Inefficiency of wide-based walking from the perspective of lateral center of gravity, gluteus medius muscle myoelectric activity, and cardiopulmonary parameters

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Abstract. [Purpose] To clarify the inefficiency of wide-based walking from kinematic and exercise physiology perspectives. [Participants and Methods] Participants consisted of 20 healthy male university students who performed treadmill walking under conditions of normal walking and wide-based walking (20-cm stride width). The lateral center of gravity movement, gluteus medius muscle myoelectric activity, oxygen uptake, minute ventilation (tidal volume, respiratory rate), heart rate, blood pressure, and rating perceived exertion just before the end of constant load exercise (4.0 km/h) were compared between the two walking conditions. [Results] All the measured parameters except for tidal volume and diastolic blood pressure were significantly higher during wide-based walking than during normal walking. However, when Δ is the difference between the two conditions, no correlation was found between Δlateral center of gravity movement, Δgluteus medius muscle myoelectric activity, Δcardiopulmonary parameters, and Δrating perceived exertion. [Conclusion] Although the precise mechanisms underlying the inefficiency of wide-based walking could not be clarified, cardiopulmonary indices such as oxygen uptake were significantly higher during wide-based walking than during normal walking. This suggests that improvement of wide-based gait is warranted from a kinematic perspective and an exercise physiology perspective. Key words: Wide-based walking, Kinematics, Exercise physiology

INTRODUCTION

A wide-based gait with increased stride width is a common feature among patients with balance disorders that becomes more prominent as the disease progresses, such as spinocerebellar degeneration. Although this gait is thought to represent a compensatory strategy to increase the base of support in order to walk without falling, attempts are still made to bring the gait closer to normal through physical therapy. One reason for such attempts is to improve gait appearance, and another is to increase the efficiency of walking. A previous study by Kawahara et al.1) found that displacement of the center of gravity (COG) of the body was significantly increased in the left-right direction when walking with an enlarged stride width, such as wide-based walking, and that maximum knee joint valgus moment in the early to mid-stance phase decreased, hip joint adduction moment decreased, and ankle joint varus moment increased as stride width increased. However, studies have yet to confirm whether wide-based walking is inefficient compared to normal walking, which is considered the most efficient form of walking.

The purpose of this study was therefore to clarify the inefficiency of wide-based walking from the perspectives of lateral COG movement, gluteus medius muscle myoelectric activity, and cardiopulmonary parameters.

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PARTICIPANTS AND METHODS

Participants were 20 healthy male university students. Mean ± standard deviation (SD) of age of the participants was 21.9 ± 1.2 years, mean height was 174.7 ± 4.9 cm, mean weight was 66.9 ± 10.1 kg, and mean body mass index (BMI) was 21.9 ± 2.5 kg/m². The purpose, methods, and freedom to take part in or withdraw from the study were explained to all participants, and written consent for participation was obtained prior to enrolment.

Participants were made to walk on a treadmill (MAT-3200; Fukuda Denshi, Tokyo, Japan) under conditions of normal walking and wide-based walking (20-cm stride width). The order of conditions was randomized, and participants were instructed to walk while stepping on the treadmill with heel contact first. Participants were asked to perform the different conditions at intervals of at least 24 h. Walking speed on the treadmill was kept at a constant 4.0 km/h, and participants walked for 5 min after a 3-min warm-up. The following items were measured during walking: lateral COG movement; gluteus medius muscle myoelectric activity; cardiopulmonary parameters; and rating perceived exertion (RPE).

A Gait-kun triaxial acceleration gait analyzer (MG-M1110; LSI Medience, Tokyo, Japan) was used to measure COG movement during walking. The Gait-kun was attached to the waist via an accessory belt, and mean lateral movement was measured. Data obtained from the Gait-kun were analyzed using Gaitview MG-M1110 software (LSI Medience). The value of lateral COG movement was obtained from 10 steps just before the end of walking. Surface electromyography (EMG) was performed on the right gluteus medius muscle using an Ultium EMG system (NORAXON EM-U810M8; SakaiMed, Tokyo, Japan). Electrodes were attached parallel to the muscle fibers with a center distance of 20 mm. The electrode was attached halfway along the line connecting the iliac crest to the greater trochanter, in accordance with the Surface ElectroMyoGraphy for the Non-Invasive Assessment of Muscles (SENIAM) guideline. Before attaching the electrode, the skin was treated with an external skin disinfectant and a skin preparation gel for biological signal monitoring (Skinpure; Nihon Kohden, Tokyo, Japan). Measurement was performed with the participant lying on their left side and raising their right leg. The measurement time was 5 s. After excluding the first and last 1 s, the middle 3 s were analyzed. The root mean square (RMS) of the waveform during maximum voluntary contraction (MVC) was set at 100%, and RMS of the EMG waveform at 4–5 min during walking was displayed as %MVC.

An exhaled gas analyzer (AE310S; Minato Medical Science, Tokyo, Japan) and a load ECG analyzer (MLX-1000 system; Fukuda Denshi, Tokyo, Japan) were used to measure the following cardiopulmonary parameters: oxygen uptake (VO₂), minute ventilation rate (VE), tidal volume (VT), respiratory rate (RR), heart rate (HR), systolic blood pressure (SBP), and diastolic blood pressure (DBP). All of these parameters were measured before the start of walking and before the end (average value for 4.5 to 5.0 min) of the 5-min walk.

For RPE, lower limb fatigue and general fatigue were measured before the start of walking and just before the end of the 5-min walk by asking participants to point to a rating on a modified Borg scale.

After confirming the normality of the distribution of parameters using the Shapiro–Wilk test, the paired t-test was used to compare the two conditions. The Wilcoxon signed-rank test was used to compare two conditions when a normal distribution was not observed. In addition, Pearson’s product-rate correlation or Spearman’s correlation by rank were used to test for the existence of correlations between differences between conditions of COG movement (Δlateral COG movement distance), differences between conditions of muscle activity (Δgluteus medius muscle myoelectric activity), and differences between conditions of cardiopulmonary parameters (ΔVO₂, ΔVE, ΔVT, ΔRR, ΔHR, ΔSBP, and ΔDBP) and differences between conditions of RPE (ΔRPE). SPSS version 21.0 software (IBM Japan, Tokyo, Japan) was used for statistical analyses, and the level of significance for all statistical processing was set at 5%.

RESULTS

Both lateral COG movements and the gluteus medius muscle myoelectric activities were significantly higher in the wide-based walking than in the normal walking (Table 1). Furthermore, all but VT and DBP of the cardiopulmonary parameters were also significantly higher in the wide-based walking than in the normal walking (Table 2). On the other hand, two items of RPE were not significantly different between the two walking conditions (Table 2).

| Table 1. Values of lateral center of gravity (COG) movements and gluteus medius muscle myoelectric activities in the normal and the wide-based walking |
|-----------------------------------------------|
|                                Normal walking | Wide-based walking |
|-----------------------------------------------|
| Lateral COG movement (cm)                 | 3.2 ± 1.2          | 7.6 ± 1.0*** |
| Gluteus medius muscle myoelectric activity (%MVC) | 34.6 ± 13.5       | 51.9 ± 17.4*** |

COG: center of gravity; MVC: maximum voluntary contraction.
Values represent mean ± standard deviation.
*Paired t-test; *Wilcoxon signed-rank test.
Comparison with normal walking condition: ***p<0.001.
The correlation coefficient $\rho$ between the $\Delta$lateral COG movement and $\Delta$gluteus medius muscle myoelectric activity was 0.250, and there was no correlation. In addition, no correlations were found at each $\Delta$lateral COG movement and $\Delta$gluteus medius muscle myoelectric activity, and $\Delta$cardiopulmonary parameters and $\Delta$RPE (Table 3).

**DISCUSSION**

The present results showed that lateral COG movement was significantly higher in the wide-based walking than in the normal walking, supporting previous findings by Kawahara et al.\(^1\).

Myoelectric activity in the gluteus medius muscle is significantly increased in the wide-based walking compared to normal walking. Kobayashi et al.\(^3\) reported, when stride width was increased from 10 cm (similar to normal walking) to about 30 cm, myoelectric activity in the gluteus medius muscle was not significantly increased, but when stride width was increased from 30 cm to 40 cm, gluteus medius muscle myoelectric activity was increased. In the present study, however, muscle activity was increased at a stride width of 20 cm compared to that during normal walking, which was not significantly different in the multiple comparison test in the study by Kobayashi et al. Only 6 participants were included in their study, and 4 types of stride widths were set, which may be one of the reasons for the difference in the results from our study. Since the stride width during normal walking is 8.0 cm\(^4\), it is considered that the setting of 20 cm for wide-based walking was sufficient to induce kinematic and exercise-physiological differences.

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**Table 2. Values of cardiopulmonary parameters and rating perceived exertion (RPE) items in the normal and the wide-based walking**

| Parameter                  | Normal walking | Wide-based walking |
|----------------------------|----------------|--------------------|
| $\text{VO}_2$ (mL/kg/min)  |                |                    |
| At rest\(^b\)             | 4.6 ± 0.7      | 4.5 ± 0.7          |
| At end of exercise\(^b\)  | 10.2 ± 0.8     | 11.8 ± 1.1***      |
| VE (L)                    |                |                    |
| At rest\(^a\)             | 11.0 ± 2.0     | 10.7 ± 2.0         |
| At end of exercise\(^a\)  | 20.0 ± 2.9     | 24.2 ± 3.6***      |
| VT (L)                    |                |                    |
| At rest\(^b\)             | 0.8 ± 0.2      | 0.7 ± 0.1          |
| At end of exercise\(^a\)  | 0.9 ± 0.2      | 1.0 ± 0.2          |
| RR (breaths/min)          |                |                    |
| At rest\(^a\)             | 14.7 ± 3.6     | 16.0 ± 4.8         |
| At end of exercise\(^a\)  | 22.4 ± 5.1     | 25.8 ± 4.1**       |
| HR (beats/min)            |                |                    |
| At rest\(^a\)             | 77.9 ± 12.6    | 80.6 ± 13.0        |
| At end of exercise\(^a\)  | 90.3 ± 14.8    | 95.7 ± 14.5*       |
| SBP (mmHg)                |                |                    |
| At rest\(^a\)             | 121.3 ± 11.0   | 127.8 ± 11.9*      |
| At end of exercise\(^a\)  | 132.8 ± 7.9    | 138.9 ± 13.8*      |
| DBP (mmHg)                |                |                    |
| At rest\(^a\)             | 80.3 ± 7.8     | 77.9 ± 7.8         |
| At end of exercise\(^a\)  | 74.2 ± 7.8     | 75.5 ± 7.3         |
| RPE Lower extremities     |                |                    |
| At rest\(^b\)             | 0.1 ± 0.3      | 0.1 ± 0.3          |
| At end of exercise\(^b\)  | 1.2 ± 1.0      | 1.7 ± 1.2          |
| RPE Whole body            |                |                    |
| At rest\(^b\)             | 0.2 ± 0.5      | 0.2 ± 0.5          |
| At end of exercise\(^b\)  | 1.2 ± 0.9      | 1.6 ± 1.1          |

$\text{VO}_2$: oxygen uptake; VE: minute ventilation; VT: tidal volume; RR: respiratory rate; HR: heart rate; SBP: systolic blood pressure; DBP: diastolic blood pressure; RPE: rating perceived exertion.

Values represent mean ± standard deviation.

\(^a\)Paired $t$-test; \(^b\)Wilcoxon signed-rank test.

Comparison with normal walking condition: *$p<0.05$, **$p<0.01$, ***$p<0.001$. 

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The correlation coefficient $\rho$ between the $\Delta$lateral COG movement and $\Delta$gluteus medius muscle myoelectric activity was 0.250, and there was no correlation. In addition, no correlations were found at each $\Delta$lateral COG movement and $\Delta$gluteus medius muscle myoelectric activity, and $\Delta$cardiopulmonary parameters and $\Delta$RPE (Table 3).
same speed affects the difference in the cardiopulmonary response. Δcardiopulmonary parameters and ΔRPE. These results suggest that lateral COG movement and gluteus medius muscle myoelectric activity are not the sole contributors to changes in cardiopulmonary parameters under the two conditions. Our prediction is that wide-based walking increases lateral COG movement compared to normal walking, and increased activity of the gluteus medius muscle suppresses it, resulting in a greater response to cardiopulmonary parameters. However, the suggestion of this study contradicted our prediction. McAndrew Young et al. reported that wide-based walking not only significantly increased stride width, but also significantly shortened step length compared to normal walking. Ohmichi also stated that HR and VO2 were the lowest in spontaneous walking at any speed, and that physiological intensity increased with both longer and shorter step lengths. Since only stride width was specified in our study, the possibility remains that the step length affects cardiopulmonary indices thus cannot be ruled out. It is considered that the step length during walking at the same speed affects the difference in the cardiopulmonary response.

Kobayashi et al. reported that myoelectric activity in the adductor longus muscle increased significantly while walking with a wider stride width of 40 cm, compared to widths of 20 cm and 30 cm, during the 70%-80% of the stance phase of the gait. This suggests that activity of muscles other than the midriff muscles during wide-based walking may affect cardiopulmonary parameters and RPE. Muscle activity of the tibialis posterior and trunk ventral muscles, in addition to the mid-diastasis and adductor muscles, is also expected to increase from the early to mid-to-late stance. However, since this remains a matter of speculation, the number of test muscles in experiments needs to be increased, and this is regarded as an issue for future investigation.

This study found that lateral COG movement and myoelectric activity of the gluteus medius muscle were not the sole factors explaining changes in cardiopulmonary parameters and RPE during wide-based walking. However, values of cardiopulmonary parameters such as VO2 were higher during wide-based walking than during normal walking. Wide-based walking is considered an inefficient gait. This suggests the desirability of improving gait for individuals showing wide-based walking, not only from a kinematic perspective, but also from an exercise physiological perspective.

**Conflict of interest**

The authors declare that there is no conflict of interest regarding the publication of this article.
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