別紙様式１（課程博士申請者用）

博 士 学 位 論 文

Effects of visual-motor illusions with different visual stimuli on the sit-to-stand of people with hemiplegia following stroke: A randomized crossover controlled trial

（異なる視覚刺激の視覚性運動錯覚が脳卒中片麻痺患者の立ち上がりに及ぼす影響：無作為化クロスオーバー比較試験）

（西暦） 2023 年 1 月 5 日 提出

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Human Movement Science 87 (2023) 103021

Contents lists available at ScienceDirect

Human Movement Science

journal homepage: www.elsevier.com/locate/humov

Effects of visual-motor illusions with different visual stimuli on the sit-to-stand of people with hemiplegia following stroke: A randomized crossover controlled trial

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ARTICLE INFO

Keywords:
Visual-motor illusion
Motor imagery
Sit-to-stand
Maximum effort
Sense of agency

ABSTRACT

Background: The objective of this study was to determine the effects of different visual stimuli during visual-motor illusion on sit-to-stand in people with hemiplegia following stroke.
Methods: This was a randomized crossover controlled trial. Twenty people with hemiplegia following stroke were randomly divided into groups. The video images used for visual-motor illusion were ankle dorsiflexion without resistance (standard visual-motor illusion [standard illusion]) and maximum effort dorsiflexion with resistance (power visual-motor illusion [power illusion]). People with hemiplegia following stroke underwent both illusion interventions with a 1-week washout period in between; group A started with the standard illusion intervention and group B started with the power illusion intervention. Outcomes included the sit-to-stand duration, maximum weight-bearing value, trunk movement during sit-to-stand, ankle joint movement during sit-to-stand, and active ankle dorsiflexion movement on the paralyzed side.
Results: The angular velocity of the trunk and ankle joints increased significantly during sit-to-stand, and sit-to-stand duration decreased significantly in response only to power illusion. In addition, the change in angular velocity of active ankle dorsiflexion was significantly greater in response to power illusion than was the change in response to standard illusion.
Conclusion: Power illusion induces a greater improvement in paralyzed ankle dorsiflexion function than standard illusion, resulting in shorter sit-to-stand duration.

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https://doi.org/10.1016/j.humov.2022.103021
Received 17 March 2022; Received in revised form 14 October 2022; Accepted 25 October 2022
Available online 11 November 2022

1. Introduction

Sit-to-stand is a frequently performed movement in daily life, and reduced STS ability interferes with activities of daily living in people with hemiplegia following stroke. (Kerr, Clark, Cooke, Rowe, & Pomeroy, 2017). The sit-to-stand is divided into four phases: the flexion-momentum phase, the momentum-transfer phase, the extension phase, and the stabilization phase (Schenkman, Berger, Riley, Mann, & Hodge, 1990). In healthy subjects, tibialis anterior muscle activity promotes forward inclination of the trunk and ankle dorsiflexion during sit-to-stand movements. The center of mass (COM) shifts forward when a person moves from the flexion-momentum phase to the momentum transition phase (Boukadida, Piotte, Dehail, & Nadeau, 2015). However, people with hemiplegia following stroke have reduced tibialis anterior muscle contraction from the flexion-momentum phase to the momentum-transfer phase (Prudente, Rodrigues-de-Paula, & Faria, 2013; Silva et al., 2013). In addition, early activation of the triceps surae muscle by spasticity in sit-to-stand of people with hemiplegia following stroke was previously reported (Camargos, Rodrigues-de-Paula-Goulart, & Teixeira-Salmela, 2009). Therefore, in people with hemiplegia, the ankle dorsiflexion angle is reduced from the flexion-momentum phase to the momentum-transfer phase compared with the angle in healthy adults, preventing forward movement of the COM and increasing the sit-to-stand duration (Lomaglio & Eng, 2005). Moreover, hypoactivity of the tibialis anterior muscle reduces the load on the paralyzed lower limb and causes an asymmetric sit-to-stand (Kusunoki, Kiyama, Kominato, & Hiyoshi, 2014). Also, asymmetric sit-to-stands are associated with a history of falling (Cheng, Chen, Wang, & Hong, 2004). Improving ankle dorsiflexion function during sit-to-stand in people with hemiplegia following stroke may improve the smoothness and asymmetry of the flexion-momentum and momentum-transfer phases.

Recently, visual-motor illusion has been shown to induce kinesthetic sensations via visual stimulation. Visual-motor illusion uses a video image displayed on a monitor to reflect limb motion and create an illusion that the participant's limbs are moving, although they are not (Aoyama, Kaneko, Hayami, & Shibata, 2012; Kaneko et al., 2015; Kaneko, Inada, Matsuda, et al., 2016; Kaneko, Yasojima, & Kizuka, 2007; Okawada et al., 2020; Sakai et al., 2021; Shibata & Kaneko, 2019). Kinesthetic sensations are perceived without peripheral sensory inputs by observing the body movement in a video (Aoyama et al., 2012; Kaneko et al., 2007; Kaneko et al., 2015; Shibata & Kaneko, 2019). Visual-motor illusion increases corticospinal tract excitability, and brain activity during visual-motor illusion intervention is similar to brain activity while the motion is actually performed (Aoyama et al., 2012; Kaneko et al., 2007; Kaneko et al., 2015; Kaneko et al., 2016). Brain regions related to motor imagery (i.e., the primary motor area, premotor cortex, and parietal area) are also activated. Visual-motor illusion studies using electroencephalography (EEG) and functional near-infrared spectroscopy (fNIRS) demonstrated an increase in event-related synchronization in the beta-band of the motor-sensory cortex and functional connectivity of the frontal-parietal network, resulting in the enhanced vividness of motor imagery (Okawada et al., 2020; Sakai et al., 2021). Furthermore, visual-motor illusion may activate brain regions associated with a sense of agency (agency) and sense of body ownership (Kaneko et al., 2015; Kaneko et al., 2016; Sakai et al., 2020; Wakata & Morioka, 2015).

Visual-motor illusion studies have focused on upper limb function on the paralyzed side in people with hemiplegia following stroke (Aoyama et al., 2021; Kaneko et al., 2016; Kaneko et al., 2019; Miyawaki et al., 2022; Okawada et al., 2022; Takahashi et al., 2022). However, improvements in the ankle dorsiflexion angle and walking ability on the paralyzed side following visual-motor illusion have recently been reported in people with hemiplegia following stroke (Sakai, Ikeda, & Amimoto, 2018). This mechanism may involve selective activation of the corticospinal tract to the tibialis anterior muscle during visual–motor illusion for the ankle joint (Aoyama et al., 2012) and activation of the premotor area (Sakai, Ikeda, Amimoto, et al., 2020), which facilitates the integration of sensory and motor information and is involved in motor planning and motor initiation (Gerardin et al., 2000; Lotze & Halsband, 2006). We recently reported that visual-motor illusion for the ankle joint on the paralyzed side improved the automatic ankle dorsiflexion angle on the paralyzed side and reduced asymmetry during sit-to-stand movement in people with hemiplegia following stroke (Tanabe, Amimoto, Sakai, Osaki, & Yoshihiro, 2022). However, visual-motor illusion did not affect the sit-to-stand duration (Tanabe et al., 2022). The video images used in previous visual-motor illusion intervention studies merely repeated the ankle dorsiflexion movement (standard visual-motor illusion [standard illusion]) (Aoyama et al., 2012; Sakai, Ikeda, & Amimoto, 2018; Tanabe et al., 2022).

Lack of visual-motor illusion-induced effects on the sit-to-stand duration may be due to the visual stimuli of the visual-motor illusion itself. Visual-motor illusion promotes motor imagery and brain excitability that is similar to the activity that occurs if the viewed joint movement was actually performed (Kaneko et al., 2015; Okawada et al., 2020). The increase in corticospinal tract excitability depends on the strength of the imagined or perceived muscle contraction (Mizuguchi, Umehara, Nakata, & Kanosue, 2013). Ishizaka, Takeda, Shimoi, and Maruyama (2012) showed that activities of the primary sensory-motor cortex, premotor cortex, and supplementary motor cortex were greater when healthy participants performed maximal-force toe flexion exercises than when they performed medium-force exercises. Because visual-motor illusion induces similar motor imagery as the actual movements (Kaneko et al., 2015; Okawada et al., 2020), ankle dorsiflexion movements with resistance (power visual-motor illusion [power illusion]) may significantly increase brain and corticospinal tract excitability compared to activity in response to standard illusion. From a cognitive psychological point of view, the agency is related to the excitability of the corticospinal tract (Weiss, Tsakiris, Haggard, & Schütz-Bosbach, 2014), and imparting a sense of effort enhances agency (Minohara et al., 2016). Therefore, power illusion may activate the tibialis anterior muscle enough to decrease sit-to-stand duration, in contrast to standard illusion. The purpose of this study was to compare the changes in STS ability in response to power illusion and standard illusion.

2. Participants and methods

2.1. Study design

This was an assessor-blinded, randomized crossover controlled trial. Participants were randomly assigned to group A or B in equal numbers via replacement block randomization by hospital staff not involved in the study. Randomization codes were generated by a computerized random number generation program. Participants drew a randomization code hidden in a sealed, opaque envelope. After allocation, the allocator informed the research coordinator of the group assignments. Those evaluating the results of the intervention were unaware of the group allocation and intervention.

The participants underwent both standard-illusion and power-illusion with a 1-week interval between the two interventions. To investigate immediate effects, outcomes were assessed immediately before and after each intervention. Group A underwent standard-illusion first and then power-illusion 1 week later; group B underwent power-illusion first and then standard-illusion 1 week later.

This study was conducted according to CONSORT guidelines (Altman et al., 2001; Boutron et al., 2008) and was registered in the University Hospital Medical Information Network Clinical Trials Registry (UMIN CTR number: UMIN000042431). The Ethics Committees of Kurashiki Rehabilitation Hospital (approval number: 1904) and Tokyo Metropolitan University approved the study design (approval number: 20013). In accordance with the Declaration of Helsinki, written informed consent was obtained from all participants before their participation in the study.

2.2. Participants

Based on an a priori power analysis conducted on G*Power (Heinrich Heine University, Dusseldorf, Germany), the required sample size was ≥17 for each of power illusion and power illusion (34 participants in total), assuming a medium effect size of $f = 0.25$ (Cohen, 1992), a significance level of 5% ($a = 0.05$), and a statistical power of 80% (Faul, Erdfelder, Buchner, & Lang, 2009). The inclusion criteria were as follows: 1) first episode of hemiplegia, 2) no orthopedic disease, 3) Stroke Impairment Assessment Set distal lower extremity score of 1 or higher (slight dorsiflexion movement but forefoot does not leave the floor), 4) able to perform sit-to-stand from a chair without using hands with more than watchful waiting, 5) triceps muscle tone on the paralyzed side of the lower extremity of 1 point or more on the Modified Ashworth Scale (Miyara et al., 2018), and 6) no dementia or higher brain dysfunction. The exclusion criteria included 1) Mini-Mental State Examination score of <21, 2) visual impairment, and 3) inability to follow verbal instructions.

2.3. VMI intervention

The visual-motor illusion videos used for the interventions showed ankle dorsiflexion motion under two conditions. Both videos showed a TheraBand (Thera-band, Abilities, Tokyo, Japan). The video for standard illusion showed ankle dorsiflexion with a TheraBand wrapped around the foot, but no tension was applied. In the video for power illusion, resistance was applied to the foot via the TheraBand to perform dorsiflexion with maximum effort. The ankle joint motion of the non-paralyzed foot was recorded. The ankle dorsiflexion frequency was 60 repetitions per minute for both conditions (Sakai, Ikeda, & Amimoto, 2018), and video images were recorded using a tablet computer (iPad Pro, Apple, Cupertino, CA, USA). The video was then inverted by video reversal software, to appear as dorsiflexion movement on the paralyzed side. During the visual-motor illusion, the participants was seated, and the monitor projected the continuity over the paralyzed ankle joint. Fig. 1 shows the visual-motor illusion protocol. The participants received the following instruction: "As you do not have to actually move while observing the video, please imagine that you are performing your

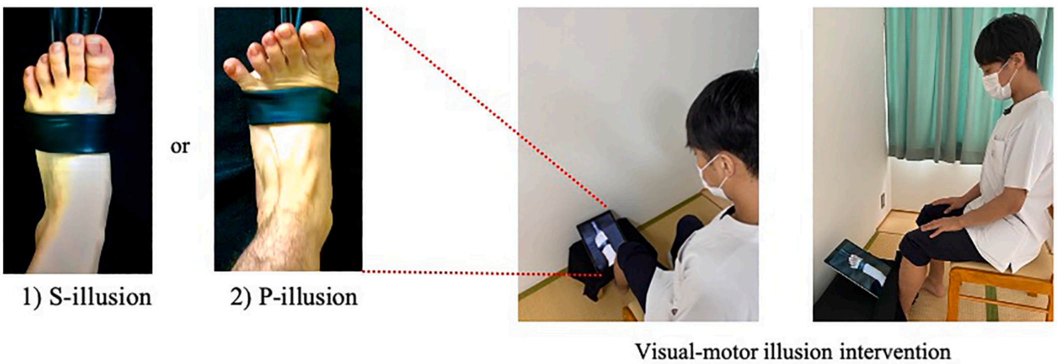

Fig. 1. Visual-motor illusion protocol. For S-illusion, a TheraBand was wrapped around the foot, but no tension was applied while performing the dorsiflexion movement. For P-illusion, resistance was applied to the foot using the TheraBand while performing dorsiflexion with maximum effort. Videos of the ankle joint S-illusion or P-illusion dorsiflexion movements were projected on a tablet computer. For visual-motor illusion intervention, participants observed the video in a sitting position for two minutes. In P-illusion, strong contraction of the tibialis anterior muscle, extension movement of the toes, and activity of the extensor hallucis longus muscle tendon and extensor digitorum longus muscle tendon were clearly observed compared to S-illusion.

own ankle movement" (Sakai, Ikeda, Yamanaka, & Noguchi, 2018).

2.4. Outcome measures

Primary outcomes included the maximum weight-bearing value (MaxWB) and sit-to-stand duration. Secondary outcomes included the angle of trunk forward inclination (angle of trunk FI) and angular velocity of trunk forward inclination (angular velocity of trunk FI) during sit-to-stand, angle of the ankle dorsiflexion (angle of ankle DF) and ankle dorsiflexion angular velocity (angular velocity of ankle DF) on the paralyzed side during sit-to-stand, and angle of the active ankle dorsiflexion (angle of active ankle DF) and angular velocity of active ankle dorsiflexion (angular velocity of active ankle DF) on the paralyzed side.

The muscle tone of the ankle plantar flexor muscle and the degree of agency during visual-motor illusion were also measured.

2.4.1. Kinematic measurements

Kinematic data from the trunk and ankle joint during sit-to-stand was collected through the use of a digital video camera (EX-FC150, Casio, Tokyo, Japan). The camera was placed on the paralyzed side of the participants to record the sit-to-stand from the sagittal plane. The sampling frequency was 120 Hz. Five markers were placed at the acromion process, greater trochanter, lateral epicondyle of the femur, lateral malleolus, and fifth metatarsal head on the paralyzed side to track motion for analysis (Tanabe et al., 2022). The markers were 30 mm in diameter.

2.4.2. Weight-bearing measurement

Two movable force plates (GP-6000 Twin Gravicoder, ANIMA, Tokyo, Japan) were used to calculate the weight load on both the paralyzed and non-paralyzed lower limbs during sit-to-stand. The sampling frequency was 100 Hz.

2.4.3. Measurement of ankle plantar flexor muscle tone

The muscle tone of the ankle plantar flexor muscle was evaluated with the 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 to 16 points, with scores of 0–9, 10–12, and 13–16 points indicating mild spasticity, moderate spasticity, and severe spasticity, respectively (Poon & Hui-Chan, 2009).

2.4.4. Measurement of agency

The agency generated during the visual-motor illusion intervention was evaluated according to participants' self-reports on a visual analog scale, ranging from 0 mm (no illusion) to 100 mm (the illusion that the ankle joint is actually moving) (Sidarus, Vuorre, Metcalfe, & Haggard, 2017).

2.5. Test procedure

The evaluations were performed in the following order: ankle dorsiflexion test, sit-to-stand test, and measurement of ankle plantar flexor muscle tone. These assessments were performed pre and post visual–motor illusion intervention. For the ankle dorsiflexion test, the participants sat on a height-adjustable bed so that the feet did not touch the floor. The participants were instructed to dorsiflex the

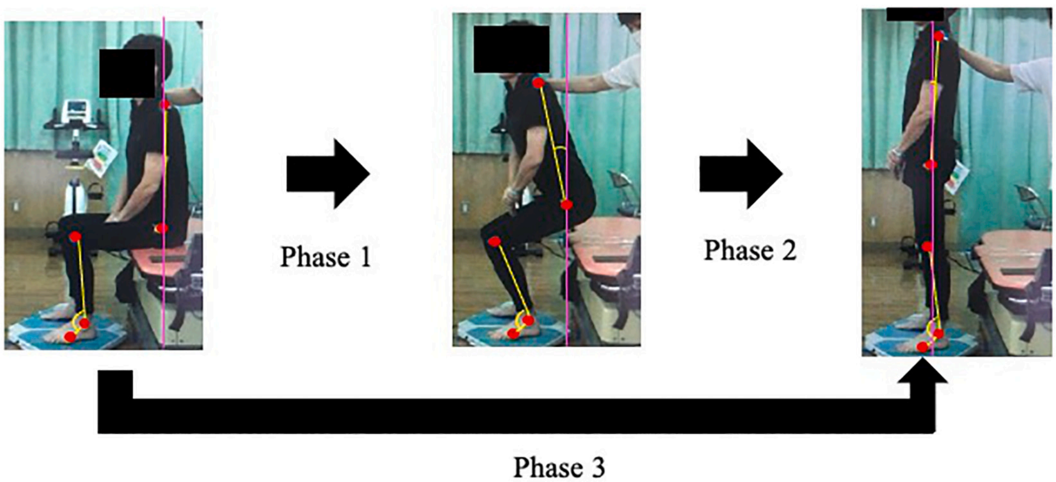

Fig. 2. Sit-to-stand phases. Phase 1: The period from the beginning of the trunk forward inclination movement to the maximum ankle dorsiflexion angle on the paralyzed side. Phase 2: The period from the maximum ankle dorsiflexion angle on the paralyzed side to the standing posture. Phase 3: The period from the start of trunk forward inclination movement to the standing posture.

ankle joint maximally (Tanabe et al., 2022). For the sit-to-stand test, the participants were asked to stand up with both arms crossed from an adjusted chair. The height of the chair was set at the shank of the participant's lower leg (Liu et al., 2016). The participant was seated so that the distance between both feet was 20 cm and the knee joints were flexed at 100°. Marks were made on the seat and ground to ensure that participants kept their buttocks and feet in the same positions across all trials. The participants were instructed to look in front of them and to stand up at a natural speed (Liu et al., 2016). The sit-to-stand test and the ankle dorsiflexion test were evaluated five times and the average value was used (Lee, Choi, & Lee, 2015). The measurements of kinematic and weight-bearing were performed simultaneously when the individuals performed sit-to-stand. Finally, for the CSS assessment, participants were evaluated the degree of Achilles tendon reflex, resistance to full-range passive ankle dorsiflexion, and foot clonus in a seated position.

2.6. Data analysis

The recorded videos were analyzed using a two-dimensional (2D) motion analysis system (ToMoCo-Lite, Toso System; Saitama, Japan) to calculate joint angles and joint movement times (Kanai et al., 2016). The previously reported intraclass correlation coefficient for the intratester reliability of the angle calculation by ToMoCo-Lite is 0.80–0.97 (Ota et al., 2014). The angle of trunk forward inclination was defined as the angle between the line connecting the acromion process and greater trochanter and a vertical line (Fig. 2) (Tanabe et al., 2022). The ankle joint angle was defined as the angle between the line connecting the lateral epicondyle of the femur and the lateral malleolus and the line connecting the lateral malleolus and the fifth metatarsal (Fig. 2) (Tanabe et al., 2022). The STS was divided into three phases based on previous studies (Fig. 2) (Hirschfeld, Thorsteinsdottir, & Olsson, 1999; Mazzà, Stanhope, Taviani, & Cappozzo, 2006; Roebroeck, Doorenbosch, Harlaar, Jacobs, & Lankhorst, 1994). Phase 1 was defined as the period from the beginning of the trunk forward inclination movement to the maximum angle of ankle DF on the paralyzed side. Phase 2 was defined as the period from the maximum angle of ankle DF on the paralyzed side to the standing posture. Phase 3 was defined as the period from the start of trunk forward inclination movement to the standing posture. For the starting point and ending point of the sit-to-stand movement, the average angle and standard deviation were calculated from the 10 frames of unchanged angle of trunk FI before the STS movement (sitting position) and after the sit-to-stand movement (standing position) using a 2D motion analysis system. Subsequently, the starting and ending points of the sit-to-stand movements were identified by adding the value of twice the standard deviation to the mean angle of the 10 frames of the unchanged angle of trunk FI (Dehail et al., 2007). The sit-to-stand duration was calculated as the number of frames required during three sit-to-stand phases using a 2D motion analysis system and dividing the number of frames by 120 (the sampling frequency) (the number of frames during sit-to-stand period/120) (Tanabe et al., 2022).

2.7. Statistical analyses

To compare the characteristics of the two groups, we used the independent *t*-test for continuous data and the chi-squared test for categorical variables. A two-way repeated-measures analysis of variance (ANOVA) was used for the statistical analysis of the two conditions (power illusion and standard illusion) and two evaluation times (pre-intervention and post-intervention). The condition and evaluation time were used to test the presence or absence of a main effect and the interactions among factors. When a main effect and interaction were present, Bonferroni's post hoc test was used to determine simple main effects. The amount of change was calculated by subtracting the pre-intervention value from the post-intervention value, and a paired *t*-test or Wilcoxon signed-rank test was used to compare the differences in intervention methods. The degrees of agency for power illusion and standard illusion were compared in paired *t*-tests. The effect size for two-way repeated-measures ANOVA was determined with η^2, and the effect size for post hoc tests was determined with Cohen's *d*. The interpretation of the effect size was based on Cohen's classification (Cohen, 2013), where the value of η^2 was defined as small (0.01 effect size), medium (0.06 effect size), and large (0.14 effect size), and the value of *d* was defined as small (0.20 effect size), medium (0.50 effect size), and large (0.80 effect size). The statistical significance level was $p < 0.05$ for all tests. SPSS ver. 20 (SPSS, IBM, Chicago, IL, USA) was used for all statistical analyses.

To determine whether the change in visual-motor illusion was clinically significant, the effect was determined based on the minimal clinically important difference (MCID). The change (from before to after the intervention) was considered to be clinically significant if it exceeded the MCID, which was defined as half the standard deviation (0.5 SD) of the pre-intervention (Lin et al., 2009; Norman, Sloan, & Wyrwich, 2003; Paravlic, Maffulli, Kovač, & Pisot, 2020).

Table 1
Characteristics of the two groups.

Variable	Group A ($n = 10$)	Group B (n = 10)	*p* value
Age (years)	59.8 (16.4)	64.1 (8.0)	0.493[a]
Gender (male/female)	7/3	5/5	0.325[b]
Time since stroke (days)	99.7 (27.2)	87.6 (28.6)	0.369[a]
Paralyzed side (right/left)	5/5	4/6	0.500[b]
Lower FMA (points)	19.7 (3.5)	21.4 (3.5)	0.316[a]
MAS	2.6 (0.7)	2.0 (1.1)	0.400[a]
MMSE (points)	27.4 (2.7)	28.4 (2.2)	0.392[a]

Notes: a, independent *t*-test; b, Chi-square test;
FMA, Fugl-Meyer assessment; MAS, Modified Ashworth Scale; MMSE, Mini-Mental State Examination.
To calculate the mean value of MAS scores, score 1+ was transformed to 2, and scores 2, 3, and 4 were transformed to 3, 4, and 5.

3. Results

3.1. Participants

The characteristics of the two groups are shown in Table 1. After screening 286 recruited people with hemiplegia following stroke from July 2019 to November 2021, 20 people with hemiplegia following stroke were included in the study and randomly assigned to group A ($n = 10$) or group B ($n = 10$). All participants were able to undergo the interventions, and no adverse events occurred during the study period. The flow diagram of the study is shown in Fig. 3. The ten people with hemiplegia following stroke in each of groups A and B performed both power illusion and standard illusion. We crossover the order of power illusion and standard illusion in Groups A and B. Therefore, sample size numbers for power illusion and standard illusion were 20 each (Fig. 3). No significant differences between the characteristics of groups A and B were detected (Table 1).

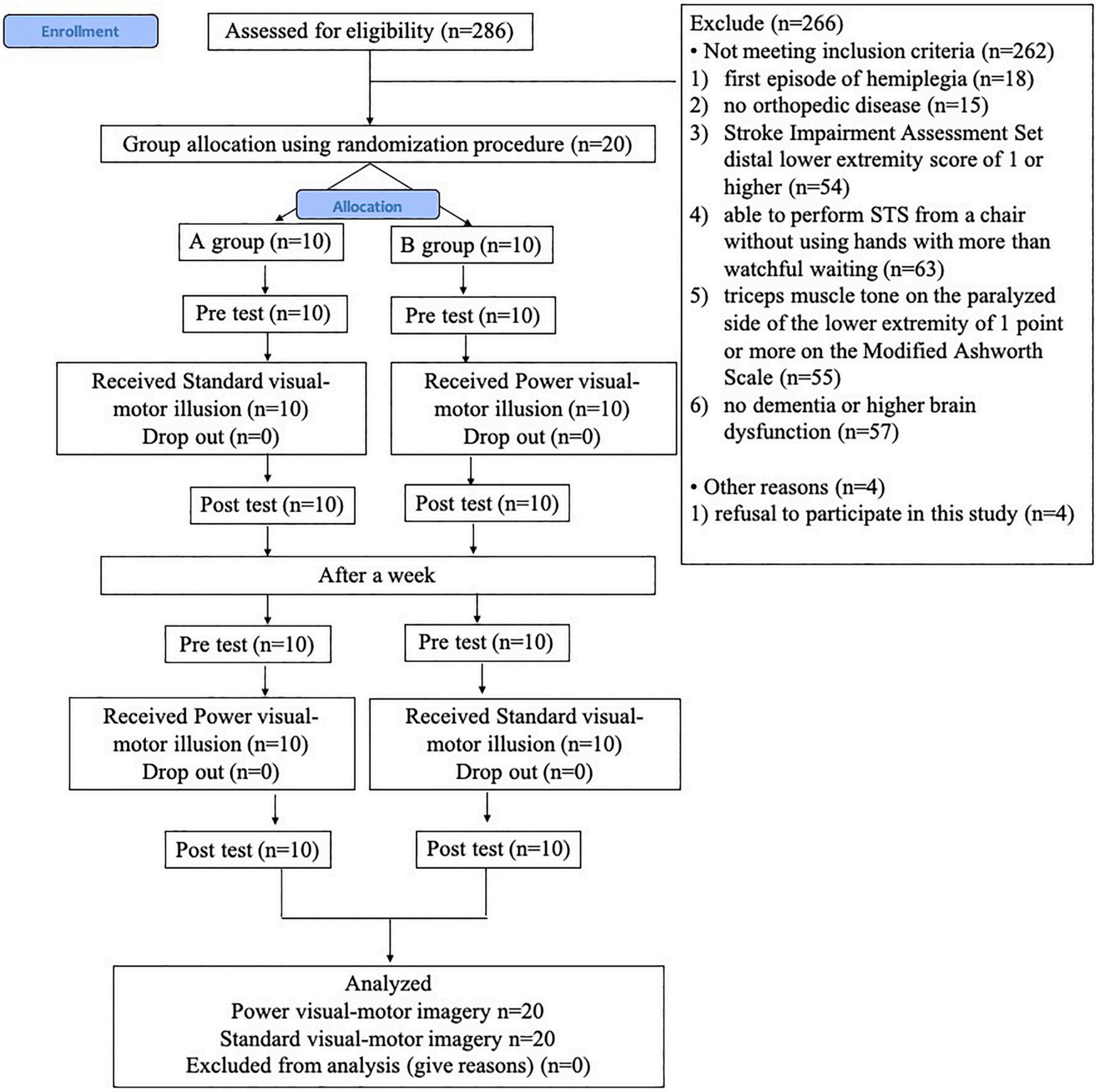

Fig. 3. Flowchart of patient participation and study.

3.2. Primary outcomes

The primary outcome results are shown in Table 2. A two-way repeated-measures ANOVA revealed interactions between intervention and evaluation time (before vs. after intervention) for Phase 1 of the sit-to-stand duration ($p = 0.034$), Phase 3 of the sit-to-stand duration ($p = 0.014$), and non-paralyzed limb MaxWB ($p = 0.023$). A simple main effect test showed that only power illusion significantly reduced the durations of sit-to-stand Phases 1 and 3 (effect sizes: sit-to-stand Phase 1 duration, medium; sit-to-stand Phase 3 duration, small). The non-paralyzed limb MaxWB was significantly lower in response to both illusions (effect sizes: power illusion, large; standard illusion, small). A significant main effect of evaluation time was observed for the paralyzed limb MaxWB ($p < 0.001$). The simple main effect test showed that the MaxWB for the paralyzed limb was significantly higher for both illusions (effect sizes: power illusion, large; standard illusion, large). No significant differences were detected in the primary outcomes between the two illusions before testing (before the intervention).

3.3. Secondary outcomes

Secondary outcome results are shown in Table 2. A two-way repeated-measures ANOVA revealed an interaction between interventions and evaluation time for angular velocity of trunk FI ($p = 0.013$), angular velocity of ankle DF during STS ($p = 0.002$), and angular velocity of active ankle DF ($p = 0.030$). A simple main effects test showed that only power illusion significantly increased angular velocity of trunk FI and angular velocity of ankle DF during STS and angular velocity of active ankle DF (effect sizes: angular velocity of trunk FI, medium; angular velocity of ankle DF during STS, large; angular velocity of active ankle DF, large).

In addition, main effects of the evaluation time were observed for angle of trunk FI ($p = 0.022$), angle of ankle DF during STS ($p < 0.001$), angle of active ankle DF ($p < 0.001$), total CSS ($p < 0.001$), CSS for Achilles tendon jerks ($p = 0.012$), CSS for resistance ($p < 0.001$), and CSS for foot clonus ($p < 0.001$). A simple main effect test showed that only standard illusion significantly increased angle of trunk FI (pre- vs. post-intervention) (effect size: medium). angle of active ankle DF was significantly increased after both interventions (effect sizes: power illusion, large; standard illusion, large). The total CSS, CSS for Achilles tendon jerks, CSS resistance, and CSS for foot clonus were significantly decreased after both illusions compared with the CSS before the illusions (effect sizes: total CSS, power

Table 2
Data for the pre-and post-intervention visual-motor illusion.

	P-illusion ($n = 20$)		S-illusion (n = 20)		Main effect		ES	Interaction		ES
Variable	Pre	Post	Pre	Post	$F_{1,19}$	p	η^2	$F_{1,19}$	p	η^2
Primary outcomes										
STS duration										
Phase 1	0.89 (0.33)	0.81 (0.41) a,†	0.86 (0.32)	0.85 (0.37)	3.893	0.063	0.08	0.216	**0.034**	0.04
Phase 2	1.35 (0.58)	1.33 (0.55)	1.38 (0.56)	1.37 (0.52)	1.163	0.294	0.01	0.015	0.904	0.00
Phase 3	2.23 (0.87)	2.15 (0.98) a, *	2.25 (0.85)	2.22 (0.86)	7.269	**0.014**	0.06	7.269	**0.014**	0.02
MaxWB										
Paralyzed limb	32.6 (6.7)	36.2 (8.3) a, §	32.9 (6.9)	35.9 (8.2) a, §	15.773	**<0.001**	0.40	2.317	0.144	0.00
Non-paralyzed limb	46.7 (9.2)	43.9 (9.7) a, §	46.3 (9.9)	44.4 (9.4) a, *	14.397	**<0.001**	0.13	6.084	**0.023**	0.01
Secondary outcomes										
TFIA (°)	32.9 (6.4)	33.7 (7.2)	32.6 (6.4)	33.9 (7.4) a,†	6.241	**0.022**	0.07	0.643	0.433	0.00
TFIAV (°/*sec*)	58.1 (14.3)	65.0 (18.4) a,†	60.2 (18.5)	61.9 (18.9)	7.549	**0.013**	0.10	4.950	**0.013**	0.05
ADA (°)	11.4 (2.8)	14.4 (3.8) a, §	11.8 (2.5)	13.9 (3.6) a,†	47.352	**<0.001**	0.24	0.769	0.391	0.01
ADAV (°/sec)	33.4 (14.2)	47.4 (25.2) a, §	34.1 (10.2)	36.5 (14.4)	16.323	**<0.001**	0.16	13.713	**0.002**	0.08
AADA (°)	14.7 (7.0)	17.5 (8.3) a, §	13.9 (8.0)	15.8 (7.1) a, §	19.412	**<0.001**	0.24	1.397	0.252	0.01
AADAV (°/sec)	28.2 (19.0)	36.6 (24.1) a, §	26.9 (22.3)	30.3 (20.7) a,†	24.688	**<0.001**	0.23	5.526	**0.030**	0.04
CSS (point)										
Total	9.6 (2.1)	7.4 (2.9) a, §	9.5 (2.3)	7.7 (2.1) a, §	91.285	**<0.001**	0.56	0.828	0.374	0.01
Achilles tendon jerks	2.3 (0.9)	1.9 (0.6) a,†	2.3 (0.9)	2.1 (0.8) a,†	7.689	**0.012**	0.21	1.879	0.186	0.02
Resistance	3.7 (0.7)	3.0 (0.9) a, §	3.6 (0.7)	3.1 (0.7) a, §	41.455	**<0.001**	0.41	0.275	0.606	0.00
Foot clonus	2.5 (0.5)	1.8 (0.9) a, §	2.4 (0.5)	2.0 (0.5) a,†	32.351	**<0.001**	0.36	3.709	0.069	0.04

Continuous data are presented as means (standard deviations). The significant p-values in the main effect and interaction are in boldface.
Notes. a Significant difference between pre-and post-intervention results according to Bonferroni's post hoc test, $p < 0.05$.
*Effect size of post hoc test is small. †Effect size of post hoc test is medium. §Effect size of post hoc test is large.
Phase 1: The period from the beginning of the trunk forward inclination movement to the maximum ankle dorsiflexion angle on the paralyzed side. Phase 2: The period from the maximum ankle dorsiflexion angle on the paralyzed side to the standing posture. Phase 3: The period from the start of trunk forward inclination movement to the standing posture.
ANOVA, analysis of variance; ES, effect size; MaxWB, maximum weight-bearing value; P-illusion, power visual-motor illusion; STS, sit-to-stand; S-illuison, standard visual-motor illusion; TFIA, trunk forward inclination angle; TFIAV, trunk forward inclination angular velocity; ADA, ankle dorsiflexion angle during STS; ADAV, ankle dorsiflexion angular velocity during STS; AADA, active ankle dorsiflexion angle; AADAV, active ankle dorsiflexion angular velocity; CSS, composite spasticity scale.

illusion, and standard illusion, large; Achilles tendon jerks CSS, power illusion, and standard illusion, medium; resistance CSS, power illusion, and standard illusion, large; foot clonus CSS, large for power illusion and medium for standard illusion).

3.4. Differences in change between power illusion and standard illusion

The changes resulting from the interventions are shown in Table 3. Power illusion showed that the change from before to after the intervention was significantly greater than the changes after standard illusion in the duration of sit-to-stand Phase 1 ($p = 0.021$; effect size: medium), MaxWB of the non-paralyzed limb ($p = 0.021$; effect size: medium), angular velocity of ankle DF during STS ($p = 0.005$; effect size: medium), and angular velocity of active ankle DF in the paralyzed limb ($p = 0.029$; effect size: medium). No significant differences in other outcomes were detected.

3.5. Degree of agency

The agencies for power illusion and standard illusion were 74.9 ± 11.4 mm and 61.7 ± 13.6 mm, respectively. The agency for power illusion was significantly higher than the agency for standard illusion ($p < 0.001$).

3.6. MCID

To gauge the clinical effects of interventions, we calculated the MCID (0.5 SD) of the outcome measures and changes before and after the visual-motor illusion intervention that were significantly different (Table 4). In both illusions, the changes in CSS (total CSS and resistance, foot clonus) and angle of active ankle DF were greater than the MCID. Furthermore, only the power illusion induced a greater change than the MCID in the angular velocity of active ankle DF on the paralyzed side and the MaxWB of the paralyzed leg during sit-to-stand.

Table 3
Changes resulting from interventions.

	Amount of change (Post-Pre)		Means difference (95% CI)	*p*-value	ES (Cohen's *d*)
	P-illusion (n = 20)	S-illusion (n = 20)			
Primary outcomes					
STS duration					
Phase 1	−0.08 (0.10)	−0.01 (0.12)	−0.06 (−0.11 to −0.01)	**0.021**	0.54
Phase 2	−0.02 (0.12)	−0.01 (0.13)	−0.01 (−0.08 to 0.07)	0.843	0.00
Phase 3	−0.08 (0.13)	−0.03 (0.18)	−0.06 (−0.18 to 0.05)	0.273	0.28
MaxWB					
Paralyzed limb	3.6 (3.9)	3.0 (3.9)	0.53 (−0.18 to 1.25)	0.139	0.05
Non-paralyzed limb	−2.7 (0.8)	−1.85 (2.9)	−0.89 (−1.62 to −0.15)	**0.021**	0.56
Secondary outcomes					
TFIA (°)	0.8 (2.2)	1.3 (2.4)	−0.46 (−1.66 to 0.75)	0.439	0.17
TFIAV (°/sec)	6.9 (12.3)	1.7 (3.2)	5.3 (−0.36 to 10.96)	0.065	0.44
ADA (°)	3.0 (2.3)	2.1 (3.1)	0.84 (−1.19 to 2.87)	0.399	0.19
ADAV (°/sec)	14.1 (13.1)	2.4 (10.4)	10.9 (3.84 to 18.1)	**0.005**	0.72
AADA (°)	2.8 (3.0)	1.9 (2.9)	0.91 (−0.73 to 2.55)	0.261	0.26
AADAV (°/sec)	8.4 (8.6)	3.4 (5.2)	4.97 (0.55 to 9.39)	**0.029**	0.52
CSS (point)					
Total	−2.2 (1.47)	−1.8 (1.40)	0.45 (−0.58 to 1.48)	0.374	0.20
Achilles tendon jerks	−0.4 (0.58)	−0.2 (0.41)	0.15 (−0.07 to 0.37)	0.186	0.29
Resistance	−0.7 (0.67)	−0.5 (0.51)	0.10 (−0.29 to 0.49)	0.606	0.11
Foot clonus	−0.7 (0.47)	−0.4 (0.60)	0.25 (−0.14 to 0.64)	0.204	0.29

Notes. Continuous data are presented as means (standard deviations). Significant p-values are in boldface. Phase 1: The period from the beginning of the trunk forward inclination movement to the maximum ankle dorsiflexion angle on the paralyzed side. Phase 2: The period from the maximum ankle dorsiflexion angle on the paralyzed side to the standing posture. Phase 3: The period from the start of trunk forward inclination movement to the standing posture.
P-illusion, power visual-motor illusion; S-illusion, standard visual-motor illusion; ES, effect size; STS, sit-to-stand; MaxWB, maximum weight bearing value; CI, confidence interval; TFIA, trunk forward inclination angle; TFIAV, trunk forward inclination angular velocity; ADA, ankle dorsiflexion angle during STS; ADAV, ankle dorsiflexion angular velocity during STS; AADA, active ankle dorsiflexion angle; AADAV, active ankle dorsiflexion angular velocity; CSS, composite spasticity scale.

Table 4
MCIDs for outcomes with significant changes.

	Amount of the change	MCID
Primary outcomes		
STS duration, Phase 1		
P-illusion	0.08	0.17
STS duration, Phase 3		
P-illusion	0.08	0.44
MaxWB, Paralyzed limb		
P-illusion	**3.6**[a]	3.4
S-illusion	3.0	3.5
MaxWB, Non-paralyzed limb		
P-illusion	2.8	4.6
S-illusion	1.4	5.0
Secondary outcomes		
TFIA		
S-illusion	1.3	3.2
TFIAV		
P-illusion	6.9	7.2
ADA		
P-illusion	**3.0**[a]	1.4
S-illusion	**2.1**[a]	1.3
ADAV		
P-illusion	**14.1**[a]	7.1
AADA		
P-illusion	2.8	3.5
S-illusion	1.9	4.0
AADAV		
P-illusion	8.4	9.5
S-illusion	3.4	11.5
CSS total		
P-illusion	**2.2**[a]	1.1
S-illusion	**1.8**[a]	1.2
CSS Achilles tendon jerks		
P-illusion	0.4	0.4
S-illusion	0.2	0.5
CSS resistance		
P-illusion	**0.7**[a]	0.3
S-illusion	**0.5**[a]	0.3
CSS foot clonus		
P-illusion	**0.7**[a]	0.3
S-illusion	**0.4**[a]	0.3

Notes: Phase 1: The period from the beginning of the trunk forward inclination movement to the maximum ankle dorsiflexion angle on the paralyzed side; Phase 3: The period from the start of trunk forward inclination movement to the standing posture.
a The amount of the change from pre- to post-intervention exceeds half (0.5 standard deviation) of the standard deviation of the pre-intervention measurement.
MCID, minimal clinically important difference; P-illusion, power visual-motor illusion; STS, sit-to-stand; S-illusion, standard visual-motor illusion; MaxWB, maximum weight bearing value; TFIA, trunk forward inclination angle; TFIAV, trunk forward inclination angular velocity; ADA, ankle dorsiflexion angle during STS; ADAV, ankle dorsiflexion angular velocity during STS; AADA, active ankle dorsiflexion angle; AADAV, active ankle dorsiflexion angular velocity; CSS, composite spasticity scale.

4. Discussion

To the best of our knowledge, this is the first randomized controlled trial to determine the effects of different visual-motor illusion videos. No study has been conducted to compare the effects of two types of visual-motor illusion on sit-to-stand. Both illusions significantly increased MaxWB on the paralyzed side and significantly decreased MaxWB on the non-paralyzed side. Only power illusion significantly affected sit-to-stand duration (Phases 1 and 3), angular velocity of trunk FI and angular velocity of ankle DF on the paralyzed side during sit-to-stand, and angular velocity of active ankle DF. In addition, changes in the duration of sit-to-stand Phase 1, MaxWB of the non-paralyzed limb, angular velocity of ankle DF during sit-to-stand, and angular velocity of active ankle DF were significantly greater in response to power illusion than those in response to standard illusion. The degree of agency was also significantly higher for power illusion than for standard illusion.

Both illusions increased MaxWB on the paralyzed side and reduced MaxWB on the nonparalyzed side during sit-to-stand. This finding was consistent with that of previous studies showing that the standard visual–motor illusion of ankle dorsiflexion increased loading on the paralyzed side during sit-to-stand (Tanabe et al., 2022). Therefore, this study similarly suggests that visual-motor illusion improved ankle joint function on the paralyzed side, which encouraged loading on the paralyzed lower limb during sit-to-stand.

The degree of agency over the viewed ankle movement was significantly higher after the power illusion than that after the standard illusion, and an interaction effect was confirmed for the angular velocity of ankle DF. In addition, power illusion induced a larger effect size, and the change in angular velocity of active ankle DF was higher after power illusion than that after standard illusion. The congruence of motor intentions and visual feedback can generate a agency and influence the excitability of the corticospinal tract (Weiss et al., 2014). Minohara et al. (2016) reported that imparting a sense of effort enhances agency. Therefore, the power illusion with resistance may induce a greater sense of effort than the standard illusion, resulting in a higher agency and promoting a stronger activation of the tibialis anterior muscle to induce greater effects on ankle dorsiflexion. Furthermore, Mizuguchi et al. (2013) demonstrated that the excitability of the corticospinal tract depends on the magnitude of the imagined muscle contraction. The video of the power illusion added resistance may promote imagery of a stronger contraction of the tibialis anterior muscle than did the videos for standard illusion. This stronger imagery may have a greater impact on ankle joint function on the paralyzed side. In addition, our results show that the effect size of power illusion on CSS (clonus items) was greater than the effect size of standard illusion. Wolpaw (1997) reported that the presence of descending signals through the corticospinal tract is necessary for the suppression of the stretch reflex. Therefore, we speculate that the excitation of the corticospinal tract for the tibialis anterior muscle during the power illusion was more affected by the suppression of muscle tone in the antagonist muscle (triceps surae muscle).

In this study, only power illusion affected the angular velocity of trunk FI and angular velocity of ankle DF on the paralyzed side during sit-to-stand and shortened the sit-to-stand duration. Yu et al. (2000) reported that trunk flexion and ankle dorsiflexion movements during sit-to-stand affect the forward movement speed of the COM. Also, the activation of the tibialis anterior muscle reflects its contribution to both stabilization of the foot and forward rotation of the shank at the ankle to assist in moving the body mass forward (Boukadida et al., 2015; Khemlani, Carr, & Crosbie, 1999). Although ankle DF muscle activity was not evaluated here, it is possible that improvements in the single-joint ankle dorsiflexion function in response to power illusion may have contributed to the ankle dorsiflexion function during sit-to-stand, resulting in increased angular velocity of trunk FI and angular velocity of ankle DF and decreased duration of sit-to-stand Phase 1. Furthermore, the shorter duration of Phase 1 may have contributed to the shortening of Phase 3.

The angle of trunk forward inclination increased significantly in response to standard illusion, while the angular velocity of trunk FI increased significantly in response to power illusion. Previous studies demonstrated two strategies for sit-to-stand movements: the "momentum strategy," in which the trunk is rapidly tilted forward and the body is moved upward before the COM enters the base of support, and the "force control strategy," in which the trunk is largely tilted forward and the COM is elevated after the COM enters the base of support (Schenkman et al., 1990). The "force control strategy" of large trunk flexion movement is a strategy to suppress ankle joint plantar flexion caused by early triceps surae muscle activity (Motojima & Kouno, 2020). In response to standard illusion, people with hemiplegia following stroke may have compensated for insufficient suppression of the triceps by using trunk flexion. The extended sit-to-stand duration in stroke people with hemiplegia following stroke is related to prolonged trunk forward inclination duration, which is influenced by weak trunk control and muscle strength (Mao et al., 2018). According to previous studies, a joint movement provided with strong resistance is associated with increased activity of proximal and distal muscles (Dettmers et al., 1995). Although activity of the trunk muscle was not evaluated here, power illusion may have facilitated the imagery of ankle dorsiflexion movement under maximal effort, affecting the activity of the trunk muscles (proximal muscles) and contributing to the increased angular velocity of trunk FI. On the other hand, the standard illusion significantly increased the angle of trunk FI but not power illusion. Power illusion affected clonus more than standard illusion and may have inhibited triceps muscle activity; thus, compensation with trunk flexion may not have been necessary.

To examine the clinical relevance of the effects of visual-motor illusion interventions, we used the MCID. For both illusions, the amount of change in CSS and angle of ankle DF exceeded the MCID. Furthermore, angular velocity of ankle DF and MaxWB of the paralyzed side lower extremity during sit-to-stand were higher than the MCID in response to the power illusion. This study focused on the immediate effect of visual-motor illusion, rather than the extended effect. Future studies with long-terms follow-up and/or repeated application of the visual motor illusions are warranted to better understand the potential clinical value of these findings. However, the power illusion may provide clinically beneficial changes in the suppression of triceps surae muscle tone and ankle dorsiflexion movement during sit-to-stand and an increase in the paralyzed side load during sit-to-stand.

The VMI visual-motor illusion method is simple and easy to use in clinical practice and may apply to many people with hemiplegia following stroke. In the process of generating visual–motor illusions (e.g., creating a video of the movement and inverting the video with software), the video is first captured on an iPad. Video inversion can be done by anyone with an iPad by downloading a free video inversion software. Visual–motor illusion videos can be created in a short time and do not require any technical knowledge. The relevance of such illusions for clinical practice remain dependent on their simplicity and ease of use in the clinical setting.

As limitation of this study, first, the excitability of brain and corticospinal tract, and the activity of ankle DF muscle and trunk muscle were not assessed. Second, we assessed movement only in the sagittal plane. In previous studies, sit-to-stand in people with hemiplegia following stroke was assessed in the frontal plane and the trunk deviated to the nonparalyzed side, affecting asymmetry (Duclos, Nadeau, & Lecours, 2008). Because we could not evaluate the frontal plane, the impact of trunk movement on the frontal plane of asymmetry could not be determined. Third, in previous studies, it has been reported that the dominant limb influences motor imagery (Zapała, Iwanowicz, Francuz, & Augustynowicz, 2021). However, this study did not examine the dominant foot, and it is possible that VMI may be influenced by the dominant foot. Forth, we examined only the immediate effects, and no clinically beneficial changes in sit-to-stand duration were observed in relation to the MCID.

In the future, the long-term effects of different visual-motor illusions and their impact on sit-to-stand movements should be investigated.

In addition, 20 people were recruited for this study from a pool of about 200 people, and many people with hemiplegia following stroke were not included in this study. This study included hemiplegics who could voluntarily perform DF of their ankle joints and sit-to-stand from a chair without using hands with more than watchful waiting. Thus, less severe people with hemiplegia following stroke may have been recruited, reducing the number of target people with hemiplegia following stroke. Therefore, people with severe hemiplegia following stroke should be included in future investigations to evaluate the generalization of visual–motor illusion effects.

5. Conclusions

To the best of our knowledge, no previous visual-motor illusion studies have examined the effects of different joint movements in visual-motor illusion videos on motor function. Our results showed that power illusion significantly affected sit-to-stand. Power illusion had a higher degree of agency than standard illusion, suggesting that the improvement in paralyzed ankle joint function resulted in a shorter sit-to-stand duration. These results may inform a randomized clinical trial of the intervention with repeated training and follow-up evaluation in the future.

Declaration of interest

The authors in this study declare that there is no conflict of interest.

CRediT authorship contribution statement

Junpei Tanabe: Methodology, Investigation, Validation, Writing – original draft, Writing – review & editing. **Kazu Amimoto:** Methodology, Validation, Writing – review & editing. **Katsuya Sakai:** Methodology, Validation, Writing – review & editing. **Motoyoshi Morishita:** Validation, Writing – review & editing. **Shinpei Osaki:** Writing – review & editing. **Nao Yoshihiro:** Writing – review & editing. **Tokuei Kataoka:** Investigation.

Data availability

Because of the nature of this research, participants of this study did not agree to the public sharing of their data, and so supporting data are not available.

Acknowledgments

The authors would like to thank the members of the Kurashiki Rehabilitation Hospital for their help with this study.

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