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Effect of contralateral cane use on whole-body angular momentum in the frontal plane during walking *

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***Abstract*— This study aims to clarify how using a cane affects the amplitude of whole-body angular momentum (WBAM) about the body's center of mass in the frontal plane during walking in older adults. Twenty older adults participated in the study, walking under two conditions: (1) without a cane and (2) with a cane. WBAM range ($WBAM_R$) in the frontal plane was calculated as the difference between the minimum and maximum values over one gait cycle. To identify biomechanical factors affecting WBAM, we examined peak moment arms from the body's center of mass to the center of pressure in the mediolateral direction and peak vertical ground reaction force (GRF). Variables were assessed using paired t-tests for normally distributed data and the Wilcoxon signed-rank test for non-normally distributed data. $WBAM_R$ was significantly smaller when walking with a cane compared to walking without one. The peak mediolateral moment arms during the second steps and peak vertical GRF during the first steps were significantly larger without a cane than with one. WBAM amplitude decreased throughout the gait cycle when using a cane. Our findings demonstrate that using a cane reduces WBAM amplitude in the frontal plane across the gait cycle, thereby enhancing mediolateral dynamic balance in older adults during walking.**

Index Terms— Cane walking, dynamic balance, older adults, whole-body angular momentum.

I. Introduction

Walking aids are crucial for enhancing mobility and reducing the risk of falls among older adults. They effectively support safe mobility, and demand for them is rising [1]. Aging leads to a decline in physical functions, which weakens balance. Annually, about one-third of older adults experience falls, resulting in musculoskeletal injuries and functional disabilities [2]. Walking aids help compensate for balance and mobility issues in older adults [3]. Of these aids, the cane is the most common. It is frequently prescribed to maintain balance, enhance mobility, and promote independence [3, 4]. Therefore, the cane is a vital tool for older adults with declining balance, supporting safe and independent social activities.

Dynamic balance during walking is commonly assessed using whole-body angular momentum (WBAM) around the body's center of mass. Stroke patients, amputees, and older adults exhibit a larger amplitude of cyclic WBAM changes compared to healthy individuals [5-8]. Previous studies have linked this increased amplitude to a higher risk of falls [8]. Older adults, in particular, show a larger WBAM amplitude in the frontal plane during walking [6, 7]. A high amplitude of WBAM in the frontal plane indicates that maintaining mediolateral balance during walking is more challenging, which correlates with a greater risk of lateral falls [6, 7]. Therefore, reducing the amplitude of cyclic WBAM changes in the frontal plane is crucial for improving dynamic balance in older adults. However, strategies to achieve this reduction have not yet been clarified.

One potential solution is using a cane, which may help reduce the amplitude of cyclic WBAM changes in the frontal plane. Older adults often have a significantly wider peak mediolateral moment arm from the body's center of mass (CoM) to the center of pressure (CoP), which is associated with a larger WBAM amplitude in the frontal plane during walking [6]. Large moments around the CoM in the frontal plane during walking contribute to the increased WBAM amplitude observed in older adults. Using a contralateral cane decreases hip abductor muscle activity and the hip abduction moment in the stance limb [9, 10]. This effect occurs because the cane contacts the ground on the opposite side of the supporting lower limb, creating an external moment relative to the body CoM that rotates toward the supporting limb during the stance phase. Consequently, a cane may reduce the external moment around the body CoM and decrease WBAM amplitude in the frontal plane during walking. Understanding the effects of cane use is crucial for promoting safe social activities among older adults.

We aim to clarify how using a cane affects the amplitude of WBAM in the frontal plane during walking in older adults. We hypothesize that using a cane improves dynamic balance by reducing WBAM amplitude in the frontal plane.

II. Methods

A. Participants

Twenty older adults participated in this study (mean ± SD age: 70.2 ± 3.2 years, height: 1.64 ± 0.06 m, and body mass: 62.9 ± 10.1 kg). Inclusion criteria included the absence of (1) body pain, (2) orthopedic diseases (e.g., anterior cruciate ligament injury), and (3) neurological disorders. All participants received written and oral explanations of the study and signed an informed consent form before participating. The study protocol adhered to the Declaration of Helsinki guidelines and was reviewed and approved by the Human and Medical Research Institute, National Institute of Advanced Industrial Science and Technology (AIST) (e-mail: shoma-kudou@aist.go.jp). G. Horiuchi. is with College of Sport and Health Science, Ritsumeikan University (e-mail: horiuchi@fc.ritsumei.ac.jp). A. Nagano. is with College of Sport and Health Science, Ritsumeikan University (e-mail: aknr-ngn@fc.ritsumei.ac.jp).

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B. Data Collection

Participants were asked to walk on a 10 m walkway under two experimental conditions: (1) without a cane and (2) with a cane. To ensure participants were accustomed to walking with a cane, multiple practice trials were conducted before the experiments. Walking with a cane might affect the amplitude of cyclic WBAM changes due to a significant decrease in walking speed and cadence [11]. To control for this, cadence was set to 100 steps/min based on previous studies involving older adults [12, 13]. Participants were instructed to use a two-point gait pattern, placing the cane down simultaneously with or just before the heel contact of the stance limb. The cane was gripped in the dominant hand and positioned laterally at shoulder width. The cane length was set to the distance from the floor to the distal wrist crease while standing still [14]. The cane used in this study had a single point of contact with the floor.

A three-dimensional motion capture system with 21 cameras recorded the trajectories of 45 markers attached to the participant's body and cane (MAC3D and Raptor-E, Motion Analysis Corporation, California, USA). Ten force plates measured the ground reaction forces acting on the stance limb and cane (TF-4060-B, Tec Gihan Inc., Kyoto, Japan). The sampling rates were 250 Hz for the motion capture system and 1250 Hz for the force plates.

C. Data analysis

A gait cycle (from right or left heel contact to the next heel contact of the same foot) was used for data analysis. Marker and ground reaction data were filtered using a fourth-order zero-lag Butterworth low-pass filter with cutoff frequencies of 5 Hz and 10 Hz, respectively. The link model comprised 15 rigid body segments (head, torso, pelvis, upper arms, forearms, hands, thighs, lower legs, and feet) for the body and one segment for the cane. For walking without a cane, the model included 15 body segments. For walking with a cane, the model included the 15 body segments plus an additional segment for the cane. The joint centers, segment mass, segment mass centers, and moment of inertia parameters were calculated using values from previous studies [15, 16]. The cane's mass was measured at 0.8 kg, and its inertia parameters were based on values for a slender rod [17]. WBAM was calculated using the following equation:

$$\overrightarrow{WBAM} = \sum_{i=1}^{n} \left[\left(\vec{r}_i^{\,CoM} - \vec{r}_{body}^{\,CoM} \right) \times m_i \left(\vec{v}_i^{\,CoM} - \vec{v}_{body}^{\,CoM} \right) + I_i \vec{\omega}_i \right]$$

where $\vec{r}_i^{\,CoM}$ and $\vec{v}_i^{\,CoM}$ are the position and velocity vectors of the segment's CoM, respectively. $\vec{r}_{body}^{\,CoM}$ and $\vec{v}_{body}^{\,CoM}$ are the position and velocity vectors of the whole-body CoM, respectively. m_i, $\vec{\omega}_i$, and I_i are the mass, angular-velocity vector, and moment of inertia of the segment, respectively. WBAM was normalized by the participants' body mass (kg), body height (m), and walking speed (m/s), following the method used in a previous study [18]. Dynamic balance control was assessed using the range of WBAM ($WBAM_R$), which was calculated as the difference between the minimum and maximum values of WBAM in the frontal plane over one gait cycle. Step length was determined as the distance between the heel marker at right or left heel contact and the heel marker at the next contralateral heel contact. Step width was measured as the lateral distance between the centers of the two feet (approximated as the midpoint between the toe and heel markers) at the heel contact event of each foot. Cadence was calculated using the time from a heel contact to the next heel contact. The walking speed was calculated by averaging the three dimensional displacement of the whole body CoM during one stride cycle into a scalar value. To evaluate the biomechanical factors influencing WBAM, we compared peak moment arms from the body CoM to the CoP in the mediolateral direction and peak vertical ground reaction force (GRF) between walking with and without a cane. The peak mediolateral moment arm for the first step was calculated during the single limb stance phase, or vice versa for the second step. Peak vertical GRF for the first and second steps were measured during each single stance phase and normalized by body weight.

D. Statistical analysis

Statistical analyses were conducted using SPSS version 28 (IBM Corp., Armonk, NY, USA). The normality of each variable's data distribution was assessed using the Shapiro–Wilk test. Paired t-tests were used for normally distributed data, and the Wilcoxon signed-rank test was used for non-normally distributed data. The significance level was set at p = 0.05. These tests compared each variable between walking with and without a cane. Effect sizes reported include Cohen's d for the paired t-test and the r-value for the Wilcoxon signed-rank test. Cohen's d value was interpreted as small ($0.2 \leq d < 0.5$), moderate ($0.5 \leq d < 0.8$), and large ($0.8 \leq d$). The r-value was classified as small ($0.1 \leq r < 0.3$), moderate ($0.3 \leq r < 0.5$), and large ($0.5 \leq r$).

III. Result

A. Whole-body angular momentum in the frontal plane

Figure 1a shows the time series data of WBAM for one gait cycle. The $WBAM_R$ during walking with a cane was 35.4 ± 8.7 (mean ± SD), whereas it was 46.5 ± 12.8 during walking without a cane. The $WBAM_R$ during walking with a cane was significantly smaller compared to walking without a cane (Fig. 1b), with an observed effect size of 1.15.

B. Gait characteristic parameters

Table 1 summarizes the gait characteristic parameters. Walking speed, the peak mediolateral moment arm for the second steps, and the peak vertical GRF for the first step were significantly larger when walking without a cane compared to walking with a cane (Table 1). The peak mediolateral moment arm during the first step was significantly larger when walking with a cane than without a cane (Table 1).

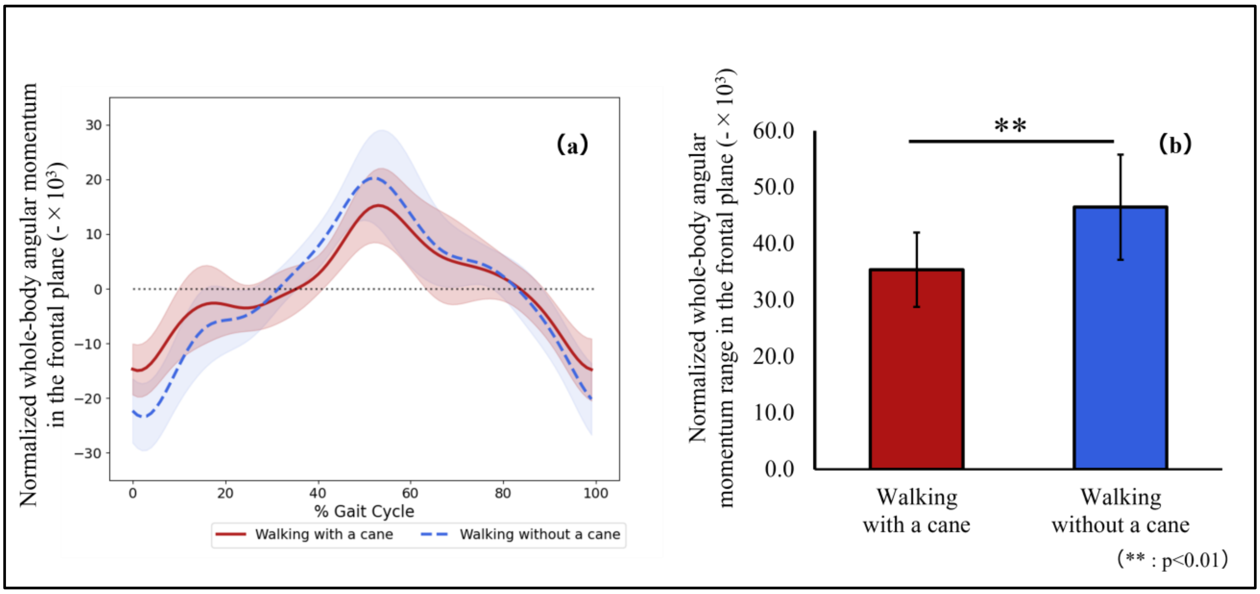

Figure 1. **(a)** The time series data of the normalized whole-body angular momentum in the frontal plane for one gait cycle during walking without and with a cane and **(b)** Range of the normalized whole-body angular momentum in the frontal plane during walking without and with a cane. Significant differences are indicated with '*'.

Table 1. Walking parameters for walking without a cane and walking with a cane.

	walking with a cane	walking without a cane	p-value	Effect size
Step length (m)	0.64 ± 0.05	0.64 ± 0.05	$p = 0.34^a$	-0.21
Step width (m)	0.13 ± 0.03	0.13 ± 0.03	$p = 0.76^a$	0.07
Cadence (steps/min)	102.0 ± 3.3	103.9 ± 4.2	$p = 0.051^a$	-0.47
Walking speed (m/s)	1.14 ± 0.11	1.18 ± 0.10	$p = 0.03^a$	-0.52
First step peak mediolateral moment arm (m)	0.09 ± 0.01	0.07 ± 0.02	$p < 0.01^a$	-1.80
Second step peak mediolateral moment arm (m)	0.02 ± 0.02	0.04 ± 0.02	$p < 0.01^b$	-0.54
First step peak vertical GRF (N / BW)	1.11 ± 0.1	1.20 ± 0.1	$p < 0.01^a$	-1.05
Second step peak vertical GRF (N / BW)	1.18 ± 0.1	1.21 ± 0.1	$p = 0.18^b$	-0.21

^{a}: Independent samples t-test. ^{b}: Wilcoxon signed-rank test. BW: Body weight

No significant differences were found in step length, step width, or the peak vertical GRF for the second step between walking with and without a cane (Table 1).

IV. Discussion

We investigated how using a cane affects the amplitude of WBAM in the frontal plane during walking in older adults. The $WBAM_R$ in the frontal plane was significantly larger without a cane than with one (Fig. 1b). Our results support the hypothesis that using a cane reduces the amplitude of WBAM in the frontal plane during walking. Additionally, WBAM amplitude decreased throughout the entire gait cycle when walking with a cane (Fig. 1a, b). We demonstrated that using a cane lowers the amplitude of WBAM in the frontal plane across the gait cycle, thereby improving mediolateral dynamic balance in older adults during walking.

The differences in WBAM in the frontal plane between walking with and without a cane may be influenced by kinetic changes resulting from the cane's support. A previous study indicated that the moment about the body CoM in the frontal plane is related to the $WBAM_R$ [6]. Peak mediolateral moment arms during the first step were significantly larger when walking with a cane compared to without a cane. Conversely, the peak vertical GRF during the first step was significantly higher without a cane (Table 1). While an increase in the mediolateral moment arm would typically contribute to a larger moment about the body CoM in the frontal plane, the smaller peak vertical GRF during walking with a cane likely reduces the moment in the frontal plane. The difference in the mediolateral moment arm between walking with and without a cane may be associated with differences in the kinematic characteristics of walking. A previous study reported that walking with a cane induces trunk leaning toward the swing side [10]. The mediolateral moment arm during walking with a cane might have increased owing to the trunk leaning toward the swing side, which shifted the body CoM closer to the swing side. The smaller $WBAM_R$ during walking with a cane is likely due to the reduction in the stance side vertical GRF caused by the cane support, which appears to have suppressed the moment about the body CoM.

It is noteworthy that WBAM amplitude was significantly smaller when walking with a cane, even when the cane was not in contact with the ground. Although there was no significant difference in the second step peak vertical GRF between walking with and without a cane, a significant difference was observed in the second step peak mediolateral moment arm from the body CoM to the CoP (Table 1). The smaller mediolateral moment arm when using a cane, due to differences in kinematic characteristics, results in a reduced WBAM amplitude throughout the entire gait cycle. This suggests that using a cane improves the mediolateral dynamic balance of older adults during walking.

One limitation of this study is the significant difference in walking speeds between walking with and without a cane (Table 1). The extremum of WBAM is negatively correlated with walking speed, as observed in studies of amputees [19, 20]. Therefore, the effect of a cane on WBAM in the frontal plane during walking in older adults may be underestimated. However, the average walking speed difference between walking with and without a cane in this study is approximately 3.5%. Previous studies have reported that a 30–50% difference in walking speed increases WBAM amplitude [19, 20]. Thus, the impact of the walking speed difference on WBAM results in the frontal plane is expected to be minimal.

V. Conclusion

This study demonstrated that using a cane reduces the amplitude of WBAM in the frontal plane throughout the gait cycle, thereby enhancing mediolateral dynamic balance in older adults during walking. The observed differences in WBAM in the frontal plane between walking with and without a cane are due to changes in the mediolateral moment arm from the CoP to the body CoM and the peak vertical GRF during the first step. Using a cane may decrease the risk of falls among older adults and facilitate social participation. Future interventional studies are needed for further investigation.

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