since stroke was 133 days. The patient had a history of hypertension, and hyperlipidemia. At the beginning of the study, the patient's left lower extremity was in Brunnstrom recovery stage IV, and exhibited mild sensory deficits. The left ankle dorsiflexion range of motion was 20°, the other lower extremity joints were normal. The muscle tone in the left ankle plantar flexor were increased to a modified Ashworth scale score of 2. The right lower extremity muscle strength was normal. The patient's STS ability was at the level of watching. However, the patient had asymmetrical STS due to increased triceps surae muscle tone and decreased load on the paralyzed lower limb during STS. The purpose of the study was explained to the patient, and written consent was obtained in compliance with the Helsinki Declaration. This study was approved by the Kurashiki Rehabilitation Hospital Ethics Committee (approval number 1903).

The ABA' single-case design was used in this study. In phase A, conventional physiotherapy was performed, with as the baseline period (phase A). Conventional physiotherapy was performed for 60 min daily by a physical therapist and involves stretching the triceps surae muscles, active dorsiflexion movements of the paralyzed ankle, STS exercise, balance exercises, and walking exercises. Phase B consisted of the same conventional physical therapy content of phase A, plus a 5-minute KiNvis period. The second part of phase A was the follow-up period (phase A'), and only conventional physiotherapy was held again. Each phase lasted for 5 days[14], and was performed for a total of 15 days (Fig. 1). Evaluations were conducted daily.

The video used in KiNvis filmed the patient's non-paralyzed ankle dorsiflexion using a tablet camera (iPad Pro, Apple; Cupertino, CA, USA) prior to the experiment. After that, the video was inverted by video reversal software, making it

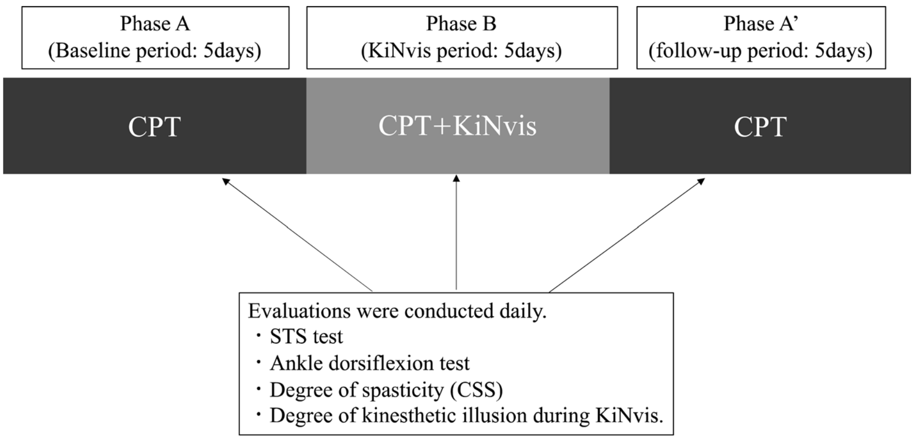

Fig. 1. The protocol of study design. CPT: conventional physical therapy; KiNvis: Kinesthetic illusion induced by visual stimulation; STS: Sit-to-stand; CSS: Composite-Spasticity-Scale.

possible to display it as a dorsiflexion movement of the ankle joint on the paralyzed side. During the KiNvis, the patient was seated and the monitor projected the continuity over the paralyzed ankle joint. Figure 2 shows how to shoot a video and how to intervene in KiNvis as a KiNvis protocol. The patient was instructed to, “As you do not have to actually move while observing the video image, please imagine that you are performing your own ankle movement”.

Evaluations were STS test, ankle dorsiflexion test, the muscle tone of the ankle plantar flexor muscle and the degree of kinesthetic illusion during KiNvis. As STS test, the weight-bearing symmetry values (WBSV), STS duration, the trunk forward inclination angle, trunk forward inclination angular velocity during the STS, ankle dorsiflexion angle on the paralyzed side, and the ankle dorsiflexion angular velocity on the paralyzed side were evaluated. As ankle dorsiflexion test, the active dorsiflexion angle and angular velocity of the paralyzed side of the single joint movement were evaluated. For measures of joint movements, a digital camera was installed on the side of the lower limb on the paralyzed side of the patient. The bone index for motion analysis to assess the acromion process, greater trochanter, lateral epicondyle of the femur, lateral malleolus, and fifth metatarsal head, all with markers attached. A digital camera (EX-FC150, Casio, Tokyo, Japan) was used and the trunk forward inclination angle and ankle dorsiflexion angle were recorded from the sagittal plane. The trunk forward inclination angle was defined as the line connecting the acromion process and the greater trochanter and a vertical line from the floor through the greater trochanter. The ankle joint angle was defined as the line connecting the fibula and the malleolus and the line connecting the malleolus and the fifth metatarsal. The sampling frequency of the digital camera was 120 Hz. The recorded video was analyzed by a two-dimensional (2D) motion analysis system (ToMoCo-Lite, Toso System; Saitama, Japan). The start and end points of the joint motion recorded in the 2D motion analysis system were defined as the average angle of 10 frames without angle change before and after the start of the joint motion, plus two times the standard deviation[16]. The WBSV and STS duration were assessed by dividing the STS into three periods. The period from the start of trunk forward inclination movement to the maximum dorsiflexion angle on the paralyzed ankle joint was defined as Period 1. The period from the maximum dorsiflexion angle on the paralyzed ankle joint to the standing posture was defined as Period 2. The total STS from the start of trunk forward inclination movement to the standing posture was defined as Period 3. In WBSV, the weight-bearing of the lower limb on the paralyzed side and the non-paralyzed side during STS was calculated by using movable force plates (GP-6000 Twin Gravicoder, ANIMA, Tokyo, Japan). The weight-bearing were collected at 100 Hz. The WBSV were expressed as the ratios between the paralyzed lower limb and non-paralyzed lower limb (i.e. paralyzed lower limb weight-bearing value / non-paralyzed lower limb weight-bearing value), with the value of 1 as an indication of perfect symmetry[7]. The STS duration was calculated by calculating the number of frames required during three STS periods using a 2D motion analysis system, and dividing the number of frames by 120, the number of sampling frequency (i.e. the number of frames required during STS period / 120). The muscle tone of the ankle plantar flexor muscle was evaluated by Composite-Spasticity-Scale (CSS). The CSS consists of the degree of Achilles tendon reflex, resistance to full-range passive ankle dorsiflexion, and foot clonus. The score ranges from 0–16 point, with a score of 0–9 point indicating mild spasticity. A score of 10–12 point indicates moderate spasticity, and a score of 13–16 point indicates severe spasticity[17]. The degree of kinesthetic illusion during KiNvis were evaluated by visual analogue scale (VAS)[14]. The patient was asked to point to a position on a 100 mm line that represented the level of illusory movement; 0 mm indicated that the patient did not experience an illusion, while 100 mm indicated that the patient experienced a kinesthetic illusion and felt as though his or her leg was moving.

In measuring ankle dorsiflexion test, the patient sat on a height-adjustable bed so that the feet did not touch the floor. The patient was instructed to dorsiflex the ankle joint maximally. In measuring the STS test, the patient asked to stand up with both arms crossed from adjusted chair, and height of the chair was set to the height of the shank lower leg of a patient[18]. The seated posture of the patient was arranged so that the distance between both feet was 20 cm and the knee joints were flexed

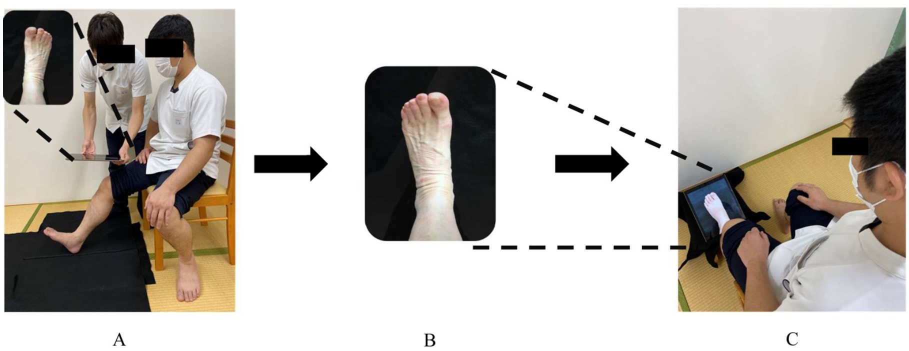

Fig. 2. Kinesthetic illusion induced by visual stimulation (KiNvis) protocol. A: The video image was shot the patient’s non-paralyzed ankle joint dorsiflexion movement by a tablet camera. B: The video image was inverted by a video reversal software, making it possible to display it as a dorsiflexion movement of the ankle joint on the paralyzed side. C: KiNvis. The patient observing the video and induced the kinesthetic illusion. KiNvis time was 5 min. Processes A and B were carried out prior to the experiment.

at 100°. The patient was instructed to look in front of them and to stand up at natural speed[18]. The STS test and the ankle dorsiflexion test were evaluated five times and the average value was used[19].

The two-standard-deviation method (2SD) was used for the data analysis of the evaluation values. This method is used when the number of data points in the baseline phase is small (10 or less) and is useful when the baseline phase data vary[20]. When the value is greater or smaller than the mean ± 2SDs of phase A at 2 or more consecutive points, the difference is regarded as significant ($p<0.05$).

RESULTS

The results of the STS test, ankle dorsiflexion test, and degree of spasticity are shown in Table 1. The WBSVs of periods 1, 2, and 3 were significantly increased in phase B compared to phase A ($p<0.05$) and persisted in phase A' ($p<0.05$). The average values of WBSV in period 1 were: phase A, 0.58 ± 0.02 ratio; phase B, 0.67 ± 0.05 ratio and phase A', 0.60 ± 0.05 ratio. The average values of WBSV in period 2 were: phase A, 0.36 ± 0.07 ratio; phase B, 0.78 ± 0.06 ratio and phase A', 0.62 ± 0.16 ratio. The average values of WBSV in period 3 were: phase A, 0.48 ± 0.04 ratio; phase B, 0.73 ± 0.06 ratio; phase A', 0.62 ± 0.10 ratio.

The trunk forward inclination angle during STS significantly improved in phase B compared to phase A ($p<0.05$) but did not persist in phase A' ($p>0.05$). The average values of the trunk forward inclination angle were as follows: phase A, 25.8 ± 1.6°; phase B, 27.9 ± 1.7° and phase A', 27.7 ± 1.3°.

The ankle dorsiflexion angles on the paralyzed side during STS significantly improved in phase B than in phase A ($p<0.05$) and this improvement persisted in phase A' ($p<0.05$). The average values of the ankle dorsiflexion angles on the paralyzed side during the STS were as follows: phase A, 9.2 ± 0.2°; phase B, 11.4 ° ± 1.2°, and phase A', 9.9 ± 0.9°.

There were no significant improvements in the STS duration, trunk forward inclination angle velocity, and ankle dorsiflexion angle velocity on the paralyzed side during STS ($p>0.05$).

The active dorsiflexion angle and angular velocity of the paralyzed side of the single joint movement significantly improved in phase B compared to that in phase A ($p<0.05$) and persisted in phase A' ($p<0.05$). The average values of the active dorsiflexion angle of the paralyzed side of the single joint movement were as follows: phase A, 11.3 ± 0.9°; phase B, 15.1 ± 1.0° and phase A', 13.5 ± 1.4°. The average values of the active dorsiflexion angular velocity of the paralyzed side of the

Table 1. Results of STS test, ankle dorsiflexion test and degree of spasticity

	Phase A	Phase B	Phase A'
STS test			
WBSV			
Period 1 (ratio)	0.58 ± 0.02	0.67 ± 0.05*	0.60 ± 0.05*
Period 2 (ratio)	0.36 ± 0.07	0.78 ± 0.06*	0.62 ± 0.16*
Period 3 (ratio)	0.48 ± 0.04	0.73 ± 0.06*	0.62 ± 0.10*
STS duration			
Period 1 (sec)	1.3 ± 0.1	1.1 ± 0.2	1.2 ± 0.1
Period 2 (sec)	1.1 ± 0.1	1.1 ± 0.1	1.0 ± 0.2
Period 3 (sec)	2.4 ± 0.2	2.3 ± 0.2	2.3 ± 0.2
Trunk forward inclination angle (°)	25.8 ± 1.6	27.9 ± 1.7*	27.7 ± 1.3
Trunk forward inclination angular velocity (°/sec)	23.4 ± 1.4	27.8 ± 4.9	24.1 ± 3.7
Ankle dorsiflexion angle (°)	9.2 ± 0.2	11.4 ± 1.2*	9.9 ± 0.9*
Ankle dorsiflexion angle velocity (°/sec)	21.4 ± 3.1	25.6 ± 7.2	24.5 ± 3.8
Ankle dorsiflexion test			
Active ankle dorsiflexion angle (°)	11.3 ± 0.9	15.1 ± 1.0*	13.5 ± 1.4*
Ankle dorsiflexion angular velocity (°/sec)	21.8 ± 0.8	27.3 ± 3.5*	24.6 ± 3.4*
Degree of spasticity			
Composite Spasticity Score (point)	11.6 ± 0.5	8.4 ± 0.5*	10.2 ± 1.5*

*The value is outside the 2SD range. The improvement was determined when there were two or more consecutive data in phase B and phase A' (considered separately) that exceeded the 2SD band constructed from the data in phase A. WBSV: weight-bearing symmetry values; STS: sit-to-stand; Period 1: From the start of trunk forward inclination movement to the maximum dorsiflexion angle on the paralyzed ankle joint; Period 2: from the maximum dorsiflexion angle on the paralyzed ankle joint to the standing posture; Period 3: from the start of trunk forward inclination movement to the standing posture; 2SD: 2 standard deviation.

single joint movement were as follows: phase A, 21.8 ± 0.8°; phase B, 27.3 ± 3.5° and phase A', 24.6 ± 3.4°.

The CSS improved significantly in phase B compared to that in phase A ($p<0.05$) and this improvement persisted in phase A' ($p<0.05$). The average values of the CSS were: phase A, 11.6 ± 0.5 point; phase B, 8.4 ± 0.5 point and phase A', 10.2 ± 1.5 point. The degree of kinesthetic illusion in phase B KiNvis averaged 83.6 ± 4.4 mm at VAS.

DISCUSSION

In the STS test, the patient showed an increase in the trunk forward inclination angle, the ankle dorsiflexion angle on the paralyzed side, and improvement the asymmetry, in phase B compared to the phase A. It has been reported that the tibialis anterior muscle is strongly contracts in the period between trunk forward motion and the maximum ankle dorsiflexion angle during STS[21]. In this study, the ankle dorsiflexion test may have improved the dorsiflexion angle and angular velocity of the ankle joint on the paralyzed side and promoted the activation of the tibialis anterior muscle on the paralyzed side. In addition, the muscle tone of the triceps surae muscle improved according to CCS. Therefore, improvement of the ankle dorsiflexion function of the single joint on the paralyzed side may have increased the ankle dorsiflexion angle and trunk forward inclination by improving the activity of the tibialis anterior muscle and triceps surae muscle during STS. Camargos et al.[7] showed that reduced activity of the tibialis anterior muscle in stroke patients resulted in reduced foot stability during STS, making it difficult for the COG to move forward and causing asymmetrical STS. Furthermore, Kusunoki et al.[9] showed that increased muscle tone in the paralyzed side triceps surae muscle during STS decreased the paralyzed side ankle dorsiflexion angle and inhibited paralyzed side weight bearing. Therefore, it is considered that an increase in the dorsiflexion angle of the ankle joint on the paralyzed side during STS enables more weight-bearing on the paralyzed side leg, and that the asymmetry is improved. In this study, the WBSV improved with the increase of the ankle dorsiflexion angle on the paralyzed side during STS, supporting the previous study[7, 9]. The increase in the dorsiflexion angle and in the weight-bearing on the paralyzed side during STS continued until phase A', so a carryover effect was observed. The reason for this is that the ankle joint dorsiflexion angle and CSS value of the single joint in the ankle joint test also improved in phase B compared to phase A and persisted in phase A', suggesting that the improvement of the ankle joint function of the single joint had an effect on STS. Lomaglio and Eng[8] reported that individuals with high symmetry had faster STS durations than that in more asymmetric individuals. However, in this study, there was no significant change in the smoothness of movements such as the trunk forward inclination angular velocity, the angular velocity of the ankle dorsiflexion during STS, or STS duration. The participants of a previous study[8] by Lomaglio and Eng were chronic stroke patients with a stroke period of 5.3 years. Therefore, they point out that chronic stroke patients can better utilize their paralyzed legs during STS tasks by completing spontaneous recovery and rehabilitation[8]. In this study, the participant was 19 weeks post stroke and showed a significant improvement in WBSV in phases B compared to phase A and persisted in phase A'. Because of this phenomenon, the patient's weight-bearing on the paralyzed lower limb was increased compared to the conventional STS, and it is considered that the STS strategy changed. As a result, it is though that the patient is in the stage of learning a modified STS strategy, which may not have affected the STS duration. As a factor in improving active dorsiflexion function, previous studies reported that KiNvis on the ankle joint of healthy participants selectively excited the cortical motor area of the tibialis anterior muscle[11]. It has been reported that KiNvis promotes the reciprocal activity of agonist and antagonist muscles[13]. From the results of ankle dorsiflexion test and CSS, the patient's activation of the tibialis anterior and suppression of the triceps surae by KiNvis may have affected the range of motion and smoothness of active ankle dorsiflexion. In a previous study by Aoyama et al.[11], the average degree of kinesthetic illusion of the participants was 58.5 ± 16.7 mm by VAS. In this study, the average degree of kinesthetic illusion by VAS was 83.6 ± 4.4 mm, which was higher than the previous study. Therefore, it is considered that the patient had the necessary kinesthetic illusion during KiNvis to change the excitability of corticospinal tract involved in the tibialis anterior muscle and increase activation of premotor area[11, 15]. It has been demonstrated that the congruence between the predicted sensation based on motor intention and visual feedback influences corticospinal tract excitability[22]. In this patient, a high kinesthetic illusion was caused by congruence between the intention to perform the ankle dorsiflexion motion and the ankle dorsiflexion motion input as a visual stimulus from the monitor, which could lead to the excitability of the corticospinal tract. From the above, KiNvis of the ankle joint of the hemiparesis patient did not affect the STS duration, but the trunk forward inclination angle and the ankle dorsiflexion angle improved during STS, resulting in improved STS asymmetry.

As a limitation of this study, the activation of the cerebral cortex and the excitability of the corticospinal tract has not been evaluated. In addition, the muscle activity of the tibialis anterior and triceps surae muscles has not actually been measured. Since this study is a single case study, it is necessary to increase the number of cases in the future. However, this study suggests that KiNvis may improve not only ankle dorsiflexion function but also the STS, which is a meaningful result that broadens the possibility of further clinical application of kinesthetic illusion.

Funding and Conflict of interest

The authors declare that they do not have conflict of interest.

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