The Relationship Between Arm Movement and Walking Stability in Bipedal Walking

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Abstract.

The research about the bipedal locomotion is advanced in all fields at present. To the research of those fields, a quantitative analysis of human's walking characteristic is indispensable. However, bipedal locomotion analysis has been performed focusing on lower limbs, and, as for research of the arm swing operation is not performed nevertheless it importance is generally told. The reason for it is to be assumed that the arm is not a necessary a part for locomotion. But it can be guessed that the arm swing operation having done a certain role about the stability of a walk which is very unstable physically. When running, the human clearly draws the arm greatly and quickly. This suggests the arm swing operation is related with the change of walking form and the move speed of the locomotion, and it influences the stability of a walk. This method becomes the useful analysis technique also not only to the above-mentioned research but to the sport kinematics research etc., if the relations to this arm swing operation and the stability of a walk is quantitatively understood. In this study, the relationship between arm swing operation in bipedal locomotion and stability of the walking was noticed.

Keywords: arm movement, walking stability, bipedal walking, walking speed, shoulder fulcrum dispersion, leg fatigue

1. Introduction

Research on bipedal walking is currently underway in a variety of fields. Bipedal walking is a biological characteristic of human beings, and much of its mechanism is as yet unclear. In engineering, for example, robots that can walk in a bipedal manner are currently under development, and, in medicine, important data on human walking characteristics is being gathered for use in the clinical analysis of walking for application in rehabilitation programs. The clinical analysis of walking behavior is focused on the effects on walking movement, particularly abnormal walking movement, in order to gather data for use in the rehabilitation of the elderly and the physically handicapped[3]. The reduction of human walking characteristics to a numerical format, and subsequent analysis, is therefore very significant in a variety of fields of walking research, and also provides information useful in the study of human biology.

The analysis of walking movement has generally focused on the legs[1,2]. While arm movements are often the subject of conversation among those who study walking movement, this has not led to significant research. This state of affairs is a result of the perception that the arms do not play an essential part in walking movement. However, any observation of human

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Abstract

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running movement shows that the arms move rapidly, and over a significant range. This is an indication that arm movement is related to overall walking behavior, speed of movement and walking stability.

If a quantitative understanding of arm movement functions can be obtained in terms of the relationship between arm movement and walking stability, this data will prove invaluable not only in the field of robotics research, but also in other fields such as sports physiology research, and medical research related to rehabilitation.

The present study therefore focused on the relationship between arm movement and walking stability during bipedal walking, and we attempted to obtain data on this relationship through an analysis of human walking movement. The investigation of stability concentrated on movement of the upper body, in particular the movement of the acromions. Movement of the shoulders was employed as an index during normal walking movement and in walking movement in which the arms were immobilized, to determine the effect of these walking postures on stability.

Movement of the center of gravity after walking was measured to provide physiological data for an understanding of the effect of movement of the arms on fatigue in the legs. Two leg movement factors, width and walking pace, were analyzed as factors affecting movement of the arms.

2. Experimental Methodology

Each subject was first placed on a CG deflectometer, and deflection of the center of gravity was measured for one minute. The subject then mounted an electric treadmill and began walking. To provide a comparison on the basis of range of arm movement, this experiment incorporated 3 modes of walking: unrestrained walking; walking in which the arms were strapped to the side of the body; and walking in which the arms were swung up 90° to the vertical (shoulder level). In each of these 3 modes, the treadmill was set to 3 speeds (2.7 km/hr, 4.2 km/hr, 5.7 km/hr).

Each subject walked for a period of 2 minutes at each speed in each mode (9 different mode-speed combinations). Deflection of the center of gravity was measured after walking was completed for each mode-speed combination. Each subject was given a preparatory walk on the treadmill prior to the experiment, in order to minimize measurement errors due to unfamiliarity with the equipment. Subjects wore full-body black tights to which white 1.5-cm-diameter markers were attached at the measurement points (see Fig. 1) to aid in analysis of movement.

The subjects were 8 healthy young males without walking disabilities. Subjects were selected that were as close as possible to a standard body type, to ensure that body characteristics did not affect results, and care was taken to ensure that subjects exhibited no walking abnormalities or particular differences in motor abilities.

Two digital video cameras were used to record walking movement. One of the cameras was located above the head of the subject, and the other was located to the right of the subject, to allow recording of walking movement from 2

positions simultaneously. The coordinate system was arranged so that, when viewed from above, the X axis extended from the left to the right of the subject and the Y axis was in the direction of walking. When viewed from the side, the X axis was in the direction of walking and the Y axis extended from the head to the feet of the subject (see Fig. 1).

Markers 4, 5 and 6 (left and right shoulders, and head, respectively; see Fig. 1) were tracked from above. Care was taken to ensure that all walking movement was within the area of the screen as seen from the arrowed surface, and markers 1, 2 and 3 (on the arms; see Fig. 1) were tracked. Measurements of 2 walking cycles were taken from above, and measurements of single walking cycles were taken from the arrowed surface. A walking cycle was defined as beginning when the right heel of the subject contacted the ground surface and ending when the right heel next contacted the ground surface. The sampling interval was 1/30th sec.

The coordinates (in pixel units) of the acromion (see Fig. 1) were used as an index of upper body movement during walking, and the SFD(Shoulder Fulcrum Dispersion) was calculated as follows using this data[4].

$$SFD = \sqrt{\frac{1}{N}\sum_{i=1}^{N}\left\{(x_i - \bar{x})^2 + (y_i - \bar{y})^2\right\}}$$

x*i* and y*i* represent two-dimensional coordinates of the shoulder, while N represents the number of data items (i.e., number of frames) obtained during a single walking cycle, beginning with the heel contacting the ground surface. x and y represent the average values of x*i* and y*i* (i.e., the average size when the average values of the coordinates x*i* and y*i* are taken as the origin), and the value of the range of movement in the x and y directions. Speeds were chosen that would not result in the subjects' feet leaving the treadmill belt; i.e., speeds that would produce gaits in which movement on the Y axis was zero (zero Y-axis movement was not achieved in practice). SFD was calculated and analyzed for the left shoulder.

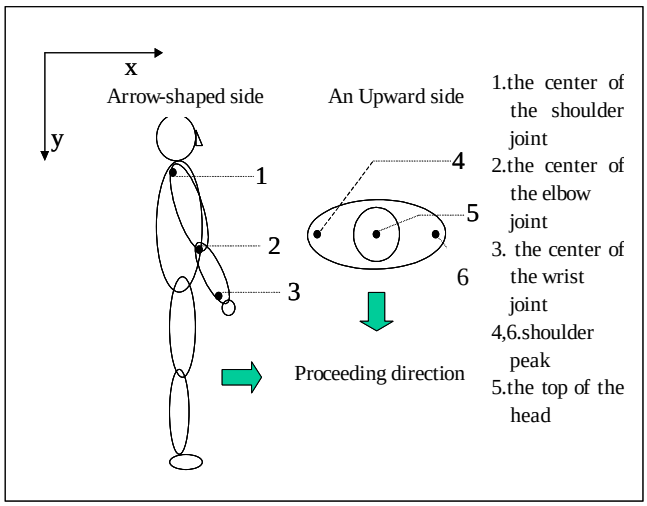


Figure1 Measurement part place and basic axis

3. Results and Discussions

A variance analysis was conducted for each measurement item, using the factors of walking posture and speed. Results showed a negative correlation between walking speed and SFD (see Fig. 2). This is considered to be a function of the human gait and its characteristic arm movements, and indicates that, as walking speed increases, movements of the upper body is reduced. As shown in Fig. 3, at a walking speed of 5.7 km/hr, the SFD for walking with arms immobilized was

greater than for unrestrained walking.

The 2 sets of data were tested for differences in average values, using an F test ($F(7,7)=6.99$, $p<0.01$), followed by a t-test (using 2 samples assumed to have equal variance). One-sided testing resulted in the hypothesis being discarded, and returned a significantly higher value for walking with arms immobilized than for unrestrained walking ($t(14)=2.62$, $p<0.01$).

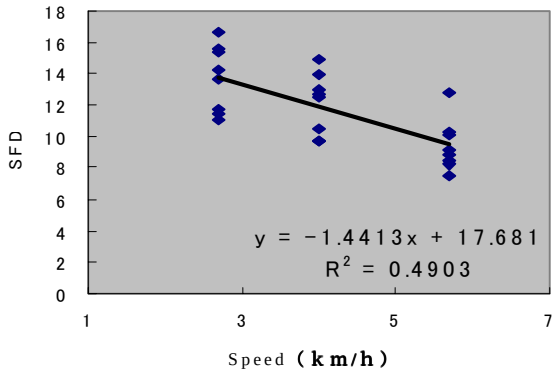
These results imply variations in movements of the upper body, and support the hypothesis that the inability of the arms to move results in a lack of stability while walking, in turn leading to excessive movements of the upper body in order to maintain stability. At the 2 lower speeds (2.7 km/hr and 4.2 km/hr), no significant difference was observed in the SFD between walking unrestrained and walking with the arms immobilized, indicating that movements of the arms has a major effect on walking stability.

Comparison of the SFD values at different speeds during unrestrained walking showed a negative correlation between walking speed and SFD (see Fig. 2). This is considered to be a function of the human gait and its characteristic arm movements, and indicates that, as walking speed increases, movements of the upper body is reduced.

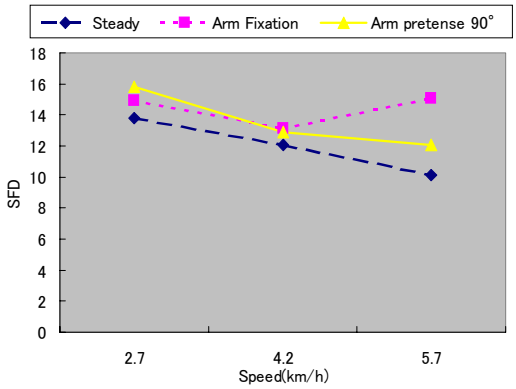
Comparison of the SFD during unrestrained walking and while walking with the arms immobilized showed the effects of the presence or absence of arm movements on stability. These effects were also apparent from a comparison of the SFD values obtained when arms were swung up 90° with those obtained when the arms were immobilized. The following discussion is based on data obtained from all 3 walking postures.

Figure 3 shows a comparison of the average SFD for all subjects at each speed (2.7 km/hr, 4.2 km/hr, 5.7 km/hr) and each walking posture (unrestrained, arms immobilized, arms swung up 90°). When walking with the arms swung up 90°, a significant difference in the SFD was apparent between the different walking speeds ($F(2,7)=3.74$, $p<0.05$). However, no significant difference was apparent between walking postures.

On the other hand, as shown in Fig. 3, there was a strong tendency for the SFD to be particularly high for walking at 2.7 km/hr with the arms swung up 90°. This tendency is similar to that seen for the high instability value at a walking speed of 2.7 km/hr in the subjective evaluation of stability. Evaluation of the data from all subjects showed that some subjects exhibited extreme movements at the walking speed of 2.7 km/hr with the arms swung up 90°, and it is thought that excessive arm movements has an effect on walking stability.



Figere2 The Regression line of SFD by steady



Figere3 The Walk Speeds of SFD, Comparison by The Walk Postures

4.Conclusions

The results of the experiment showed that, at a high walking speed (5.7 km/hr), the SFD was significantly higher for walking with arms immobilized than for unrestrained walking. This indicates that, at low and medium speeds, the effect of restricted arm movements on the upper body posture was minimal, whereas, at high speed, its effect on stability is considerable. At the same time, movements of the upper body, particularly movements of the shoulders in the front-rear direction, maintains stability in the human gait (see Fig. 4). Motion of the lower limbs determines motion of the upper limbs, and this relationship is very effective in maintaining stability during walking. Measurements of deflection of the center of gravity showed that the distance of its movements during walking with the arms immobilized corresponded to the subjective evaluation of difficulty in walking (see Fig. 5). This indicated the difficulty of walking in this posture, and illustrated the effect of arm movements on stability of posture of the upper body, and the effect on conservation of energy.

The use of the SFD as an index in this study provided a comparison with the subjective evaluations of the subjects, and provided a quantitative understanding of walking stability based on variance analysis.

The above findings provide information on the effects of arm movements on walking stability, and are applicable to the study of the role of arm movements, research on variations in walking speed, and research on bipedal robots. Use of the SFD as an index to quantify movements of the upper body will prove significant in rehabilitation, clinical analysis of walking, and analysis of walking from the point of view of sports physiology.

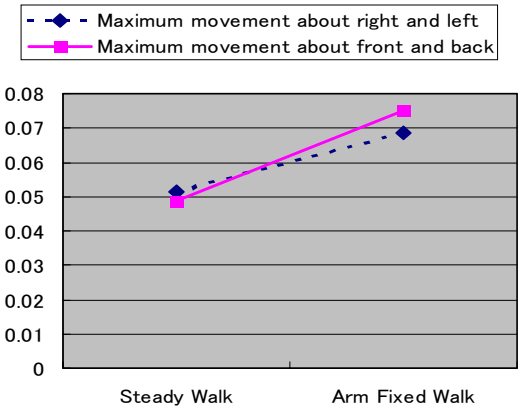


Figure4 Every Direction Maximum Movement Width by the Walk Posture in a Speed 5.7km/h

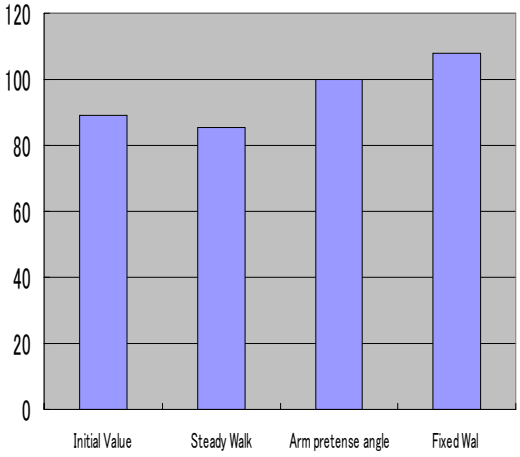


Figure 5 xy Composition Center of Gravity Movement Distance

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