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NEUROSCIENCE | RESEARCH ARTICLE

Effects of action observation on learning non-weight-bearing gait with crutches

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Abstract: Action observation (AO) has been used to improve rehabilitation outcomes. We examined the effects of AO gait training on the acquisition of a non-weight-bearing (NWB) gait with crutches. Eighteen healthy young male participants were assigned to control (n = 9) and AO groups (n = 9). All subjects were instructed to walk with crutches at a comfortable speed on a 10-m walkway (10 trials). Participants received a verbal explanation of the experimental task (NWB gait with crutches), after which, those in the AO group watched a video of another person performing the task. An accelerometer was positioned on the third lumbar vertebra and used to measure the trunk acceleration during the experimental task. Gait speed and acceleration root mean squares (RMS) were calculated during the 1st, 5th, and 10th trials for each group. The two-way ANOVA for acceleration RMS revealed significant main effects of trial and group, as well as a significant trial by group interaction. During the first trial, fewer trunk fluctuations were observed in the AO group compared to that in the control group. Thus, AO is effective in improving NWB gait training with crutches during the early phase of acquisition.

Subjects: Neurological Rehabilitation; Fractures; Prosthetics & Orthotics

Keywords: action observation; motor learning; non-weight-bearing; rehabilitation

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PUBLIC INTEREST STATEMENT

Action observation (AO) treatment has become well accepted as a new tool in rehabilitation that the observation of actions performed by others activates in the perceiver the same neural structures responsible for the actual execution of the observed actions. AO has been used to improve rehabilitation outcomes for stroke patient and postsurgical orthopaedic patients. In the present study, we examined the effects of AO gait training on the acquisition of a non-weight-bearing (NWB) gait with crutches in healthy young male participants. Participants who underwent AO, which was adapted to the learning of the NWB gait, obtained more stable walking, with a significantly smaller trunk fluctuation than that in participants who did not undergo AO in the early phase. Thus, AO is effective in improving NWB gait training with crutches during the early phase of acquisition.

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1. Introduction

The use of restricted weight-bearing is widespread in adult rehabilitation. A non-weight-bearing (NWB) gait pattern may be prescribed following lower extremity injuries and surgeries, fractures, severe sprains, joint replacements, and vascular disorders to assist in independent mobility and promote healing (Kathrins & O'Sullivan, 1984). Three-point NWB gait with crutches has been shown to double the energy expended by patients compared to that in normal walking (Fisher & Patterson, 1981; Waters, Campbell, & Perry, 1987). In addition, three-point ambulation with crutches demonstrates significant increases in oxygen consumption (VO_2), carbon dioxide consumption (VCO_2), minute ventilation, respiratory rate, and pulse compared to that in normal walking (Patel et al., 2016). NWB gait requires more strength of the upper extremities, and the standing balance results in less lower extremity bearing compared to that in normal walking. Balance problems can be an obstacle in the acquisition of a NWB gait (Kathrins & O'Sullivan, 1984), and learning how to perform a NWB gait is difficult due to the risk of falls.

Recently, the use of action observation (AO) treatment has become well-accepted as a new tool in rehabilitation (Buccino, 2014). In humans, the observation of actions recruits the same motor representations that are active during the actual execution of those same actions (Bellelli, Buccino, Bernardini, Padovani, & Trabucchi, 2010). Elements of this common circuitry involve the supplementary motor area (SMA), premotor cortex (area 45), inferior parietal cortex (area 40), and primary motor cortex (M1) (Celnik, Webster, Glasser, & Cohen, 2008; Fadiga, Fogassi, Pavesi, & Rizzolatti, 1995; Maeda, Kleiner-Fisman, & Pascual-Leone, 2002; Vingerhoets et al., 2012). Together, these regions constitute the mirror neuron system (Rizzolatti & Craighero, 2004). Several reports on the clinical application of AO exist. In stroke patients, a significant improvement in upper extremity motor function was obtained by providing AO with intensive repetitive practice (Ertelt, Hemmelmann, Dettmers, Ziegler, & Binkofski, 2012). Even in postsurgical orthopaedic patients, the use of AO with conventional physiotherapy results in a significant improvement in balance ability and the functional independence measure (FIM) score compared to that with conventional physiotherapy alone (Bellelli et al., 2010). Furthermore, in a previous study, AO was used to aid in learning how to use prostheses (with stabilized performance as the outcome); the results suggest that AO may play a significant role in residual limb adaption (Lawson et al., 2016). Thus, AO may be adaptable, allowing the improvement of motor function and motor learning for a variety of patients. We hypothesized that NWB gait training can be more efficient through the application of AO. Therefore, the purpose of the present study was to examine the effects of AO gait training on the acquisition of a NWB gait with crutches.

2. Materials and methods

2.1. Participants

Eighteen healthy young male participants (mean age, 20.2 ± 0.6 years) were recruited. The participants were randomly assigned to control (n = 9) and action observation (AO, n = 9) groups. Participants with experience using crutches were excluded from the study. Informed consent was obtained, and the study design was approved by the Ethical Committee of Kawasaki University of Medical Welfare.

2.2. Experimental procedure

The experimental design is depicted in Figure 1. All participants performed the experimental task, which involved swinging a NWB leg according to the gait cycle while walking with crutches (swinging gait). For all participants, the NWB leg (the swinging leg) was on the side of the dominant foot, which was established by asking the participants which foot was used to kick a ball (Schneiders et al., 2010). All participants were right-foot dominant.

Before the participants performed the experimental task, all participants received a verbal orientation while relaxing in a sitting position. During the verbal orientation, one examiner read an explanation on how to use the crutches and swing the dominant foot during the NWB gait.

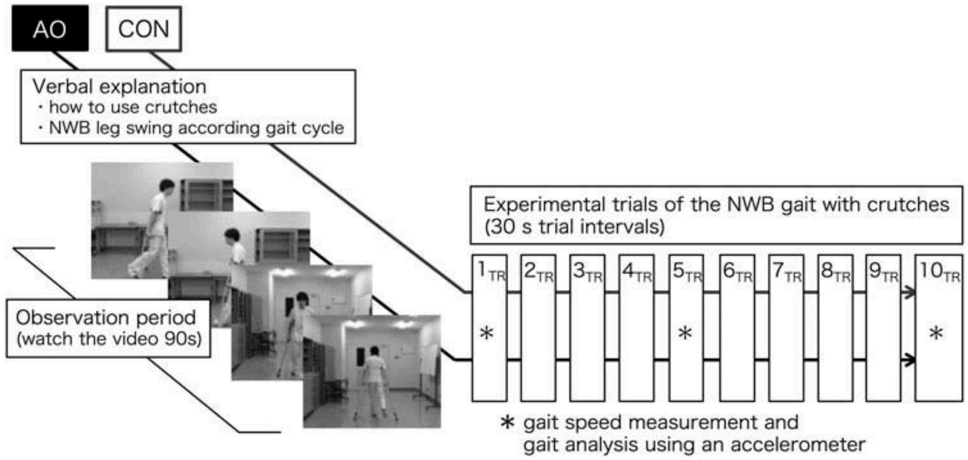

Figure 1. Both control (CO) group and action observation (AO) group received verbal explanation before starting the experiment task. In addition to the verbal explanation, AO group watched a video of another person performing the same task (observation period). The non-weight-bearing (NWB) gait showed a third-person perspective of the entire body from the front, back, right, and left sides in the video. All participants were performed a total of 10 trials. The interval between trials was set to 30 s or more. Gait speed and trunk acceleration were measured during the 1st, 5th, and 10th trials for each group.

Participants in the control group received only the verbal explanation of the task, whereas those in the AO group watched a video of another person performing the same task, after receiving the verbal explanation. The video clips showed the performance of the NWB gait with crutches, paced at a comfortable speed, with a third-person perspective of the entire body from the front, back, right, and left sides. The video was presented for 90 s on a 50-inch monitor. The video was watched from a relaxed sitting position and no instructions were given.

The length of the crutches was adjusted by the examiner who had read the verbal explanation. All participants were instructed to walk with the crutches at a comfortable speed on a 10-m walkway and return, performing a total of 10 trials. The interval between the trials was set to 30 s or more.

A tri-axial accelerometer (MVP-RF8-AC; Microstone, Japan) was used to measure trunk acceleration during the NWB gait. The accelerometer was positioned on the third lumbar vertebra (L3) and secured to the patient using an elastic band and Velcro® (Iosa et al., 2012; Moe-Nilssen, 1998). A footswitch synchronized to the acceleration signal was placed on the heel of the nondominant foot (i.e. the left heel) and the gait cycle was recorded. The gait speed during the NWB gait was measured using a stopwatch. Gait speed and trunk acceleration were measured during the 1st, 5th, and 10th trials for each group.

2.3. Data processing

The acceleration signals were sampled at a rate of 100 Hz, stored in a laptop computer, and analyzed after applying a 10-Hz low-pass filter. Root mean square (RMS) values, which represent time-series acceleration data and reflect fluctuations during walking (Menz, Lord, & Fitzpatrick, 2003), were calculated randomly at 256 points, with reference to the signal of the foot switch. Acceleration RMS is closely associated with gait speed (Menz et al., 2003), and was calculated by dividing the RMS by the gait speed squared. The RMS and walking speed were calculated during the 1st, 5th, and 10th trials, with the average values of the going and returning phases used as representative values for analysis. Using a tri-axis accelerometer, the vertical, anteroposterior, and mediolateral directional components of the trunk acceleration were assessed; however, in the present study, only the acceleration of the vertical component was analyzed (Osaka et al., 2011).

2.4. Statistical design

Statistical analyses were performed using SPSS version 22.0 (IBM, Armonk, NY, USA). All parameters (i.e. gait speed and acceleration RMS) were checked for normality using the Shapiro-Wilk test, and data are presented as means ± SD. Two-way analyses of variance (ANOVAs) were used to evaluate differences between trials and groups in gait speed and acceleration RMS. Between-trial differences were evaluated using one-way ANOVAs and Turkey *post hoc* tests, while between-group differences were evaluated using paired *t* tests. Statistical significance was set at the 5% level.

3. Results

3.1. Gait speed

The two-way ANOVA for gait speed revealed a significant main effect of trial ($p < 0.05$), but the effect of group ($p > 0.05$) and the interaction ($p > 0.05$) were not significant (Figure 2(a)). *Post hoc* analyses demonstrated a significant increase in gait speed in the 5th and 10th trials compared to that in the 1st trial in both groups. Although the gait speed increased between the 5th and 10th trials in both groups, the difference did not reach significance.

3.2. Acceleration RMS

The 2-way ANOVA for acceleration RMS revealed significant main effects of trial ($p < 0.05$) and group ($p < 0.05$), as well as a significant trial by group interaction ($p < 0.05$) (Figure 2(b)). *Post hoc* analyses further showed a significantly smaller acceleration RMS in the AO group compared to that in the control group during the 1st trial ($p < 0.05$).

4. Discussion

In the present study, we aimed to examine the effects of AO gait training on the acquisition of a NWB gait with crutches. We hypothesized that the application of AO results in more effective learning. Although the present results demonstrated a significant increase in gait speed over the trials, there were no group differences. In contrast, there was a significant group by trial interaction for acceleration RMS during a NWB gait with crutches, such that the acceleration RMS in the 1st trial was significantly smaller in the AO group compared to that in the control group, supporting our hypothesis. However, there were no significant group differences in acceleration RMS in the 5th and 10th trials.

To our knowledge, the present study is the first to examine the learning process of a NWB gait with crutches, and to further adapt AO for the acquisition of the NWB swinging gait. In both

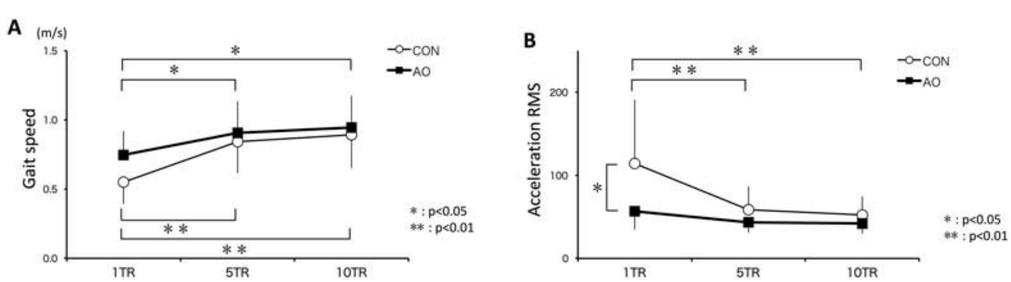

Figure 2. (a) Gait speed in the 1st, 5th, and 10th trials. Two-way ANOVA revealed a main effect of trial ($p < 0.05$), but no effect of group ($p > 0.05$) and interaction ($p > 0.05$). (b) Acceleration root mean square (RMS) in the 1st, 5th, and 10th trials. The two-way ANOVA also revealed a main effect of trial ($p < 0.05$), group ($p < 0.05$), as well as trial and group interaction ($p < 0.05$). *Post hoc* analysis further showed significant differences in acceleration RMS ($p < 0.05$) between the control (CON) and action observation (AO) groups during the 1st trial.

groups, there was a significant increase in gait speed in the later trials compared to that in the 1st trial, reflecting an improvement in the performance of a NWB gait with crutches. Although the AO group had a faster gait speed compared to that in the control group, the difference did not reach significance. However, a significant difference between the AO and control groups was revealed in the acceleration RMS during the 1st trial. The trunk acceleration RMS during walking was used as an indication of the average acceleration during walking (Menz et al., 2003), and reflects the amount of centre of gravity (COG) displacement in the vertical direction (Osaka et al., 2011). Thus, the AO group was able to acquire the NWB gait with significantly lower disturbance of the COG during the early learning phase compared to that in the control group, consistent with previous studies reporting improved early learning through AO. For example, in a study comparing AO, motor imagery (MI), and control groups in the learning of a four-limb hand-foot coordination task, the AO group had a better performance compared to that in the MI and control groups, with a significant reduction in error time during task execution between the first and second 30-second trials (Gonzalez-Rosa et al., 2015). Furthermore, in a study on grasping motions, participants were able to discriminate object size from the observation of grasping motions delivered during the early phase after movement onset (Ansuini et al., 2016). Thus, some authors have proposed that a rapid activation of mirror neurons in the ventral premotor cortices (vPMC) may reflect an initial guess regarding the specific action being perceived (Urgen & Miller, 2015). Furthermore, in at least some instances of AO, the prior information used as the input for the initial guess originates very early in visual processing, perhaps in early visual cortex, and is mediated by thalamocortical projections connecting the medial pulvinar and vPMC. In the present study, the acceleration RMS in the 1st trial was significantly lower in the AO group compared to that in the control group, suggesting the possibility that better NWB gait performance could be obtained in the early phase, as the predictive coding of the motion was generated by the AO before the trial.

In the 5th and 10th trials, there were no significant differences in gait speed and acceleration RMS between the AO and control groups. In addition, the 5th and 10th trial did not differ in gait speed and acceleration RMS. Thus, NWB gait performance had already reached a plateau by the 5th trial. Although learning the NWB swinging gait is generally a difficult task, it is possible that the motor learning was quick because the participants were young and healthy.

The present study revealed that by applying AO to the learning of a NWB gait with crutches, there was less trunk acceleration RMS during the early phase of learning. Trunk acceleration RMS during walking has been reported to be associated with the risk of falling, and individuals with a fall history have increased acceleration RMS during walking. By applying AO to the learning of a NWB gait, it may be possible to obtain a stable NWB walk early, contributing to fall prevention. The effectiveness of AO treatments in the rehabilitation of postsurgical orthopaedic patients, such as those with hip or knee osteoarthritis, has been recently reported (Bellelli et al., 2010). Thus, in addition to conventional physiotherapy, AO is beneficial for the early acquisition of a NWB gait with crutches.

There are several limitations in the present study. First, the participants were healthy subjects, without lower extremity orthopaedic disease. Furthermore, only male subjects participated in this study; however, the proportion of patients who walk with NWB using crutches is larger for males than for females. In a previous cohort study on NWB using crutches (Quested, Wiltshire, Sommerville, & Lutz, 2017), 64□ of the patients were male, while 36% were female. Osteoporotic fractures of the lower limbs are female predominant; however, lower extremity orthopaedic diseases requiring the use of crutches, such as ligament injuries and open fractures, are considered to be more common in men than in women. The average age of patients using crutches is 45 years, and it is necessary to verify the results with age-matched subjects. Second, we only examined the immediate effect of adapting AO to the learning of a NWB gait with crutches. Further investigations are necessary to examine the continuous effects of applying AO to NWB gait learning in patients with orthopaedic disease, as well as to evaluate transfer effects to partial weight-bearing gait with crutches.

5. Conclusions

The present study demonstrated the effect of AO on the learning of NWB walking with crutches. Participants who underwent AO, which was adapted to the learning of the NWB gait, obtained more stable walking, with a significantly smaller trunk acceleration RMS, in the first trial. Therefore, AO is an effective approach during NWB gait training with crutches in the early acquisition phase.

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Competing Interest
The authors report no conflict of interest.

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