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A Study on Impressions of Walking Motion

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Abstract

We investigate the impressions of two walking styles (good and poor posture). An optical motion capture system is used to measure the two walking styles, which are performed by a walking instructor. Furthermore, a subjective evaluation experiment is conducted to examine the impressions of the two walking styles. The results suggest that the impression of leg motions, in addition to the impression of the trunk posture, may influence the impressions of walking motion. Walking with good posture, in which a person keeps the trunk upright and clearly flexes and extends the knee and ankle joints, gives the impressions of "beautiful", "elegant", "attractive", and "healthy".

1. Introduction

"Beautiful walking," or walking elegantly while maintaining proper posture, is gaining popularity, especially among women. Walking is an aerobic exercise that aids in the burning of body fat, reduction of peripheral vascular resistance, and improvement of insulin sensitivity. In addition, walking is beneficial for the prevention of lifestyle-related diseases such as obesity, hypertension, and diabetes [1,2]. Walking benefits the musculoskeletal system by strengthening the lower limb muscles and maintaining bone mass. Walking at a fast pace and with a wide stride is an effective way to prevent sarcopenia in the elderly [3]. Furthermore, exercise can potentially improve mental function [4]. Rhythmic exercises such as walking, which relax and tense muscles at a constant tempo, increase serotonin secretion. Serotonin, which is a neurotransmitter in the brain, is effective in mitigating anxiety and depression [5]. Walking has several health-enhancing effects. However, while it is easy for anyone to walk, it is a monotonous exercise, and it is important to maintain the motivation to continue walking over a long period. To maintain motivation, you can take the following measures: take a different route than usual, listen to music while walking, and be aware of how you “look” to others. Changing the walking style with an awareness of how you “look” can be done immediately, anytime, anywhere, and can improve your mental health by making you feel “beautiful” and “healthy,” thereby contributing to keeping you motivated to continue to go walking. Therefore, it is important to not only walk healthily with good posture, but also to clarify from a kinematic perspective which body parts need to be moved and how to move them to look “beautiful” and “healthy.”

Human gait has long been researched. The ground reaction force [6], joint angle [7], joint moment [8], and joint power [9] have all been identified as kinematic and kinetic features of walking. For example, the peak ground reaction force and peak joint angle are used as kinematic and kinetic data for feature extraction in gait comparison between hemiplegic gait and normal gait [10]. The joint angle is different from the ground reaction force and the joint moment because it can be recognized by appearance. Therefore, the joint angle may be closely related to the evaluation of the appearance of walking.

The study of gait kinematic parameters that influence the perception of beauty gave consideration to changes in joint angles [11]. According to the findings, keeping the pelvis anteriorly tilted and the trunk extended while walking is regarded as attractive by others. Several studies have evaluated walking style from an aesthetic point of view by using the silhouette of the frontal plane and the difference in impression evaluation due to the difference in stride length [12, 13,14]. Almost all studies that evaluate walking style from an aesthetic point of view have focused on the motion and impression of the whole body.

Almost no studies have been conducted on walking styles focusing on individual parts such as the upper and lower body. It is obvious that trunk posture influences the impressions of others. However, since multiple body parts are coordinated during walking, the coordination of body parts may affect the impression of walking. Even if the movement of only the upper body or only the legs does not give the impression of "health", the "impression fusion effect" that makes the impression of "health" stronger might occur from the movement of the whole body. To verify the "impression fusion effect," it is necessary to perform kinematic and impression evaluations for each body part such as the whole body, only the upper body, and only the legs.

Therefore, in this study, an optical 3D motion capture system is used to measure two types walking styles. Keeping the pelvis in a neutral position and the trunk upright while walking is defined as Style A, which is often described as good posture. Keeping the pelvis in the posterior tilting position and being hunched over while walking is defined as Style B, which is often described as poor posture. The burden on the neck, shoulders, and waist is small during walking because "Style A" keeps the trunk upright. The burden on the neck, shoulders, and waist is large during walking because "Style B" is a stoop and the head protrudes forward. In addition, it is necessary to balance the lower limbs in the anterior-posterior direction because the upper body is out of balance. Furthermore, trunk posture greatly affects the impression during walking because the trunk is the largest part of the human body. The two walking styles are diametrically opposite from the viewpoint of body burden and visual effects. Therefore, the two walking styles were selected based on the trunk posture and pelvic tilt angle, which are important for maintaining the trunk posture. An optical motion capture system was used to measure the two walking styles performed by a walking instructor with runway modeling experience. To avoid the influence of appearance, we attempted to measure only one person. Furthermore, a subjective evaluation experiment was conducted to examine impressions of the two walking styles. Further, we performed the two-way ANOVA to show the relationship between the "impression fusion effect" and the evaluation words by verifying the interaction between the impressions of body parts (whole body, upper body, and legs) and each evaluation term. This study aims to describe the relationship between the kinematic characteristics and subjective evaluation of the two walking styles by demonstrating the features of motions during walking.

2. Walking measurement

2.1 Participants and experiment conditions

The experiment involved a walking instructor with experience as a runway model. An explanation of the purpose and requirements of the study was provided to the participant, after which written informed consent was obtained. The study was approved by the Kogakuin University Research Ethics Board.

Kinematic data for the two walking styles were collected using an optical 3D motion analysis system (MAC3D; Motion Analysis) equipped with 12 cameras (eight Kestrel 2200 cameras and four Kestrel 300 cameras). The Helen Hayes marker set was employed to determine the positions of reflective markers for the optical 3D motion analysis system (Figure 1). Style A was defined as keeping the pelvis in a neutral position (forward tilt of approximately 10 - 15°) and the trunk upright while walking [15]. Style B was defined as keeping the pelvis in a posterior tilting position and being hunched over while walking. Figure 2 shows the two walking styles. The participant was instructed to move the upper and lower limbs naturally and walk with a natural stride timed using a metronome (90 bpm) along a walking path, as shown in Figure 3. The optical 3D motion analysis system had

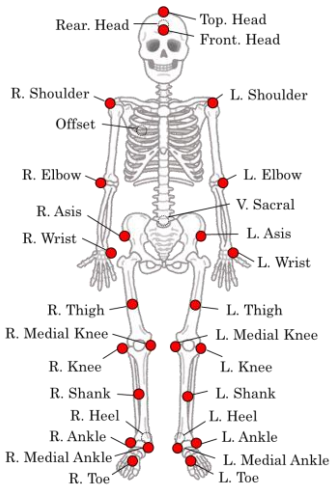
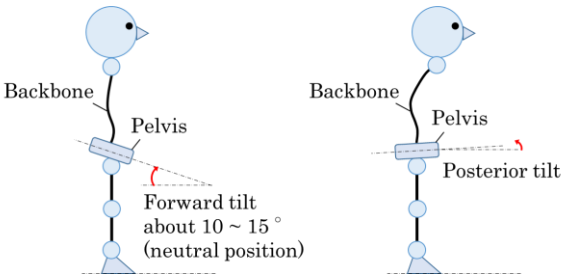


Figure 1. Marker positions



(a) Style A (b) Style B

Figure 2. Definitions of the two types of walking styles

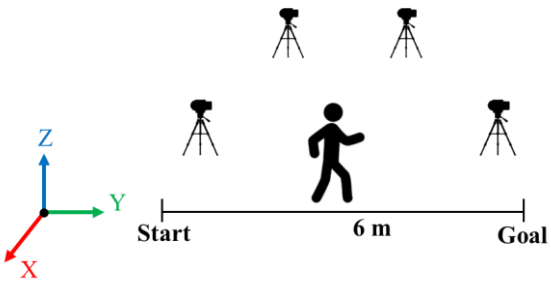


Figure 3. Reference coordinates and walking path

a sampling frequency of 100 Hz.

2.2 Experimental results

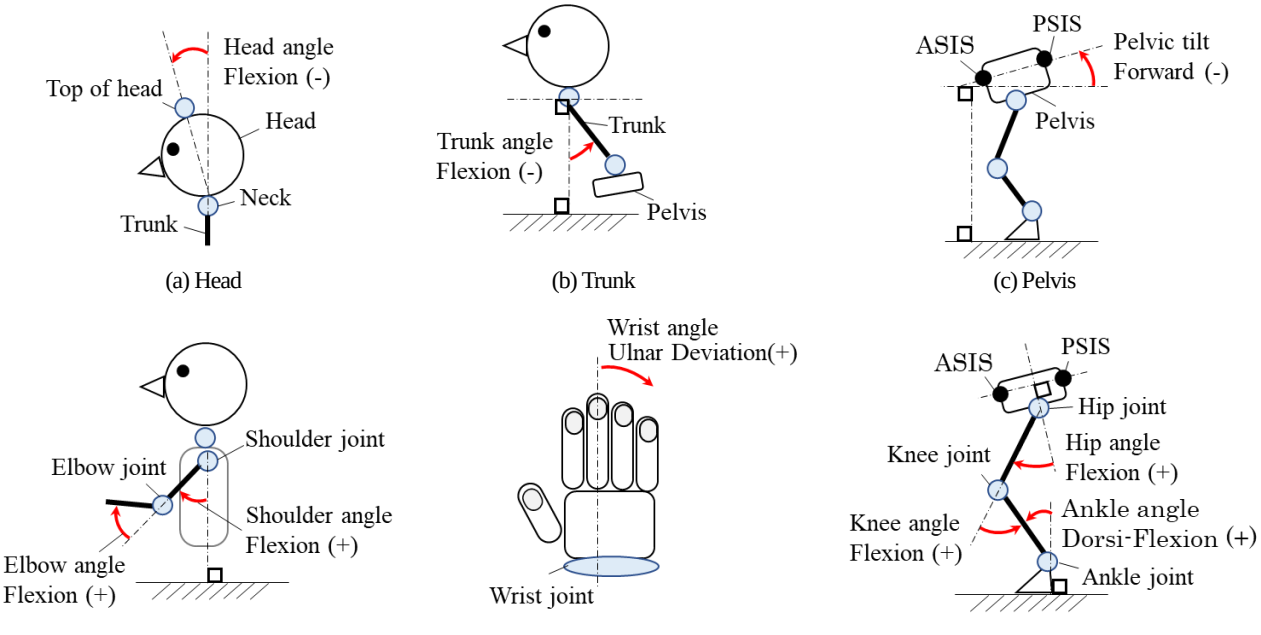
The two walking styles were defined using the pelvic tilt and trunk angles in the sagittal plane. The lower limb kinematic features during walking are mainly visible in the sagittal plane. Therefore, the sagittal plane kinematics were investigated in this study. Figure 4 shows the definitions of the head, trunk, pelvis, upper limb, and lower limb angles. The results for the joint angles are shown in Figure 5. The red and blue solid curves represent the results obtained with Style A and Style B, respectively. The results for the head, trunk, and pelvis angles show the average of six trials. The results for the joint angles of the upper and lower limbs show the average for six trials, including the left and right sides. The standard deviations are represented by dashed lines. The horizontal axis represents normalized time, where one gait cycle equals 100%. One gait cycle is shown in Figure 5(a)-(c) from the start of the stance phase to the end of the swing phase of the right leg. In Figure 5(d)-(i), one gait cycle extends from the beginning of the stance phase to the end of the swing phase of the right and left legs, respectively. In one gait cycle of both walking styles, the toe-off occurred at around 60%.

To detect the kinematic differences between the two walking styles, the root-means-square errors (RMSEs) and correlation coefficients for the joint angle results were compared. Table 1 summarizes the RMSEs for the joint angle results obtained from the two walking styles. Table 2 summarizes the general range of motion of the joints in the sagittal plane [16]. Table 3 lists the correlation coefficients for the joint angles obtained from the two walking styles. The kinematic features were extracted under the assumption that there were particularly large differences between the two walking styles when the RMSE exceeded 5% of the range of motion of the joints listed in Table 2. The range of motion of each joint is the sum of its maximum flexion and maximum extension angles.

The RMSE for the shoulder, elbow, wrist, and hip joints is 5% or less of the total range of motion. The correlation coefficients for those joint angles are 0.9 or higher. As shown in Figure 5 (f), (g), the wrist and hip joint results of Style A are generally consistent with those of Style B. As shown in Figures 5 (d), (e), the shoulder and elbow joint results of Style A are slightly different from those of Style B. However, the waveforms of the shoulder and elbow joint results of Style A are nearly identical to those of Style B. As a result, we concluded that each movement of those joints had no influence on the impressions of the two walking styles.

The RMSE for the head angle is less than 5% of the range of motion. The correlation coefficient for the head angle is -0.744. As shown in Figure 5 (a), the head angles of both Style A and Style B did not vary over one gait cycle. A slight increase and decrease in extension during walking with Style A and Style B, respectively, are presumed to be the causes of the negative correlation coefficient. Therefore, we concluded that head movement would not affect the impressions of the two walking styles.

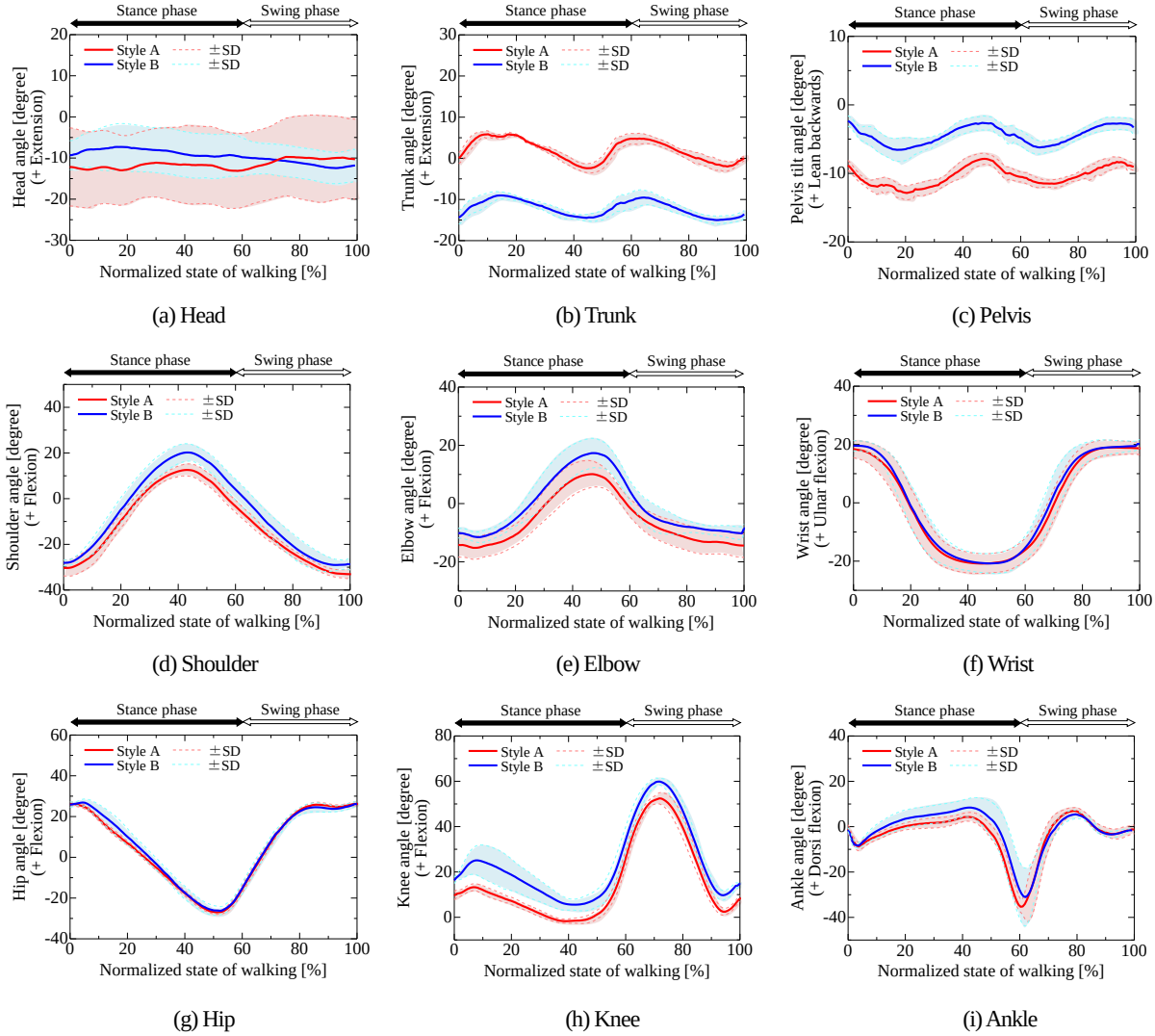
The RMSE for the trunk, pelvis, knee, and ankle joints is more than 5% of the range of motion, and the correlation coefficients are 0.9 or higher. The waveforms of the trunk and pelvis results of Style A are nearly identical to those of Style B, as shown in Figure 5(b), (c). The range of angles during one gait cycle varies significantly. As shown in Figure 5(b), the trunk was kept upright in Style A, whereas the participant was hunched over in Style B. Figure 5(c) shows that the



(a) Head (b) Trunk (c) Pelvis

(d) Shoulder and elbow (e) Wrist (f) Lower limbs

Figure 4. Definitions of the sagittal joint angles



(a) Head (b) Trunk (c) Pelvis

(d) Shoulder (e) Elbow (f) Wrist

(g) Hip (h) Knee (i) Ankle

Figure 5. The sagittal joint angles during walking obtained from the 3D motion analysis system

Table 1. Root mean square errors for joint angles results obtained from the two types of walking

	Head	Trunk	Pelvis	Shoulder	Elbow	Wrist	Hip	Knee	Ankle
RMSE [degree]	3.1	14.2	6.0	5.7	5.13	1.2	1.81	8.8	4.1

Table 2. Joint range of motion [13]

	Head	Trunk	Pelvis	Shoulder	Elbow	Wrist	Hip	Knee	Ankle
Flexion [degree]	0~60	0~45	0~15	0~180	0~145	0~25	0~90	0~130	0~20
Extension [degree]	0~50	0~30	0~15	0~50	0~5	0~55	0~15	0	0~45

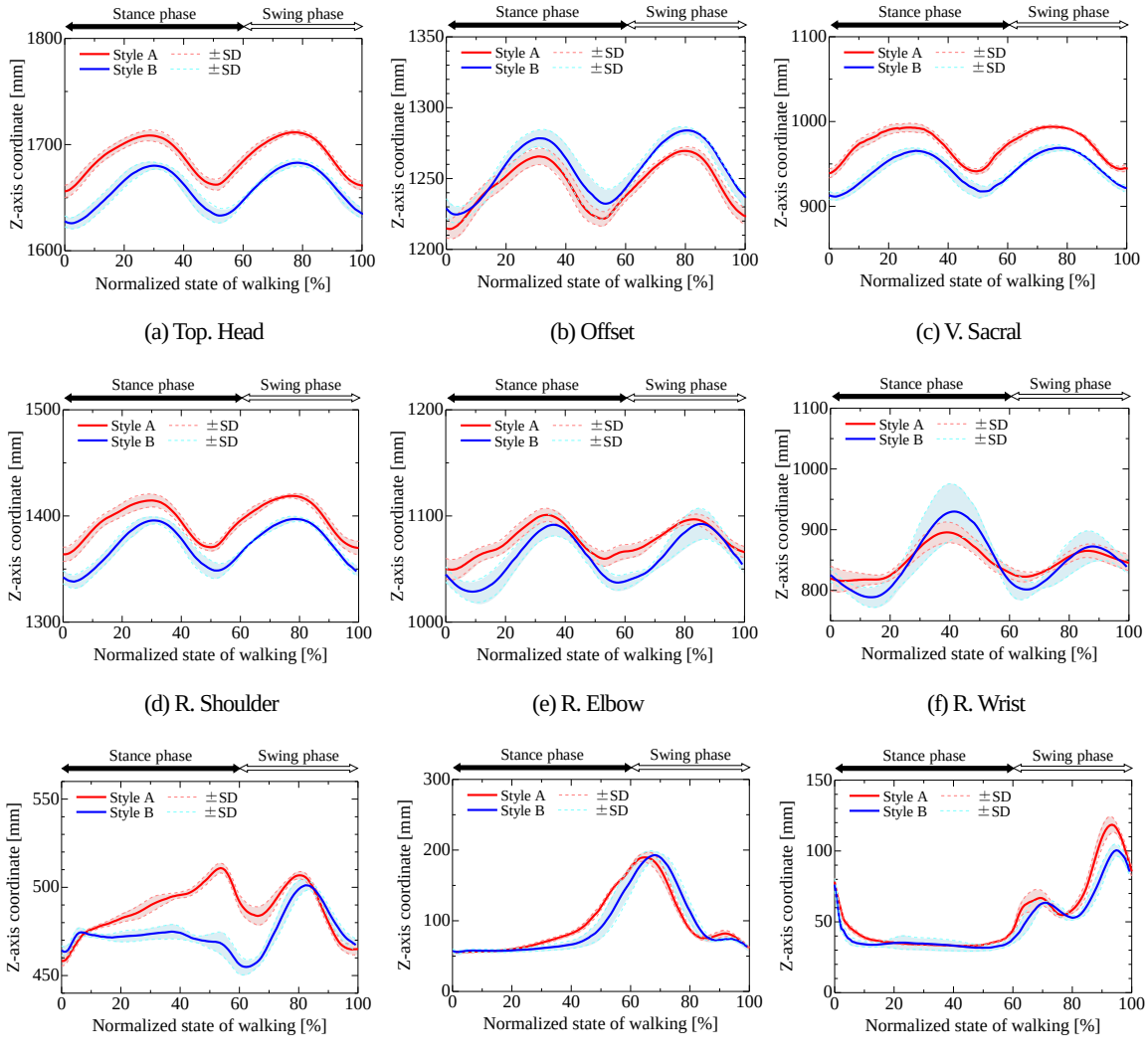
Table 3. Correlation coefficients for joint angles results obtained from the two types of walking

	Head	Trunk	Pelvis	Shoulder	Elbow	Wrist	Hip	Knee	Ankle
Correlation coefficient	-0.74	0.96	0.93	0.99	0.99	0.99	0.99	0.99	0.94

pelvis was kept in a neutral position (forward tilt of approximately 10 - 15°) in Style A and at a forward tilt of approximately 0 - 5° in Style B. Because the differences in the results of the two walking styles are defined by the trunk and pelvis, these results indicate that the participant walked in accordance with the definition of the walking style. As shown in Figure 5(h), the result of the knee joint of Style A differs significantly from that of Style B. As shown in Figure 5(i), the ankle joint result of Style A differs slightly from that of Style B. Because the participant was instructed to move the upper and lower limbs naturally and walk with a natural stride, the differences between the two walking styles in the knee and ankle joints could have been caused by the trunk and pelvis postures. After the experiment, the participant stated that she kept her knee and foot flexed to maintain balance because she was hunched over in Style B. Therefore, we determined that, in addition to the trunk and pelvic postures, the flexed state of the knee and ankle joints in Style B may influence the impressions of the walking style.

As stated previously, we found significant kinematic differences in the trunk, pelvis, knee, and ankle angles. However, when humans perceive beauty by observing the movements of others, they do not observe only the movement of each body part. The smoothness and sharpness of such movements may also influence the impression of walking. Therefore, we focused on the trajectory of the reflective markers that were attached to each body part as an index to evaluate its movement in a three-dimensional space.

Figure 6 shows the trajectories of nine markers selected to represent the movement of each body part. The horizontal axis represents normalized time, where one gait cycle equals 100%. In Figure 6, one gait cycle extends from the beginning of the stance phase to the end of the swing phase of the right leg. The vertical axis shows the Z-coordinate of the markers [mm]. Because the participant walked along the positive direction of the Y-axis over time, the marker trajectories represented in the graph generally match those when the markers are observed from the participant's right side. The red and



(a) Top. Head (b) Offset (c) V. Sacral

(d) R. Shoulder (e) R. Elbow (f) R. Wrist

(g) R. Knee (h) R. Ankle (i) R. Toe

Figure 6. Z-axis coordinates of markers during walking obtained from the 3D motion analysis system

blue solid curves represent the results obtained with Style A and Style B, respectively. The results show the average for six trials. The standard deviations are represented by the dashed lines.

As shown in Figure 6(g), the lateral epicondyle marker of the femur (R. Knee) had a significantly different trajectory in the two walking styles. Conversely, the other eight markers had similar trajectories in the two walking styles. The Z-coordinate R. Knee marker changes mainly because of the movement of the lower limbs. As Figure 5(g) shows that the hip joint angle in Style A is generally consistent with that in Style B, the Z-coordinate of the R. Knee marker seemed to be affected by the movement of the knee and ankle joints.

In Style B, the Z-coordinate of the R. Knee marker was nearly unchanged throughout the stance phase and only significantly moved up and down during the swing phase. Thus, Style B may have given the impression that it was not smooth throughout one walking cycle. However, the R. Knee marker in Style A gradually moved upward throughout the stance phase, and the change from the toe-off (60%) to the middle of the swing phase (80%) was small. In contrast to Style B, Style A may have given the impression of smoothness throughout one gait cycle.

3. Subjective evaluation experiment

3.1 Procedures of subjective evaluation

The lower limbs motions during walking with the trunk upright differed from those motions during walking with a slight stoop. The posture of the trunk and pelvis as well as the movement of the lower limbs could influence the impression of walking. Thus, in the subjective evaluation experiment, only the upper body impression and only the legs impression during walking were evaluated in addition to the whole-body impression. We have prepared three videos for each of the two walking styles: the first video captured the participant's entire body, the second captured her upper body, and the third captured her legs. Three videos were used to conduct a questionnaire survey. All videos were shot with a video camera which was on the left of the walking instructor. The time required for each video was about 10 s. In each video, the walking instructor who walked about 3 m in the forward direction (4 steps in total on the left and right) twice was seen. A total of 6 videos were used to conduct the survey.

Using the literature and dictionaries, 400 adjectives were selected as the candidate’s evaluation words [17]. The authors used three options to determine whether the collected adjectives were appropriate for evaluating the walking style (1: Applicable 2: Neither 3: Not applicable). Three of the authors and four students who fully understood the purpose of this research participated in the selection of the evaluation terms selection experiment. When the seven people answered three options for 400 adjectives, they paid attention to the following two items: "A word is used by students in their 20s," and "A word can be used to evaluate motions for all videos of the whole body, upper body only, and legs only in two types of walking." After seven people of participants in the subjective evaluation answered three options for 400 adjectives, the number of adjectives was then narrowed down from 400 words to 146 words by deleting adjectives with an average evaluation score of 2.5 or higher. The 146 adjectives were further classified into eight groups. The adjectives belonging to the same group had similar meanings. The adjective with the lowest score in each group was selected as the evaluation word. In addition, "favorite", which denotes a personal preference, was added as an evaluation word. Finally, nine words were determined: "favorite", "beautiful", "elegant", "stable", "soft", "calm", "comfort", "attractive", and "healthy." The antonyms on the nine words were then determined. Table 4 shows the definition for grouping and the words which were selected as representative words in each group. Table 5 shows the nine pairs of antonyms.

The questionnaire survey was based on videos taken from the participant’s left side during walking. Figure 7 depicts videos of walking with style A. Figure 8 depicts videos of walking with style B. In Figure 7, video Ⅰ shows the participant’s whole body, video Ⅱ shows only her upper body including her hands, and video Ⅲ shows only her legs. In Figure 8, video i shows the participant’s whole body, video ii shows only her upper body including her hands, and video iii shows only her legs.

Table4. Definitions for grouping

	Definitions for grouping	Selected term
Group A	A word that describes external beauty.	beautiful
Group B	A word that describes both external and internal beauty.	elegant
Group C	A word that describes the degree of balance for movement.	stable
Group D	A word that describes the continuity of the movement.	soft
Group E	A word that describes the momentum of the movement.	calm
Group F	A word that describes the psychological state of a person.	comfort
Group G	A word that describes the degree of interest.	attractive
Group H	A word that describes the state of the body.	healthy

Table5. Antonyms pairs

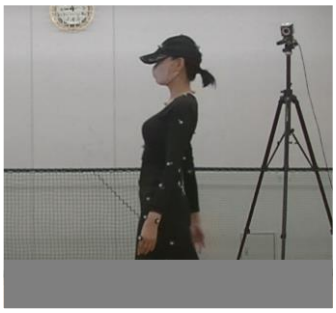
unfavorable	⇔	favorite
ugly	⇔	beautiful
inelegant	⇔	elegant
unstable	⇔	stable
hard	⇔	soft
grim	⇔	calm
discomfort	⇔	comfort
boredom	⇔	attractive
unhealthy	⇔	healthy

The subjective evaluation experiment included 55 students in their early twenties. In determining the sample size, the population parameter was set at 6000 (the total number of students at the university). We confirmed that n = 50 is required by calculating with a margin of error of 10%, reliability of 90%, and response ratio of 80%. For informed consent, we explained the followings: "The questionnaire is voluntary," "You will not face any disadvantages if you do not cooperate in this survey," "There are no anonymous and personally identifiable questions," and "Although the statistically processed questionnaire results will be used for conference presentations and academic papers, individual results will not be disclosed." After giving a brief overview of the survey and an explanation for informed consent, we sent them six URLs for the questionnaire surveys. We did not explain the difference between the videos. Each URL had one walking video and the evaluation sheet shown in Figure 9. They answered 1 to 5 for each evaluation word (1: Very XXX 2: Slightly XXX 3: Neither 4: Slightly ○○○ 5: Very○○○) in the evaluation sheet within 10 min.

3.2 Results

Fifty valid responses were obtained from 55 students. Figure 10 depicts the results of the questionnaire. A two-way analysis of variance (ANOVA) was also performed on the results in order to get a detailed analysis of questionnaire results. The results of the two-way ANOVA are shown in Figure 11. During walking, multiple body parts are coordinated. Even if the movement of only the upper body or only the legs does not give the impression of "health", the "impression fusion effect" that makes the impression of "health" stronger might occur from observing the movement of the whole body. Therefore, we performed the two-way ANOVA to show the relationship between the

(a) Whole body (Video I)



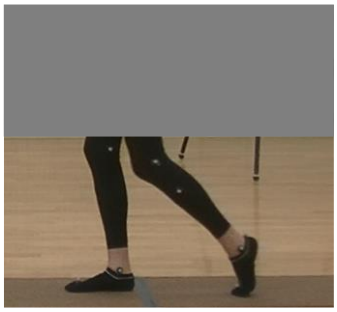
(b) Upper body (Video II)

(c) Lower leg (Video III)

Figure 7. Videos of walking with Style A

(a) Whole body (Video i)

(b) Upper body (Video ii)



(c) Lower leg (Video iii)

Figure 8. Videos of walking with Style B

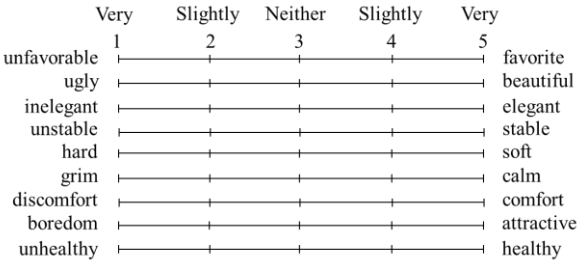


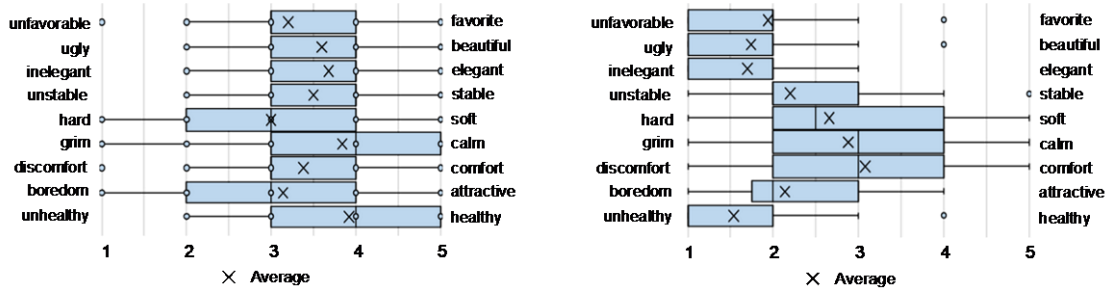
Figure 9. Evaluation sheet.

"impression fusion effect" and the evaluation words by verifying the interaction between the impressions of body parts (whole body, upper body, and legs) and each evaluation word. The black solid curves represent the results for the whole body. The orange solid curves represent the results for the upper body. The green solid curves represent the results of the legs. The average scores are shown in the vertical axis, and the two types of walking are shown on the horizontal axis. The correlation coefficient between each evaluation word is shown in Table 6.

The questionnaire results shown in Figure 10 indicate that Style A scored higher than Style B. According to the two-way ANOVA results, the interaction between the body parts and the walking styles was significant in "favorite", "soft", "attractive", and "healthy" ($p < 0.05$). Here, * denotes an evaluation word with a significant difference ($p < 0.05$) in the evaluation scores.

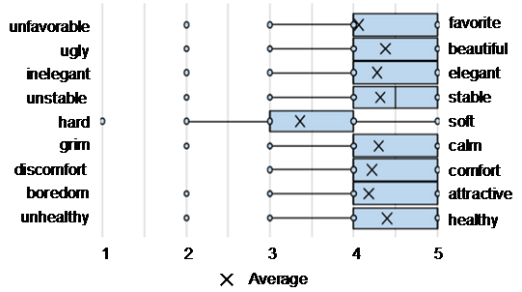
In the results of "favorite", "soft", and "attractive", the score differences between the two types of walking for the legs videos are large. The results indicate that the impression of the legs during walking with Style B approaches much closer to "unfavorable", "hard", and "boredom". Thus, the main reason for the interaction in the results of these words might have been affected by the changes in the impressions of the legs in the two types of walking. Although there was no significant interaction in the results of "beautiful", "elegant", "stable", "calm", and "comfort," the score differences between the two types of walking for the legs videos are also large.

The score difference between the three videos during walking with Style A is small in the "healthy" results, whereas the score difference between the three videos during walking with Style B is large. The result of the whole-body video of "healthy" had the largest difference score between the two types of walking. The result of the legs video of "healthy" had the second-largest score difference between the two types of walking. The impression given by the appearance of being hunched over and the impression given by the appearance of both the knee and ankle joints remaining flexed may have been integrated into

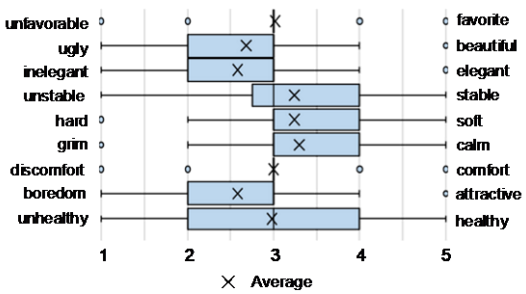


(a) Style A (Whole body)

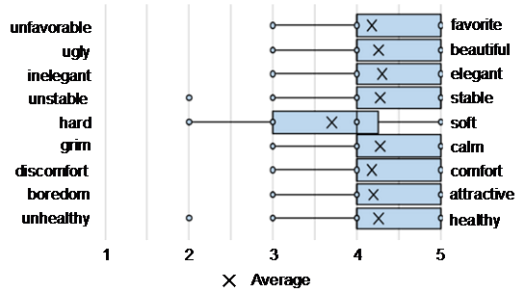
(b) Style B (Whole body)



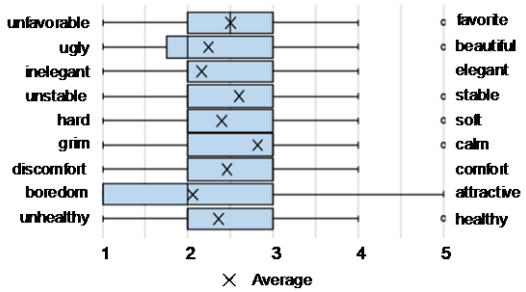
(c) Style A (Upper body)



(d) Style B (Upper body)



(e) Style A (Legs)



(f) Style B (Legs)

Figure 10. Questionnaire results

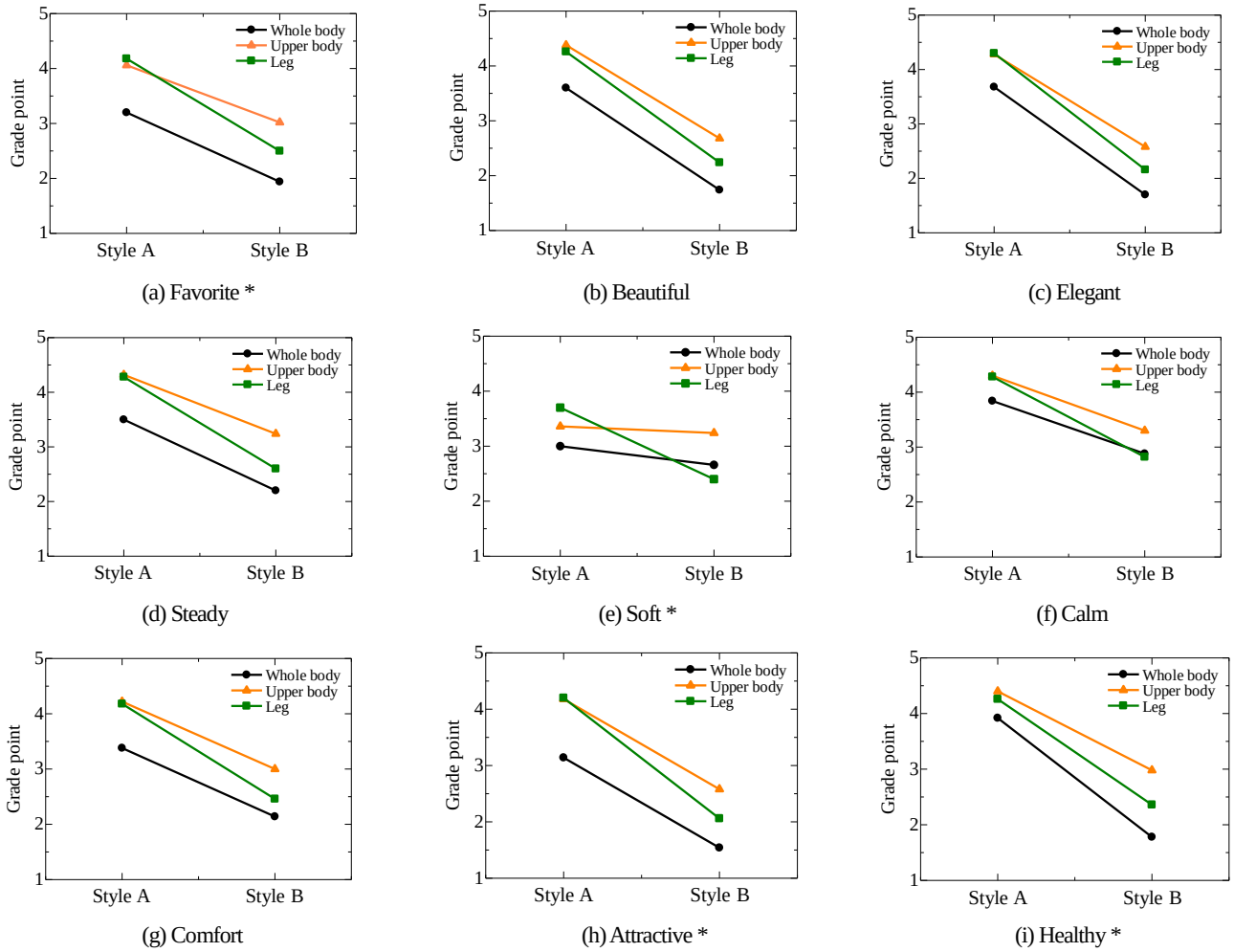


Figure 11. Two-way ANOVA results

Table 6. Correlation coefficient between evaluation words

	favorite	beauty	elegant	steady	soft	calm	comfort	attractive	healthy
favorite	1.00								
beauty	0.69	1.00							
elegant	0.59	0.75	1.00						
steady	0.50	0.58	0.56	1.00					
soft	0.34	0.30	0.27	0.30	1.00				
calm	0.43	0.37	0.41	0.55	0.30	1.00			
comfort	-0.16	-0.13	-0.04	-0.13	-0.04	-0.12	1.00		
attractive	0.67	0.65	0.62	0.51	0.41	0.47	-0.22	1.00	
healthy	0.63	0.69	0.64	0.48	0.35	0.42	-0.15	0.72	1.00

the impression of the whole body of Style B, thus leading the whole body to give the unhealthiest impression.

The evaluation term with the largest score difference between the two walking styles in the whole-body video was "healthy", followed by "beautiful" and "elegant." The evaluation terms with the largest score difference in the upper-body video were "beautiful" and "elegant", followed by "attractive" and "healthy." The evaluation term with the largest score difference in the leg video was "attractive", followed by "elegant" and "beautiful". Focusing on values of 0.7 or higher in Table 6, "beautiful" has a strong correlation with "elegant" and "attractive" has a strong correlation with "health". The correlation coefficient between "beautiful" and "healthy" is 0.69, which is slightly less than 0.7; however, a positive correlation is observed. Therefore, keeping the trunk in an upright position and flexing and extending the knee and ankle joints clearly while walking appear to give impressions of "beautiful", "elegant", "attractive", and "healthy". Meanwhile, keeping the pelvis in the posterior tilting position and keeping the knee and ankle joints flexed appear to give strong impressions of "ugly", "inelegant", "boredom", and "unhealthy." In particular, the impression of the legs appears to differ greatly between the two walking styles.

4. Conclusions

This study investigated the impressions of the two walking styles as a first step toward clarifying the differences between such impressions. The findings led to the following conclusions.

1. The walking measurement revealed that there were differences in the joint angle changes of the knee and ankle, as well as in the angle changes of the trunk and pelvis, between the two walking styles. In Style B, both the knee and ankle joints remained flexed throughout one gait cycle, whereas they were clearly flexed and extended in Style A.

2. The impressions of "healthy" for the whole body, upper body, and legs in Style A are similar; however, the legs gave an impression of “unhealthy” in Style B compared to the upper body. The impression given by the appearance of being hunched over and the impression given by appearance of both the knee and ankle joints being flexed may have been integrated into the impression of the whole body, causing the whole body to give the unhealthiest impression.

3. Style A, in which a person keeps the trunk upright and clearly flexes and extends the knee and ankle joints, may have given the impression of "beautiful", "elegant", "attractive", and "healthy". By contrast, Style B, in which a person is hunched over and flexes and extends the knee and ankle joints in an unclear manner, may have given the impression of "ugly", "inelegant", "boredom", and "unhealthy".

We concluded that the impression of leg motions, in addition to the impression of the trunk posture, may have influenced the subjective evaluation. Therefore, the findings of this research are important findings for practicing beautiful and healthy walking. The results of the subjective evaluation might be affected by the physique and appearance of a walking person; however, the score of "Style A" seems to be higher than that of "Style B" if the same person performs two types of walking motions. Nevertheless, the score for each walking style might change significantly depending on the physique and appearance of a walking person. Therefore, it is difficult to determine that the results of the two-way analysis of variance obtained in this study are universal. Since this study was conducted with a female, the results cannot be extrapolated to males. In addition, since only the students in their twenties participated in the subjective evaluation experiment, the results cannot be extrapolated to age groups that do not comprise individuals in their twenties. Moreover, the male-female ratio of the students who participated in the subjective evaluation experiment was about 80% males and 20% females. Therefore, it is possible that the subjective evaluation results may change depending on the gender of the respondents. In future work, we would like to investigate the effect of gait characteristics on affective evaluation by considering differences between the sexes. Further we would like to include people belonging to a wider range of ages to answer the questionnaire.

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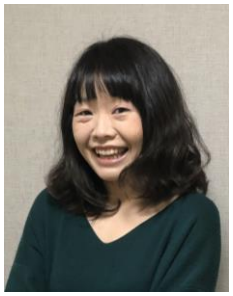

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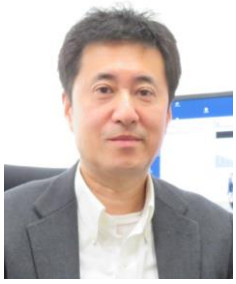

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