J. Phys. Ther. Sci. 31: 20–23, 2019

The Journal of Physical Therapy Science

Original Article

Motor strategy for rapid gait initiation under conditions of limited center of pressure control

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Abstract. [Purpose] The general motor strategy for gait initiation is achieved by the difference between the center of gravity and center of pressure; it be as bigger under speed optimization. This study aimed to investigate the motor pattern in rapid gait initiation under conditions of limited backward displacement of center of pressure. [Participants and Methods] The participants were 30 healthy young males (mean age, 19.7 ± 1.0 years). They performed a gait initiation task at three center of pressure start positions (anterior, middle, and posterior) and two speed conditions (normal and rapid). The gait initiation motion was measured using a video camera and motor pattern in the images was classified. The center of pressure position was continuously monitored using a pressure distribution measurement system. [Results] Forward tilt pattern was the most common under no limited center of pressure control and normal speed. The backward tilt pattern was the most preferred in the posterior position under limited center of pressure control and rapid speed. Displacement of the center of pressure showed a significant decline when the center of pressure start position was displaced backward. [Conclusion] The backward tilt pattern is the most effective motor strategy to increase the forward speed of the center of gravity.
Key words: Gait initiation, Motor pattern, COP

(This article was submitted Jul. 12, 2018, and was accepted Oct. 7, 2018)

INTRODUCTION

Gait initiation is expressed as the transient state between standing and walking[1)], and the control of the center of pressure (COP) and the center of gravity (COG) is characteristic. The COP displaces once toward the swing leg side and backward. This is realized by the unloading of the stance limb and activation of the dorsiflexors. Thereafter, the COP displacement toward the stance limb side and the anterior side is controlled by the plantarflexors. However, with the COG displacement toward the stance side and the anterior side, gait initiation can achieve the necessary energy to start movement by the difference between the COG and COP (COG-COP moment arm)[2–4)]. Thus, the general motor strategy involved in gait initiation includes the minimization of the energy cost by the generation of the COG-COP moment arm.

While previous studies have investigated the normal gait pattern using gait speed effects[5, 6)], the motor strategy of gait initiation under speed optimization hasn't been sufficiently clarified. Moreover, if the general motor strategy of gait initiation is taken motor strategy to minimize cost, when the COP start position is displaced posteriorly and the COP backward displacement is limited, what is the motor strategy that provides the energy for starting movement? This is an interesting

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research question in kinesiology.

We hypothesized that the motor strategy involves the generation of the COG-COP moment arm by pelvic forward displacement in the backward displacement condition. The purpose of this study was to investigate the motor pattern involved in gait initiation for each COP start position.

PARTICIPANTS AND METHODS

Thirty young adult male (age: 19.7 ± 1.0 years, height: 172.3 ± 5.7 cm, and weight: 64.6 ± 6.1 kg) were recruited in the study. None of the participants had a history of neurological or orthopedic problems. The participants were explained about the study procedure in detail; thereafter, they signed consent forms for study participation. The study was approved by the Tohoku Bunka Gakuen University (No. 16-21).

The motion was measured using a portable video camera (HC-W870M: Panasonic) from the sagittal plane (left side of the participants). The COP position was continuously monitored with the pressure distribution measurement system (BIG-MAT; NITTA) to regulate the starting posture. The signal device as cue signal used sound and light signals at same time, light signal was as participants start signal, sound signal was as video analyze start. So light signal of signal device and performed motion were recorded together with a video camera.

The participants started walking after receiving a sound cue and walked the length of a 5-m walkway. The experimental conditions included different speeds and the COP start positions. The speed conditions were normal (N) and rapid speed (R), they were instructed to start walking in their usual manner at N and to start walking as fast as possible from the first step at R. The COP start position matched the position of the fifth metatarsal head at the anterior position (AP), natural standing position at the middle position (MP), and position of the lateral malleolus at the posterior position (PP). In addition, the starting posture was adjusted so that the line connecting the acromion process and the greater trochanter was vertical, and the load to the left and right limbs was equal (Fig. 1).

The participants crossed their arms over their chest, and gazed at the target at a distance of 5 m. They performed 6 tasks (AP-N, AP-R, MP-N, MP-R, PP-N, and PP-R) after practicing each task randomly; each task was performed once. We measured the duration time, the COP displacement, and motor pattern. The duration time was calculated as the time from the cue signal (light signal) to the heel contact of the swing leg. The COP displacement was calculated as the difference between the COP start position and the peak COP posterior position. Motor patterns in gait initiation were analyzed using animation by author. It was analyzed from the cue signal to the heel contact of the swing leg, was classified into four patterns: forward tilt pattern (with trunk forward tilt), backward tilt pattern (with pelvic anterior displacement before trunk backward tilt), step pattern (with backward step of stance limb) and rotation pattern (with pelvic and trunk rotation in the same direction).

Two-way analysis of variance (ANOVA) was performed with duration time and COP displacement as dependent variables, and the COP start position (AP, MP, and PP) and speed condition (N and R) as within-participant factors. A p-value of 0.05 was accepted as statistically significant. When main and interaction effects were significant, post-hoc comparisons were performed as described by Holm.

RESULTS

Figure 2 showed typical of observed motor patterns in gait initiation. Forward tilt pattern was selected most commonly in the AP-N, AP-R, MP-N, MP-R and PP-N tasks. However, the backward tilt pattern was the most preferred in the PP-R task (Table 1).

Table 2 showed two-way ANOVA between the COP start position and speed condition. The duration time was a significant effect of the COP start position ($F(2,58)=25.57$, $p<0.01$) and speed ($F(1,29)=120.58$, $p<0.01$). It was significantly shorter at R than that at N. The duration time at PP was also significantly longer than those at AP and MP. There was no significant interaction of the COP start position and speed factors ($F(2,58)=0.67$, $p=0.52$).

The COP displacement was also a significant effect of the COP start position ($F(2,32)=116.48$, $p<0.01$) and speed ($F(1,16)=40.87$, $p<0.01$). There was a significant interaction between the COP start position and speed factors ($F(2, 32)=15.74$, $p<0.01$). Furthermore, the reports by Holm also revealed that COP displacement was unaffected by the speed during the PP task ($F(1,16)=1.25$, $p=0.28$).

DISCUSSION

In this study, we investigated motor pattern in rapid gait initiation at each speed and COP condition. The duration time was provided as the time from the cue signal to the heel contact of the swing leg, it was significantly shorter at R than that at N. The results indicated that the motor pattern was selected to optimize the speed.

Forward tilt pattern was selected by all participants at AP-N and MP-N (Table 1). Previous research revealed motor pattern of activity of daily living (ADL) is taken motor pattern to minimize the energy cost[7–9]. Thus, the forward tilt pattern was used the most frequently at N to minimize the energy cost by the generation of the COG-COP moments arm.

The forward tilt pattern was also most common in AP and MP at R, and the COP displacement increased at R. Thus, R

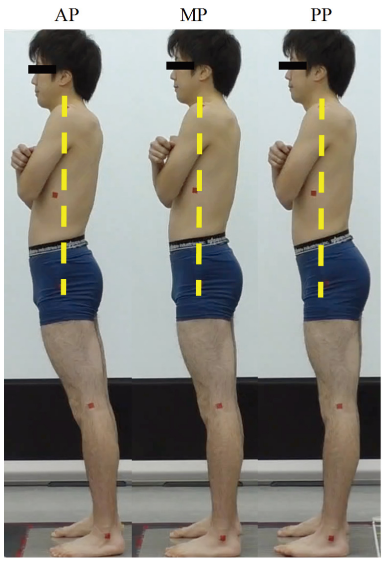

Fig. 1. Starting posture at each center of pressure start condition.
The anterior position (AP) was the center of pressure (COP) start position matched the position of the fifth metatarsal head, the middle position (MP) was natural standing position, and the posterior position (PP) was position of the lateral malleolus. The starting posture at all COP start condition is also provided the line connecting between the acromion process and greater trochanter, dashed line indicated as it.

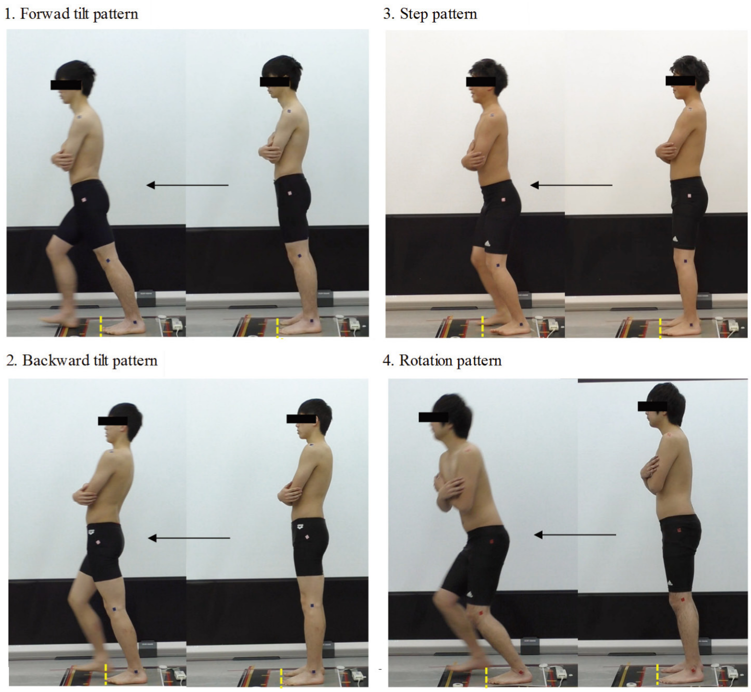

Fig. 2. Classified four patterns of motor strategy in gait initiation.
Dashed line indicated foot start position at each participant.

Table 1. Relationship of motor pattern between speed conditions at each center of pressure start position

Motor pattern	N			R		
	AP	MP	PP	AP	MP	PP
Forward tilt pattern	100.0	100.0	86.7	100.0	76.7	10.0
Backward tilt pattern	0.0	0.0	13.3	0.0	10.0	46.7
Step pattern	0.0	0.0	0.0	0.0	6.7	43.3
Rotation pattern	0.0	0.0	0.0	0.0	6.7	0.0

Unit: number of people (%)
N: normal speed condition; R: rapid speed condition; AP: the anterior position was the center of pressure start position matched the position of the fifth metatarsal head; MP: the middle position was natural standing position; PP: the posterior position was position of the lateral malleolus.

Table 2. Comparison of parameters between speed condition at each center of pressure start position

	N			R		
	AP	MP	PP	AP	MP	PP
Duration time (s)	0.94 ± 0.13	0 .96 ± 0.13	1.06 ± 0.12 c*, d*	0.79 ± 0.08	0.82 ± 0.10 a*, b*	0.89 ± 0.11 a*, c*, d*
COP displacement (cm)	8.10 ± 3.38	6.86 ± 1.64	3.70 ± 0.68 c*, d*	13.40 ± 1.58	8.50 ± 1.46 a*, b*	4.10 ± 0.95 a*, c*, d*

N: normal speed condition; R: rapid speed condition; AP: the anterior position was the center of pressure start position matched the position of the fifth metatarsal head; MP: the middle position was natural standing position; PP: the posterior position was position of the lateral malleolus. [a]Statistically significant difference between N and R, [b]Statistically significant difference between AP and MP, [c]Statistically significant difference between AP and PP, [d]Statistically significant difference between MP and PP. *$p<0.05$.

could obtain energy for motor initiation. Therefore, the forward tilt pattern was the most preferred at AP-R and MP-R tasks. In contrast, the forward tilt pattern was used by 86.7% participants in the PP-N task, while 10.0% used it for the PP-R task. Nevertheless, the backward tilt pattern was used by nearly half (46.7%) of the participants for the PP-R task. The COP displacement at PP was a significantly smaller than those at AP and MP. This result was believed to indicate the generation of insufficient COG-COP moments arm to propulsion at PP since the COP backward displacement at PP was limited. The backward tilt pattern starts with the forward tilt of the lower leg and moves ahead the pelvic displacement with trunk backward tilt. We considered that the preceding motion of a part of the trunk facilitated COG forward displacement. In addition, these motions were similar to the movement of a whip, and these movements were believed to be superior in terms of efficient movement of the upper trunk and the head.

Backward tilt pattern was the largest 46.7% at PP-R but step pattern was also 43.3%. Step pattern was strategically taken to increase movement energy by controlled COP backward displacement and by push off since the posterior stability limit at PP was narrow.

The results suggested that the backward pattern was the optimal motor pattern for increased COG velocity when sufficient COG-COP moments arm could not be generated. Thus, further study is required to analyze the COG velocity at the motor pattern constraint condition.

Conflict of interest

None.

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