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Immediate after-effects of shapes of clothing worn on tandem gait performance

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Purpose: This study investigated the immediate after-effects of clothing shape on tandem gait performance. *Methods*: Nineteen healthy men (21.8 ± 1.8 years) performed tandem gait tests while blindfolded under three clothing conditions: only half or short tights, a cotton cloth wrapped around the waist and draped to the middle point of the lower leg (DC), and tracksuit bottoms (TS). Participants performed pre- and post-gait tests at their fastest possible speed while wearing tights. Between the pre- and post-tests, participants practiced the same tandem gait, but at their own chosen speed while wearing DC or TS. *Results*: The practice with the DC increased gait speed and decreased lateral shift during the post-gait test compared to the pre-gait test. The practice while wearing the TS also reduced lateral shift but did not increase gait speed. *Conclusions:* These results suggest that some clothing shapes are more effective for motor learning of balance control during tandem gait by enhancing the feedback for body orientation. Clothing that has a certain amount of space between the material and the body and that makes contact with the body as it moves may be more effective.

Key words: *light touch, gait speed, balance control, motor learning, garment*

1. Introduction

Successful independent gait depends on balance control to build and support the appropriate postural orientation of body segments relative to one another and to the environment and also ensures dynamic balance control during movement [4]. Such a gait process depends on the integration of a variety of sensory inputs and must be conducted within the limits of biomechanical constraints inherent to the individual's ability and the difficulty of the tasks [4]. Sensory information may come from "intrinsic" feedback from many kinds of receptors, including the muscles, joints, tendons, skin, visual, auditory, somatosensory, and other systems, or post-movement production [23]. Conversely, "extrinsic" feedback is information from an external source that augments the intrinsic feedback [23].

A variety of sensory feedback, including visual, auditory, and others, are usually utilised to obtain the motor learning effect of movement control [28], and the development of easy-to-use feedback devices has also been reported [32]. Unlike during standing, vision plays many roles during locomotion, providing information for upright stability and body position relative to the external environment [12]. Therefore, visual feedback may be an important technique for enhancing path consistency during over-ground locomotion [1]. However, previous studies have demonstrated that auditory feedback practice, but not visual feedback practice, enhances the motor learning effect of dynamic postural control [5], [6], [25]. This is because visual feedback increases dependence on visual sensation for human movement, while auditory feedback may create a learning process that gradually increases reliance on proprioceptive sensation [27], and auditory feedback practice is thought to enhance the integration of proprioceptive sensory systems that contribute to motor learning [6]. However, not everyone can make use of such feedback systems on a daily basis, as they require a device to provide feedback.

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Somatosensory inputs, such as haptic or cutaneous sensations, are also important for balance control. For instance, the importance of sensory input from plantar mechanoreceptors for balance control and in times when balance is disturbed has been reported in many previous studies [13]–[15], [22], [24]. Furthermore, haptic sensory input through touch also contributes to postural control. Previous studies demonstrated that although individuals touch a fixed pedestal [7], [20], cane [17], [29], body parts [16], and other individual [26] with a poor force to hold mechanically on their own body, postural stability is enhanced due to touching. This kind of additional light haptic input is thought to augment the perception of one's own body orientation [7]. Such additional haptic input also contributes to postural control during human movement [3], [10], [18], [21]. Further, the influence of this haptic input has also been observed to persist even immediately after the withdrawal of touch. For instance, Johannsen et al. [8] reported that reductions in postural sway during a tandem stance persisted even after touch withdrawal. Oshita and Yano [17] also reported that postural sway during a single-leg stance was decreased during a 30-s touch of a cane, which decreased immediately after removal of the cane. Therefore, additional light haptic input through touch during standing is suggested to promote the practice effect of balance control.

Such an influence of additional light haptic input is observed by the increase in gait speed during tandem gait while wearing a fluttering cloth wrapped around the waist and extended to the lower leg as opposed to wearing tights [18], [19]. This is because individuals might be able to recognise the movement direction (i.e., putting a foot forward) based on wearing the cloth [18]. Furthermore, skirt-like outfits such as kilts in Scotland and the hakama in Japan, which provide a certain space between the skin of the leg and the cloth (leg can touch cloth only by movement), are observed to be effective in improving gait ability. This is compared to trousers or tracksuit bottoms, where the body and cloth are in continuous contact [19]. A previous study demonstrated that real-time haptic feedback of direction in center of foot pressure displacement using vibration attached around trunk could enhance the motor learning effect [31]. Furthermore, studies on upper limb movements have also reported that haptic input enhances motor learning effects and leads to retention of learning effects [30]. Based on these previous reports, this study hypothesizes that depending on the type of the clothing enhances learning effect of gait performance because the clothing touches the body as it moves, leading to feedback of body orientation. If such an effect can be observed, it may be useful to utilize personal belongings for the motor learning of human movements in performing daily activities. Therefore, this study investigated the immediate after-effects of the shapes of garments worn on gait performance during tandem gait.

2. Materials and methods

Participants

Data were obtained from 19 healthy men (age, 21.8 ± 1.8 years; height, 1.70 ± 0.11 m; weight, 69.1 ± 3.0 kg) recruited from a local university in Japan. Participation was voluntary, and the men being examined could drop out at any time. Prior to their inclusion in the study, the participants were informed of the purpose of the study, and informed consent was obtained from each participant. Further, the following inclusion criteria were applied: no current or previous medical history of neural, muscular, or skeletal disorders, level of physical fitness that facilitates this study's gait test without any orthopaedic aids (supporters, taping, crutches, etc.). This study was approved by the Human Ethics Committee of the Graduate School of Human Development and Environment, Kobe University (No. 331).

Experiment

All experiments were carried out between February and April 2020 in air-conditioned laboratory at a comfortable room temperature. The experimental setup and protocol of this study were carried out as previously described [19]. Because a larger effect of haptic input through wearing cloth was observed during tandem gait than during normal gait [19], tandem gait was conducted as the gait test in the present study.

The participants were asked to perform an 11 m gait test (Fig. 1). The centre line was drawn to cross the start (0 m) and finish (11 m) lines. Sensors in photocell timing system (TMN-02, TAMAKAWA, Hiroshima, Japan) were located 1 m and 11 m from the starting point. Gait time (in seconds) was automatically measured by this system and the gait speed was calculated. The participants were instructed to remove their footwear, stand on the starting line, and wear a blindfold (black-painted swimming goggles). Participants stood with tandem feet (heel-to-toe) on the starting line, and the centre line was located at the centre of their feet. Subsequently, the participants were instructed to begin walking at an arbitrary time

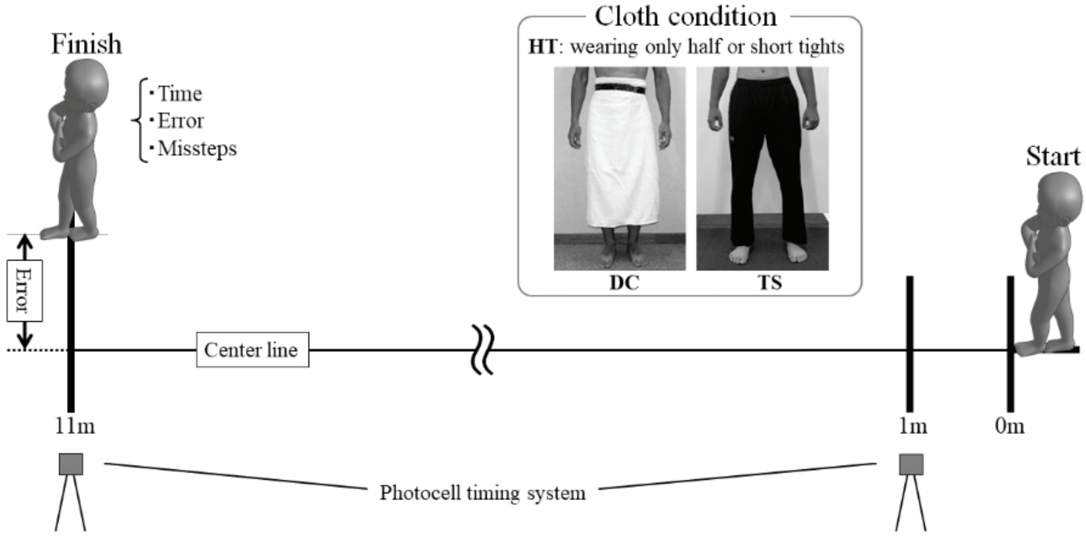

Fig. 1. Schematic of the experimental setup

and to walk with the heel of one foot continually placed directly in front of the toe of the other foot. During the gait test, the arms were crossed in front of the chest to avoid timing by swinging their arms.

When the participant's trunk reached the 11 m point, a beep sound was made by the timing system, and the participants stopped walking and maintained their posture. The distance between the intersection of the centre of the feet and the finish line from the centerline was measured and evaluated as a mediolateral error (Error; in meters). A step deviating from the toe-to-heel line during gait test was defined as a misstep, with the total number of misstep (s) counted by the experimenter and confirmed using video camera (GZ-E109, JVCKENWOOD, Kanagawa, Japan) which was placed diagonally in front of the finish line.

The gait test was performed while wearing three different garments: 1) only half or short tights (HT); 2) HT and a cotton fibre-draped cloth secured with a belt, draping from the waist from the L3 to L5, to the middle point of the lower leg (DC); and 3) HT and tracksuit (TS) bottoms (QO31701, Underarmour). Small, medium, large, and extra-large tracksuits were prepared, and the participants chose the tracksuit with the best fit.

Before the experiment, participants were allowed to familiarise themselves with the gait test only under the HT condition for approximately 5 min. Each participant was asked to perform a gait test two consecutive times while wearing the HT and was instructed to walk as fast and straight as possible (pre-trial). After the pre-trial, participants practiced the same gait test twice, but at their own chosen gait speed (practice session). Participants were divided into two groups during the practice session: the DC group (wore DC) (n = 10) and the TS group (wore TS) (n = 9). Further, the participants were instructed by the examiner to feel the direction in which they stepped forward and the swaying of their body as a result of contact with the cloth. A study investigating the effect of haptic addition on the immediate after-effect of postural control reported that the decrease in postural sway was sustained even after 30 s of haptic addition [17]. Based on a previous study in which tandem gait was performed using the same method as in the present study [19], it is considered that a tandem gait of 11 m (under the condition of as fast as possible) takes approximately 13 s. In the present study, two practice sessions were chosen, because it was estimated that two 11 m tandem walking sessions would take about 30 s, since the practice session was conducted at the participants' chosen speed. In the post-trial, each participant was asked to perform the gait test again, as in the pre-trial.

An intra-class correlation coefficient (ICC) was used to calculate the level of agreement between normal gait tests in HT condition and a highly reliable from trial to trial was reported in the previous study [19] which was same experimental setup in this study.

Statistical analysis

Of the gait parameters (gait speed, mediolateral error, and number of missteps) measured twice for each trial, those with the shortest gait time were chosen for analysis. In order to evaluate intergroups differences in gait parameters in the pre-trial, the Student's t-test was conducted after a significantly equal population variance was observed by the F-test. The effects of the practice session and the type of cloth on gait parameters were evaluated using a two-way repeated-measures analysis of variance (ANOVA) to compare the time factor (pre- and post-trial) and type of clothing. Post hoc analysis of achieved power (1-β) for ANOVA (repeated measures, within-between interaction) was conducted using G*Power software (version 3.1.9.7) with effect size, α error, total sample size, number of groups, number of measurements, correlation among repeated measures (= 0.5), and non-sphericity correction ε (= 1). When a significant interaction was observed in the ANOVA test, the p-values were corrected using the Holm procedure for multiple testing.

These analyses were performed using JSTAT (version 20.0 J) and js-STAR software (version 9.8.6j). The level of statistical significance was set at $p < 0.05$. In addition to the significance testing, the effect size was calculated for the ANOVA test (only in interaction) using the F-value for calculating statistical power. Further, in addition to the multiple testing, the effect size between the pre- and post-trials was calculated using Cohen's d, which was evaluated as small for $d < 0.2$, large for $d > 0.8$, and medium as between small and large. Data are presented as mean ± standard error of the mean (SEM) unless otherwise stated.

3. Results

The t-test observed no significant difference in these variables between the groups (pre-trial in Table 1). Table 1 shows the changes in the gait variables for each group. For gait speed, the ANOVA revealed that although the effects of time (pre- and post-trial) or group (DC and TS) on gait speed were not significant, there was a significant interaction between time and group ($p = 0.03$). Furthermore, although gait speed in DC group significantly increased after practice session and the effect size was moderate ($d = 0.47$), it was not observed in TS group. For the error, although the ANOVA revealed significant effects of time on the error ($p = 0.02$), no significant effect of the groups and their interactions were observed. However, the change in error was large in the DC group, with a moderate effect in the TS group. For the missteps, ANOVA revealed that there were no significant effects of time, group, and their interactions

4. Discussion

The obtained results indicate that practicing tandem gait with a cloth wrapped from the waist to the lower leg increases the gait speed and decreases the lateral shift (error) during tandem gait even immediately after the cloth is removed. The practice with the track suit also showed the effect of reducing the lateral shift, but not the effect of increasing the gait speed.

It has been reported that balance control is improved with the addition of light haptic input, not only during standing [7], [8], [16], [17], [20], [26], [29] but also during gait [3], [10], [18], [19]. In a previous study using the same shape of clothing as this study, it was reported that the speed of tandem gait improved while wearing DC, but not TS [19]. Although it is unclear how gait ability changed while wearing clothes in this study, gait practice while wearing the DC improved gait speed immediately after removing the clothing. On the other hand, errors were significantly smaller after the practice session, regardless of clothing type. The interaction between pre- and post-practice and clothing type was not significant, but the effect size of the change in error was larger when practicing with the DS. Therefore, regardless of the shape of the clothing, practice effects on improving lateral shift during tandem gait are observed, but the effect may be greater when practicing with the DS. A previous study reported that the addition of light haptic input to the hand or fingers reduced postural sway while standing, even immediately after removing the haptic input [8], [17]. The results of this study suggest that feedback enhancement of body orientation by adding haptic input is effective for motor learning of balance control

Table 1. Means and S.E.M. of each variable in pre- and post-test

Variables	Group	Pre				Post				Effect size (d)	ANOVA (F)		
		MEAN	±	SEM		MEAN	±	SEM			time	group	interaction
Gait speed [m/s]†	DC	0.573	±	0.055		0.669	±	0.068	#	0.495	3.036	0.225	5.624*
	TS	0.596	±	0.021		0.582	±	0.017		0.259			
Error [m]†	DC	0.670	±	0.132		0.300	±	0.049		1.176	6.944*	0.070	1.156
	TS	0.533	±	0.110		0.378	±	0.089		0.520			
Missteps [steps]†	DC	0.800	±	0.237		0.600	±	0.290		0.240	0.220	0.389	1.533
	TS	0.333	±	0.157		0.778	±	0.210		0.800			

* – $p < 0.05$ (ANOVA), # – $p < 0.05$ (vs. DC group, Holm's test), † – statistical power $(1 - \beta) \geq 0.80$.

in both upright stance and gait. A previous study has reported the shape of clothing that has a certain space between the body and the clothing and that touches the body only during movement (i.e., DS) may be more effective in enhancing balance control than clothing with a shape in which the body and clothing are always in contact (i.e., TS) [19]. Therefore, the results of this study show that, depending on the shape, clothing can have a transient learning effect on balance control.

Perceived enhancement of body orientation has been pointed out as a mechanism by which additional light haptic input enhances balance control [7]. As for the effect of clothing on gait ability, there was a significant correlation between the subjective change in walking sensation and the change in gait speed due to the wearing of clothing [18]. This means that those who were able to recognise the positional sense of body parts and/or direction more easily through contact with clothing also improved their gait ability. In terms of the motor learning effect, Ronsse et al. [27] found that the learning effect in the after-feedback condition was only observed in the group practicing with auditory feedback, despite there being no difference in task performance during visual or auditory feedback. Furthermore, functional nuclear magnetic resonance tomography revealed that brain activity in visual areas increased during the practice period with visual feedback, while in contrast, brain activity in auditory areas decreased and a broad network activity related to auditory and proprioceptive networks increased during the practice period with auditory feedback [27]. It has been shown that this phenomenon may also occur in dynamic balance control, and it suggests that sensory reweighting reduces the contribution to proprioception and increases reliance on visual input [25]. Because visual feedback practice may make it difficult to achieve a learning effect after feedback removal, feedback using other senses can be useful for motor learning. In the present study, the direction of movement and the degree of postural sway could be recognised by the contact of the clothing with the legs during movement when the visual input was blocked, and it is thought that augmentation of such haptic feedback led to the learning of gait ability. However, these mechanisms of motor learning by additional haptic input should be investigated and clarified, including brain activity, as described above in the future.

Gait speed in DC group significantly increased after practice session. However, two participants in the DC group did not show improved gait speed. Although we could not identify the reason for this, it is possible that the participants' sensory dependence on balance control was different. Lion et al. [11] investigated the sensorimotor strategies in balance control of cyclists and found that the use of proprioception in mountain bikers was increased by a higher intensity of off-road cycling while the use of vision was increased by a higher intensity of on-road cycling. Furthermore, balance performance in road cyclists was better than that of mountain bikers both during quiet stance with eyes opened and when only somatosensory information was disrupted, highlighting higher use of vision to control balance in road cyclists [11]. Similarly, gymnasts, who usually control their body movements by vision, have been reported to improve their balance control only in conditions without visual deprivation [2]. It has also been reported that there was no significant improvement in the parameters of upright postural control after snowboard training, which would highly require balance control [9]. These studies suggest that the effect of feedback stimuli on motor learning may be different depending on adaptive processes elaborated from environmental stimuli and the technical specificity of their background (i.e., sport activity, etc.). Therefore, it is necessary to consider the background of the participants in future experiments.

The current study has several limitations. First, it is unclear how effective haptic feedback is for motor learning compared to other types of feedback. Second, the detailed mechanism of motor learning using the haptic sensation with cloth is unknown. Furthermore, whereas the characteristics of clothing that individuals usually wear differ depending on their gender, the participants in this study were only men. Therefore, future studies are required to investigate what kind of feedback methods are effective for improving gait performance, muscle activity and motor learning system, including the effect of gender differences. However, the present study showed that a feedback method that is accessible to everyone (i.e., no specific device), such as a personal belonging (i.e., clothing), enhances motor learning of balance control during gait. Further investigation of the details of the shape and material of the clothing will make these results more applicable to daily life.

5. Conclusions

This study investigated the immediate after-effects of the shapes of garments worn on gait performance during tandem gait. Practicing tandem gait with a cloth wrapped from the waist to the lower leg increases the gait speed and decreases the lateral shift during tandem gait, even immediately after the cloth is removed. The practice with the track suit also showed the effect of reducing the lateral shift, but not the effect of increasing the gait speed. These results suggest that some clothing shapes are effective for motor learning of balance control during gait by enhancing the feedback of body orientation. Clothing that has a certain amount of space from the body, only making contact with the body, may be more effective compared to clothing which makes constant contact with the body.

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