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Influence of Haptic Sensory Input through Different Kinds of Clothing on Gait Performance

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Abstract: This study investigated the effects of haptic sensory input by different types of clothing worn on gait performance. Twelve healthy men performed normal and tandem gait tests with blindfolds under three different clothing conditions: (1) wearing only half tights (HT); (2) wearing a skirt-like draped outfit such as a cotton cloth wrapped around the waist and extended to the lower leg (DC); and (3) wearing a trouser-like outfit such as tracksuit bottoms (TS). Although gait speed was significantly increased in DC as compared with HT, this was not observed in TS. Missteps during tandem gait were significantly reduced with DC. In addition, DC made walking easier for individuals as compared with TS. These findings suggest that wearing a skirt-like outfit such as kilts in Scotland or the hakama in Japan may provide haptic sensory cues to enhance individuals' perceptions of their body orientation as compared with trouser-like clothing that is in continuous contact with the legs.

Keywords: light touch; gait time; tandem gait test

1. Introduction

Various sensory inputs, such as visual, vestibular, and somatosensory inputs, contribute to the adjustment of balance control during posture maintenance [1]. Haptic sensory information through touching also contributes to balance control. Previous studies reported that although individuals touch a fixed pedestal with an insufficient force to support their own body weight mechanically, postural sway during upright posture is attenuated by the touching cue [2,3]. This phenomenon is called the "light touch" effect. This light-touch effect is observed not only with a fixed pedestal, but also with unstable objects such as cloth curtains [4], canes [5,6], the individual's own body [7], and other individuals [8,9]. Such haptic information through light touch is thought to enhance individual perception of body orientation [10]. Therefore, light touch enhances the existing sensation of the body or body segments and contributes to an individual's perception of the relative changes in the position or direction of the trunk, arms, thighs, and so on.

Light touch contributes to balance control not only in certain postures, but also for postural control during motion. The functional reach test, known as the dynamic balance measure, is improved by light touch [11]. During constant-speed gait on a treadmill with eyes closed, the center of the body sway was attenuated by light touch to the side rail [12]. Even during gait on the ground with eyes closed, the mediolateral step width variability was decreased while touching a fixed object on the side of the walking lane [13]. These results suggest that various balance controls while performing daily activities may be enhanced by light touch. Furthermore, if the light touch effect can be provided by personal belongings, it will be useful for improving human movements in daily activities.

Although postural stability is improved by light touch, the effects of light touch on gait speed are inconsistent. Oates et al. [14] reported in their review that the effects of light touch on gait speed and step length may depend on the type of tool used. Kodesh et al. [13] reported that gait speed was decreased by light touch, suggesting that adding light touch may add not only haptic information but also attentional demands. Such additional attentional demand is called the "dual task" effect and might interfere with gait performance, that is, when an individual generally walks slowly when asked to walk and perform another task [15]. On the other hand, the light-touch effect is observed not only in active touching but also in passive haptic sensory input [16], and it is thought the passive touching could not be an additional attentional demand. In fact, a decrease in gait time was observed during tandem gait on the narrow walkway board with the eyes closed and a fluttering cloth wrapped around the waist and extended to the lower leg (cloth passively touching the lower leg) as compared with wearing only tights [17]. Therefore, depending on the shape of the garment worn, balance control during locomotion might be enhanced.

However, the effect of passive haptic sensory input such as a fluttering or draping cloth on fundamental gait parameters, including gait speed and step length, during normal gait on normal ground (daily conditions) has not been reported. Furthermore, a previous study compared the gait parameters between wearing fluttering clothing and half or short tights. If passive haptic sensory input through wearing clothing was effective for gait performance, wearing only trousers could also be effective. A previous study suggested that individuals can recognize the moving direction (i.e., putting foot forward) on the basis of the fluttering of the cloth [17]. According to this suggestion, 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 by movement), might be effective for improving gait parameters. In addition, these outfits make contact with body parts as they move. Conversely, clothing such as trousers, where the body part and cloth are in continuous contact, might not help to improve the gait performance.

Therefore, this study investigated the effects of the shapes of garments on fundamental gait parameters during normal and tandem gaits on a normal surface to acquire a preliminary data. The garments were a skirt-like outfit such as a cotton cloth wrapped around the waist and extended to the lower leg and trouser-like outfits that did not interfere with movement, such as tracksuit bottoms.

2. Materials and Methods

2.1. Participants

Data were obtained from 12 healthy men (age, 18–37 years; height, 1.60–1.78 m; weight, 52.6–100.1 kg) with no current or previous medical history of neural, muscular, or skeletal disorders. Prior to inclusion in the study, the participants were informed of the purpose of the study and informed consent was obtained from each participant. This study was approved by the Human Ethics Committee of the Graduate School of Human Development and Environment, Kobe University (No. 331).

2.2. Experimental Setup (Figure 1)

The participants were asked to perform two types of 11 m gait tests under three clothing conditions. The center line was drawn to cross the start (0 m) and finish (11 m) lines. Photocell sensors were located 1 and 11 m from the starting point. A digital video camera (GZ-E109, JVCKENWOOD, Kanagawa, Japan) for step and misstep counting was placed diagonally in front of the finish line. The participants were instructed to remove their footwear, stand on the starting line, and wear a blindfold (black-painted swimming goggles). Subsequently, the participants were instructed to begin walking as straight as possible at an arbitrary timing. During the gait test, the arms were crossed in front of the chest to avoid timing by swinging their arms. When the participants' trunk reached the 11-m point, a beep sound was made by the timing system. The participants stopped walking upon hearing the beep sound (i.e., reaching the finish point; Figure 1).

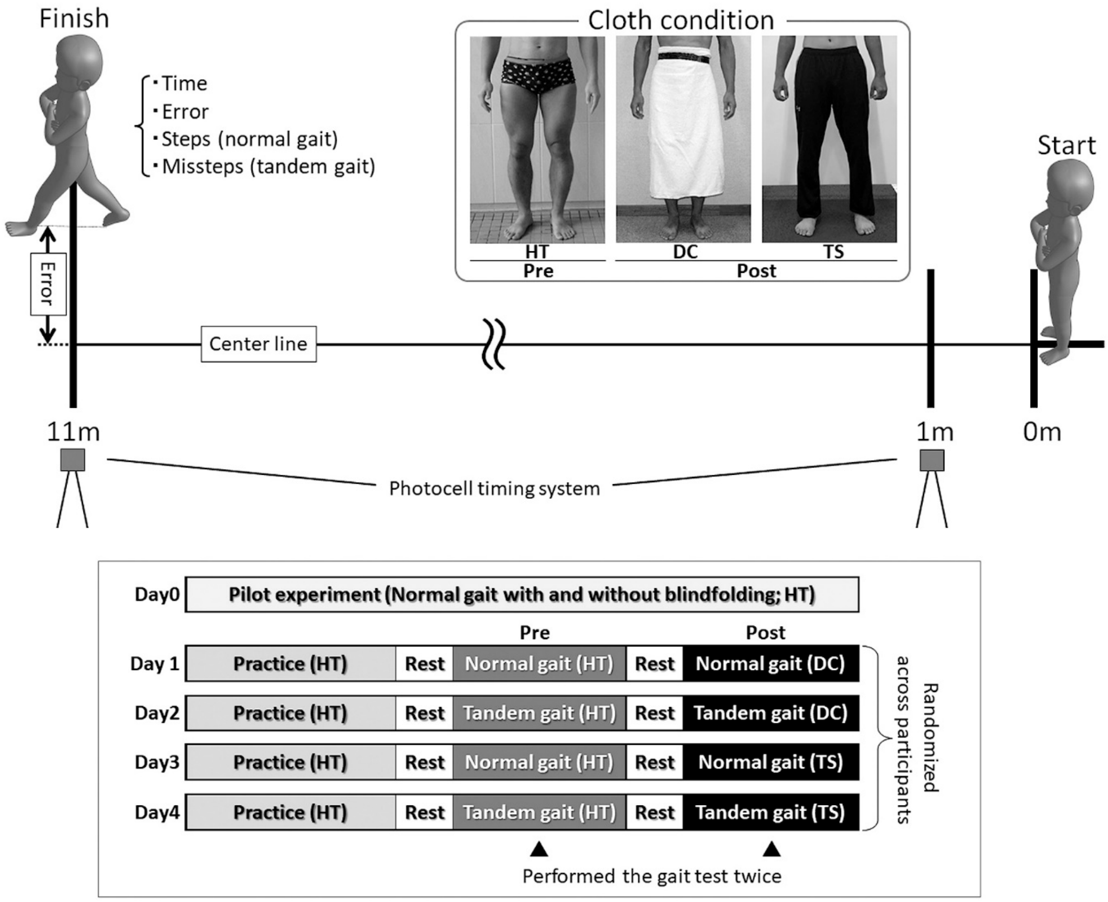

Figure 1. Schematic of the experimental protocol.

The gait tests showed normal and tandem (heel-to-toe) gaits. In the normal gait, the participants stood on the starting line with the feet placed in such a manner that the center line was located between the feet. The participants were instructed to walk at their usual speed. For the tandem gait test, the participants stood with tandem feet (heel-to-toe) on the starting line and the center line was located at the center of their feet. The participants were instructed to perform tandem gait with the heel of one foot continually placed directly in front of the toe of the other foot. During tandem gait, the participant was instructed to walk as fast and straight as possible.

These gait tests were performed while wearing three different garments as follows: (1) only half or short tights (HT); (2) HT and a cotton fiber draped cloth wrapped around the waist, 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 bottoms (QO31701, Underarmour). Small, medium, large, and extra-large tracksuits were prepared, and the participants chose the tracksuit with the best fit (TS).

2.3. Protocol

A pilot experiment was conducted on the day prior to the experiment with all participants. The participants performed an 11-m normal gait with and without blindfolding. These gait tests were conducted twice while wearing the HT. The gait time and number of steps were measured.

For the main experiment, each participant was asked to perform one gait test (normal or tandem) while wearing the HT at the pre-trial. In the post-trial, the participants were instructed to perform the same gait test while wearing the DC or TS. The participants performed the same test twice in each trial with a 3 min rest period between trials. Before the experiment, a practice session was conducted to familiarize the participants with each gait test using a blindfold only under the HT condition for approximately 5 min. The experiment was conducted on four separate days by a combination of normal or tandem gait test and wearing DC or TS in the post-trial. The order of the gait test and types of clothing in the post-trial were randomized across the participants.

2.4. Procedures

The gait time, mediolateral error, number of steps (normal gait), and number of missteps (tandem gait) were measured as fundamental gait parameters. Subjective walking sensation was measured using a visual analogue scale (tandem gait). Of the test parameters measured twice for each trial, those with the shortest gait time were chosen for analysis.

Gait time: gait time (in seconds) was measured using a photocell timing system (TMN-02, TAMAKAWA, Hiroshima, Japan). The time was automatically measured by photocell sensors when the participant's trunk reached two points, at 1 m and 11 m from the starting line (Figure 1).

Medio-lateral error (Error; in meters): Error was defined as the distance of the lateral deviation from the center line when the participant reached the finish line (Figure 1). The participants stopped walking on reaching the finish line and maintained their posture. In the normal gait task, the distance of the intersection between the line connecting the outside portion of the first metatarsophalangeal joint in both feet and the finish line from the center line was measured. In the tandem gait task, the distance of the intersection of the center of the feet and the finish line from the center line was measured.

Number of steps: the number of steps made by the participant between the 1-m line and the finish line was counted by the experimenter and subsequently confirmed in the video footage. The number of steps was measured only in the normal gait test because of the absence of step length (toe-to-heel) in tandem gait.

Number of misstep(s): a step deviating from the toe-to-heel line was defined as a misstep, with the total number of misstep(s) counted by the experimenter, which was confirmed in the video footage.

Visual analogue scale (VAS): the subjective walking sensation was measured using the VAS, which is a 100 mm horizontal line, because the tandem gait task is originally difficult to perform on the basis of previous research [17]. The degree of difficulty with regard to the walking sensation was marked within a range of 0 mm (able to walk easily, similar to the task performed with eyes open in the pilot experiment) to 100 mm (difficult to keep tandem while standing upright) by the participant. The VAS score was measured immediately after the DC and TS condition trials, with the participants not being informed of any result of the trial, such as gait time. Furthermore, the VAS scores in the other trials were not divulged to the participants when the VAS score was measured in the trials; that is, the participants could not compare their own VAS scores between trials.

2.5. Statistical Analysis

In the pilot study, the gait time and number of steps with or without blindfold were compared using a paired t test. An intra-class correlation coefficient (ICC) was used to calculate the level of agreement between the pilot experiment and two pre (HT) condition for gait time in normal gait. The effects of wearing clothes in each gait test on the gait time, number of steps, number of misstep(s), and errors were evaluated using a two-way repeated-measures analysis of variance (ANOVA) to compare the time factor (pre and post) and type of clothing. Post hoc analysis of achieved power ($1 - \beta$) 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 significant interaction was observed in the ANOVA test, the p values were corrected using the Holm procedure for multiple testing. To investigate the effect of wearing DC or TS on subjective walking sensation, the VAS scores were compared using a paired t test. These analyses were performed using the JSTAT (version 20.0J) and js-STAR software (version 9.8.6j). The level of statistical significance was established at <5%. In addition to the significance testing, the effect sizes were calculated for ANOVA test (only in interaction) using F-value, and differences between the pre- and post-trials using Cohen's d. Cohen's d

was evaluated as small for d less than 0.2, large for d greater than 0.8, and between small and large is medium. Data are presented as mean ± standard error of mean (SEM), unless otherwise stated.

3. Results

In the pilot experiment, the gait time was significantly shorter without the blindfold than with the blindfold (9.07 ± 0.35 s vs. 12.42 ± 0.81 s, $p < 0.01$) and the effect size was large ($d = 1.48$). The number of steps was significantly fewer without the blindfold than with the blindfold (16.33 ± 0.58 steps vs. 19.08 ± 0.79 steps, $p < 0.05$), and the effect size was large ($d = 1.10$). The ICC for gait time was 0.84, indicating that it was highly reliable from trial to trial.

Table 1 (upper) shows the mean value of each variable during the normal gait test. The ANOVA revealed that although the effects of time or clothing on gait time were not significant, the interaction between them was significant ($p = 0.02$). The multiple testing revealed that although the post-gait time in DC showed a significantly shorter times as compared with the pre-gait time ($p < 0.05$), it was not observed in the TS condition. Furthermore, significant difference in gait time was not observed between cloth conditions in the HT (pre-) condition. The effect sizes of the change in gait time in DC and TS conditions were medium ($d = 0.39$ and 0.24). For the number of steps, the ANOVA revealed that although the effects of time or clothing were not significant, a significant interaction between them was observed ($p = 0.04$). However, multiple testing revealed no significant differences. For the error, the ANOVA revealed no significant differences. Therefore, although the walking speed in the normal gait increase significantly with DC, significant difference in walking speed was not observed in the case of TS.

Table 1 (lower) shows the mean values of the variables during the tandem gait test. The ANOVA revealed that although the effects of time or clothing on gait time were not significant, the interaction between them was significant ($p = 0.02$). The multiple testing revealed that although the post-gait time in DC showed a significantly shorter times as compared with the pre-gait time ($p < 0.05$), it was not observed in the TS condition. Furthermore, a significant difference in gait time was not observed between cloth conditions in the HT (pre-) condition. Although the effect size of the change in the gait time in TS was medium ($d = 0.26$), a large effect was observed in DC ($d = 0.80$). For the number of missteps, ANOVA revealed that although the effect of time or clothing on missteps was not significant, the interaction between them was significant ($p < 0.01$). The multiple testing revealed that although the post-missteps in DC showed a significantly fewer missteps as compared with the pre-missteps ($p < 0.05$), it was not observed in the TS condition. Furthermore, a significant difference in missteps was not observed between cloth conditions in the HT (pre-) condition. Although the effect size of the change in missteps in TS was medium ($d = 0.45$), a large effect size was observed in DC ($d = 0.88$). For the error, the ANOVA revealed no significant differences. Therefore, the walking speed in tandem gait was significantly increased, and the missteps were significantly reduced with DC. However, these were not observed in the case of TS.

Figure 2 shows the walking sensation (through VAS) in the tandem gait. The VAS scores in DC were significantly lower than those in TS ($p < 0.05$); however, a medium-sized effect was observed ($d = 0.64$). Therefore, the participants in the DC group found it easier to walk than those in the TS group.

Table 1. Mean value of each variable during normal and tandem gait tests. Values are expressed as mean ± standard error of the mean.

	DC		TS		ANOVA			Effect Size		
	Pre (HT)	**Post (DC)**	**Pre (HT)**	**Post (TS)**	**Pre-Post**	**DC-TS**	**Interaction**	**ANOVA (Interaction)**	**DC (Pre-Post)**	**TS (Pre-Post)**
Normal gait test										
Gait time (s)	12.50 ± 0.85	11.34 ± 0.87 *	11.66 ± 0.79	12.42 ± 1.06	N.S.	N.S.	$p = 0.02$ †	$F = 0.56$	$d = 0.39$	$d = 0.24$
Number of steps	18.75 ± 0.84	18.08 ± 0.85	18.25 ± 0.85	19.00 ± 1.07	N.S.	N.S.	$p = 0.04$	$F = 0.48$	$d = 0.23$	$d = 0.22$
Error (m)	0.56 ± 0.20	0.73 ± 0.15	0.92 ± 0.26	1.11 ± 0.22	N.S.	N.S.	N.S.	$F = 0.01$	$d = 0.27$	$d = 0.23$
Tandem gait test										
Gait time (s)	17.21 ± 1.51	14.09 ± 0.76 *	15.39 ± 0.89	16.23 ± 1.00	N.S.	N.S.	$p = 0.02$ †	$F = 0.53$	$d = 0.80$	$d = 0.26$
Number of missteps	0.58 ± 0.22	0.08 ± 0.08 *	0.42 ± 0.14	0.67 ± 0.18	N.S.	N.S.	$p < 0.01$ †	$F = 0.60$	$d = 0.88$	$d = 0.45$
Error (m)	0.58 ± 0.12	0.41 ± 0.13	0.37 ± 0.08	0.48 ± 0.09	N.S.	N.S.	N.S.	$F = 0.31$	$d = 0.39$	$d = 0.37$

N.S.: Not Significant, *: vs. "Pre", $p < 0.05$ (Holm's test), †: Statistical power $(1 - \beta) \geq 0.80$.

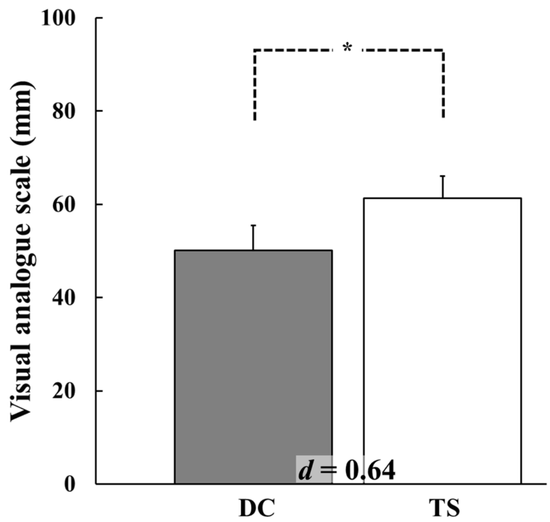

Figure 2. Effect of the type of clothing worn on subjective gait sensation during the tandem gait test. A range from 0 mm (able to walk easily, similar to the task with eyes open in the pilot experiment) to 100 mm (difficult to keep tandem while standing upright). Values are expressed as mean ± standard error of the mean. *: $p < 0.05$.

4. Discussion

The present study revealed that although the walking speed in the normal and tandem gaits significantly increased while wearing unbifurcated draped clothing around the leg, it was not observed in the case of wearing tracksuit bottoms. In addition, the missteps during tandem gait were significantly reduced by wearing a draped cloth. With regard to the subjective gait sensation, the participants who wore a draped cloth found it easier to walk as compared with those who wore the tracksuit bottoms.

A previous review reported that the effect of light touch on gait speed may depend on the type of touching tool used [14]. Although the walking time in the normal and tandem gaits in the present study was significantly shorter while wearing DC, it was not observed in the case of wearing TS. As an increase in error means that the straight-line distance increases, the actual walking distances were slightly longer than 11 m in the present study. However, we found no significant differences in error during both normal and tandem gaits or pre and post wearing of clothing. Therefore, almost all changes in gait time were presumed to be affected by wearing DC. This result is consistent with that of a previous study, which involved a more challenging gait task, wherein the gait time during tandem gait on a narrow board was shortened by wearing fluttering clothing [17]. Although the gait time and number of steps during the normal gait in the pilot experiment were significantly increased with the blindfold than without the blindfold, normal and tandem gait tasks might not be significantly difficult for young healthy adults, as in the present study. The effect size in the previous study was large (d = 1.31) [17], which was larger than that on tandem gait (d = 0.80) or normal gait (d = 0.39) in the present study. The effect of light touch on postural sway during standing has been reported to be relatively more effective during a relatively difficult postural task, i.e., individual is standing on a pneumatic balance disk [7], foam rubber mat [18], or under the reduced plantar sensitivity condition [19]. Therefore, these results suggest that the effectiveness of light touch became larger, accompanied by the difficulty of the gait task.

Missteps during tandem gait were significantly reduced by wearing DC. During tandem gait, the participants should control their postural balance in a narrower base surface than that during normal gait. When a participant lost balance, the center of foot pressure greatly deviated from the basal plane. Subsequently, the basal plane area was enlarged by a misstep (the step deviated from the tandem line) to maintain balance. Light touch is thought to enhance an individual's perception of body orientation [10], making it easier to control balance. In fact, the participants who wore DC found it easier to walk as compared with those who wore TS, as measured by subjective gait sensation.

A previous study also reported that when participants had more improved gait performance when wearing fluttering clothing, they also felt that it was easier to walk [17]. This result suggests that because wearing a DC allows individuals to better control balance through the enhancement of the perception of body orientation, missteps were decreased. Therefore, although such a tandem gait will not be performed in daily living, it may lead to enhanced postural stability depending on the kind of garment worn in situations where better balance ability is required during human movement, such as on an unstable surface and high and dark places.

The aim of the present study was to investigate the effect of the shapes of garments on fundamental gait parameters in order to acquire preliminary data. Although wearing a draped cloth around the lower leg might have had a positive effect on the gait parameters, their underlying mechanisms were not fully investigated. Previous studies that investigated gait performance and light touch indicated that adding haptic input changes to the variability of gait step parameters and body stability, and a decrease in lower limb muscle activity, have significant effects on gait performance [14]. Therefore, future studies with more participants are required to analyse the effect of wearing different shapes of clothes on muscular activity, fluctuation of center of mass, or center of foot pressure. In the present study, tracksuit bottoms were chosen as one of the garments since the authors presumed that trouser-like clothing, which creates a continuous contact between the cloth and body part, cannot improve gait performance. Similarly, a draped cloth was used in the study instead of skirt-like outfits, which have a certain space between the leg and cloth and thus allow for contact on movement. The clothing used in the present study might affect the gait parameters and correspond to kilts in Scotland and the hakama in Japan. Furthermore, the characteristics of clothing that individuals usually wear differ depending on their gender. Therefore, future studies are also required to investigate what kind of skirt-like clothes are effective for improving gait performance, including the effect of gender differences. However, our present results show the possibility of using a new outfit to enhance balance control during human movement utilizing the light-touch effect.

5. Conclusions

This study investigated the effects of haptic sensory input by different types of clothing worn on the fundamental gait parameters during normal and tandem gaits. The participants performed normal and tandem gait tests with blindfolds under three different clothing conditions: (1) wearing only half tights; (2) wearing unbifurcated draped clothing around the leg; and (3) wearing tracksuit bottoms. Although gait speed was significantly increased by wearing draped clothing, this increase was not observed in the case of wearing the tracksuit. Missteps during tandem gait were significantly reduced by wearing draped clothing, as this made walking easier for individuals, as compared with wearing tracksuit bottoms. These findings suggest that wearing a skirt-like outfit may provide haptic sensory cues to enhance individual perception of body orientation as compared with wearing a trouser-like garment, which is in continuous contact with the legs. This suggests the possibility of a new use of outfitting to enhance balance control during human movement. Therefore, depending on the shape of the garment, gait performance might be improved by the light-touch effect. Future studies are required to investigate what kinds of garment are effective for improving gait performance to utilize study results in actual daily living.

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Conflicts of Interest: The authors have no competing interests to declare.

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