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Original Article

The effect of gait speed and gait phase to the allocation of attention during dual task gait

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Abstract. [Purpose] The purpose of this study was to determine the change of allocation of attention caused by a difference in gait phase and gait speed. We also determined the relationship between attentional demand and gait automaticity change caused by the gait speed alteration. [Subjects and Methods] Ten male participated. Participants were instructed to perform the probe reaction time (RT) task during treadmill walking in four different gait speed conditions (60%, 80%, 100%, and 120% of preferred speed). Walking ratio in each gait speed conditions were calculated, and RTs and walking ratios were compared in each gait speed condition and in the single-support and double-support gait phase. [Results] RTs were significantly delayed with decline of gait speed. Walking ratio was significantly decreased in proportion of decrement of gait speed. There was no difference of gait phase between single-support and double-support phase. [Conclusion] This study showed that relationship between attentional load and deficit of gait automaticity. While gait phase didn't influence attentional demand, and this result showed the characteristics of treadmill gait.
Key words: Attention, Gait, Dual task

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INTRODUCTION

Control of gait is highly automated by the central nervous system. This system consists of subcortical areas associated with locomotor regions and spinal central generator[1, 2)]. In addition to these basic neurological functions, allocation of attention is needed in various gait situations[3)]. For example, Lundin-Olsson et al. have reported that older adults who cannot process concurrent tasks during gait, such as talking while walking, are prone to falling[4)]. Such studies suggest that distributed of attention is associated with gait instability and falling[4–7)]. More recently, gait ability has been shown to be affected by cognitive functions in patients with Alzheimer's disease as well as those with mild cognitive impairment[8, 9)]. Therefore, understanding the characteristics of distribution of attention during gait is important for prevention of falling caused by cognitive impairment. To quantify the allocation of attention, previous studies have used a dual-task paradigm. In this paradigm, subjects are required to perform a motor task and a cognitive task concurrently, and changes in performance are attributed to changes in allocation of attention[10, 11)]. Specifically, a probe reaction time (RT) task has often been used as the cognitive task to manipulate allocation of attention; that is, while performing the motor task, subjects are asked to respond as fast as possible

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to presented stimuli[12–14]. RT delay in dual-task versus single-task performance indicates reallocation of attentional resources to accommodate both tasks. Using a probe RT task, Lajoie et al. reported that allocation of attention is different between the single-support and double-support phases of walking[15]. Kurosawa focused on the effect of gait speed on the allocation of attention, and showed that slower gait speeds produced greater delays in RT[16]; more recent studies have reported similar results[17]. Hence, both gait speed and gait phase appear to affect the allocation of attention during gait. However, it has been unknown the relationship between allocation of attention and gait characteristics such as gait phase (single-support and double-support phase), and gait speed. In addition, previous studies showed the influence of the allocation of attention to the gait performance such as gait speed and step width[4–7], but there is no study examined the relationship between allocation of attention and gait automaticity.

The present study examined the influence of the gait speed change toward the difference of attentional load in each gait phase to find out if difference of attentional load. We also measured "walking ratio" as an index of the gait automaticity to find out the gait characteristic change caused by the change of gait speed, and we verified the relationship between gait automaticity change and allocation of attention in each gait phase.

SUBJECTS AND METHODS

Ten males (mean age: 21.2 ± 1.0 years, mean height: 173.8 ± 6.9 cm, mean weight: 66.0 ± 4.6 kg) participated. This sample size was calculated using G power 3, and the configuration was as follows: effect size=0.40, and power=0.95. All participants did not have orthopedic or neurological disease that could affect gait as well as those with any auditory disorder that could affect performance in the probe RT task. This study was approved by the Sapporo Medical University Hospital Ethics Committee (approval number: 27-2-16). Written informed consent was obtained from participants before examination.

All participants performed the treadmill walking task in four gait speed conditions: (1) preferred speed (preferred condition); (2) 120% of preferred speed (120% condition); (3) 80% of preferred speed (80% condition); and (4) 60% of preferred speed (60% condition). Preferred speed was defined as the speed at which the participant felt comfortable. Order of conditions was randomized. Four footswitches were attached to the heels of their shoes and to their ankles were used to determine participants' walking ratios and gait phases in each speed condition. Walking ratio was calculated as the ratio of step length to cadence, and this characteristic has been considered as a measure of gait automaticity[18, 19]. Cadence was measured by footswitch waveform in 1 min, and step length was calculated from cadence and gait speed. Single- and double-support gait phases were defined from footswitch waveforms in each gait speed condition[15] (Fig. 1). Subjects walked on the treadmill wearing light clothing, shoes attached four footswitches, headphone and microphone. A probe RT task was the cognitive task in this dual-task paradigm. Subjects were instructed to respond as quickly as possible by saying "pa" when they heard an auditory tone. The 1,500 Hz tone was played through headphone, at a volume of 60 dB. Duration of the auditory stimulus varied randomly from 100 ms to 200 ms in 10 ms increments. RT was defined as the interval between onset of the tone and the subject's verbal response (Fig. 1). Verbal responses were captured by the microphone. The sampling rate was 1,000 Hz and the verbal responses to auditory tone were synchronized with the footswitch waveforms used by Chart 5 (AD Instruments Pty Ltd, South Wales, Australia). For each gait speed condition, 100 auditory stimuli were presented during treadmill walking. For each gait phase in all speed conditions, RTs for the average of first 5 presentations were submitted to statistical analysis to consider the learning effect and the difference of the total number of RT in each participant (Fig. 2).

Two-way repeated measures ANOVA was used to determine the effect of speed condition and of gait phase on RT. In addition, one-way repeated measures analysis of variance (ANOVA) was used to study the effect of speed condition on walking ratio. If a main effect was observed, post hoc tests were performed using Sidak's test. A p value of less than 0.05 was considered statistically significant. All statistical analyses were performed using SPSS statistics version 20 (IBM Japan Ltd., Tokyo, Japan).

RESULTS

Mean RTs in each speed condition and gait phase are presented in Table 1. Two-way repeated measures ANOVA showed a significant main effect of speed condition [$F(3,27)=7.71$, $p=0.001$]. Post hoc analysis revealed a significant delay in RT that was proportional to the decrement in gait speed, and RT differences were found between the 80% and the 60% condition ($p=0.001$), and between the 120% and the 60% condition ($p=0.025$). However, there was no significant main effect of gait phase ($F1,9=3.275$, $p=0.104$), nor any interaction effect ($F3,27=0.122$, $p=0.952$).

Mean walking ratios in each speed condition are presented in Table 2. One-way repeated measures ANOVA revealed a main effect of speed condition on walking ratio [$F(3.27)=33.0$, $p<0.001$]. Post hoc analysis also revealed significant differences in walking ratios between the preferred condition and the 60% condition ($p=0.010$), between the preferred condition and the 120% condition ($p=0.035$), between the 80% condition and the 60% condition ($p=0.001$), and between the 120% condition and the 60% condition ($p<0.001$).

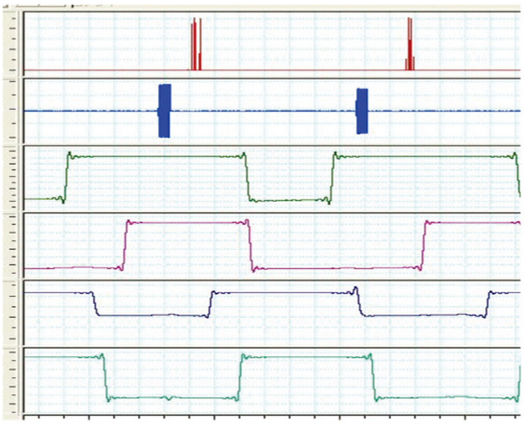

Fig. 1. An example of the waveform during the dual cognitive and gait tasks. In this example, the auditory stimulus is presented in the single support phase. Gait phase is detected the pattern of foot switch waveform. The interval between auditory stimulus and verbal response is defined as RT in this study.
1. Verbal reaction.
2. Auditory stimulus.
3. Foot switch of left heel.
4. Foot switch of left toe.
5. Foot switch of right heel.
6. Foot switch of right toe.

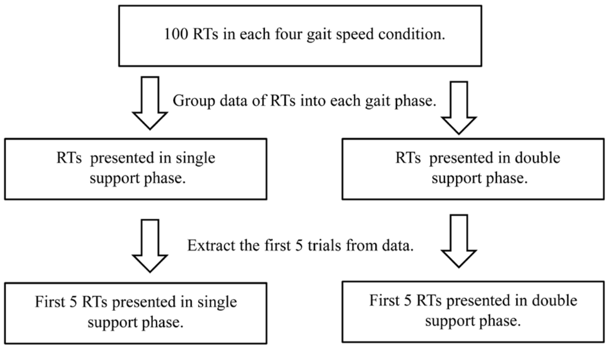

Fig. 2. Process used for extracting the RT data.

DISCUSSION

The main goal of this study was to determine the change of allocation of attention caused by the gait speed change in each gait phase. Firstly, this study showed delayed RTs, especially in the slowest (60%) condition, a result consistent with those of previous studies. The relationship of gait speed to allocation of attention has been examined in many previous studies[15–17, 20]. However, these studies did not show changes in gait performance indicators, such as walking ratio, caused by changes in gait speed. Therefore, the mechanism by which slower gait speed conditions affect allocation of attention has yet to be identified. In this study, walking ratio was calculated as a measure of gait automaticity in four gait speed conditions. The results showed a significant decrement in walking ratio with a decline in gait speed. In general, walking ratio has been considered a parameter of gait automaticity and therefore would be expected to remain constant in automated gait situations such as the preferred speed condition[18, 19, 21, 22]. Decreased walking ratios represent a shorter-stepped gait, and this change of gait strategy was considered as adaptation to the change in gait speed. Consequently, the deficit in gait automaticity caused by more extreme changes in gait speed such as occurred in the 60% condition might be expected to affect the allocation of attention more seriously.

In contrast, there were no differences in RT between the single-support and double-support phases in any speed condition. Previous studies have shown that attention is allocated differently in these two phases. Lajoie et al. reported greater RT delays in the double-support phase in an overground gait condition[15]. Regnaux et al. also showed RT delay in the double-support phase during treadmill gait of stroke patients[23]. The disparity between results of the current and previous studies might be caused by differences in the gait conditions (overground vs. treadmill) or in the populations (stroke patients vs. non-clinical subjects). Consequently, this result has a possibility that treadmill gait is highly automated gait control motion in young adults. Previous studies showed difference between overground and treadmill. Lee et al. reported a difference in muscle activation patterns in the two gait conditions[24]. Rispens et al. showed increased gait instability in overground vs. treadmill gait[25]. These studies indicated that overground gait is affected many environmental factors such as ground condition and information of walkway. So overground gait is difficult to control of environment. On the other hand, treadmill gait is easy to control of condition such as gait speed and surrounded environment. The result of this study showed that there was no difference between single-support and double-support phase, in other words, allocation of attention partially constant through one gait cycle in treadmill gait. Consequently, treadmill gait is useful for dual task study because amount of attentional load is stable through one gait cycle relative to the overground gait.

In summary, this study examined how gait speed affects the allocation of attention during treadmill gait. The results showed a delay in RT and a decrease in walking ratio at slower gait speeds. The deficit in gait automaticity caused by the

Table 1. Comparison of RTs in the four gait speed conditions and two gait phases

	Single support phase				Double suport phase				Main effect		Interaction
	120%[a]	preferred	80%[a]	60%[b,c]	120%[a]	preferred	80%[a]	60%[b,c]	Gait speed condition	Gait phase	Gait speed codition ×Gait phase
RTs (ms)	223.5 ± 30.6	237.5 ± 42.5	227.8 ± 30.9	256.3 ± 25.6	213.5 ± 25.6	234.0 ± 37.3	223.0 ± 34.7	251.5 ± 33.5	*		

Data are expressed as mean ± standard deviation.
*p<0.05 for main effect of two-way repeated measures ANOVA.
Multiple comparisons analyzed by Sidak test.
a: Significant difference from 60% condition, Sidak test.
b: Significant differencefrom 80% condition, Sidak test.
c: Significant difference from 120% condition, Sidak test.

Table 2. Comparison of walking ratios in the four gait speed conditions

	Gait speed condition			
	120%[a,b,c]	preferrd[a,d]	80%[a,d]	60%[b,c,d]
Walking ratio*	$5.27\times10^{-3} \pm 6.26\times10^{-4}$	$4.77\times10^{-3} \pm 6.50\times10^{-4}$	$4.35\times10^{-3} \pm 7.23\times10^{-4}$	$3.86\times10^{-3} \pm 7.56\times10^{-4}$

Data are expressed as mean ± standard deviation.
*p<0.05 for main effect in one-way repeated measures ANOVA.
Multiple comparisons analyzed by Sidak test.
a: Significant difference from 60% condition, Sidak test.
b: Significant difference from 80% condition, Sidak test.
c: Significant difference from preferred condition, Sidak test.
d: Significant difference from 120% condition, Sidak test .

change in gait speed, especially in the 60% condition, may have a crucial impact on allocation of attention during treadmill gait. On the other hand, there was difference of gait phase, and this result indicated that treadmill gait needs constant amount of attentional demand through one gait cycle and attentional demand is only affected by deficit of gait automaticity caused by gait speed change in treadmill gait.

Conflict of interest

In this study, the authors declare that they have no conflicts of interest.

REFERENCES

1) Nutt JG, Marsden CD, Thompson PD: Human walking and higher-level gait disorders, particularly in the elderly. Neurology, 1993, 43: 268–279. [Medline] [CrossRef]
2) Dietz V: Neurophysiology of gait disorders: present and future applications. Electroencephalogr Clin Neurophysiol, 1997, 103: 333–355. [Medline] [CrossRef]
3) Sheridan PL, Solomont J, Kowall N, et al.: Influence of executive function on locomotor function: divided attention increases gait variability in Alzheimer's disease. J Am Geriatr Soc, 2003, 51: 1633–1637. [Medline] [CrossRef]
4) Lundin-Olsson L, Nyberg L, Gustafson Y: "Stops walking when talking" as a predictor of falls in elderly people. Lancet, 1997, 349: 617. [Medline] [CrossRef]
5) Hausdorff JM, Yogev G: Cognitive function may be important for fall injury prevention trials. J Am Geriatr Soc, 2006, 54: 865–866, author reply 865–866. [Medline] [CrossRef]
6) Verghese J, Buschke H, Viola L, et al.: Validity of divided attention tasks in predicting falls in older individuals: a preliminary study. J Am Geriatr Soc, 2002, 50: 1572–1576. [Medline] [CrossRef]
7) Faulkner KA, Redfern MS, Cauley JA, et al. Health, Aging, and Body Composition Study: Multitasking: association between poorer performance and a history of recurrent falls. J Am Geriatr Soc, 2007, 55: 570–576. [Medline] [CrossRef]
8) Doi T, Shimada H, Makizako H, et al.: Cognitive function and gait speed under normal and dual-task walking among older adults with mild cognitive impairment. BMC Neurol, 2014, 14: 67. [Medline] [CrossRef]
9) Mirelman A, Herman T, Brozgol M, et al.: Executive function and falls in older adults: new findings from a five-year prospective study link fall risk to cognition. PLoS One, 2012, 7: e40297. [Medline] [CrossRef]
10) Wright DL, Kemp TL: The dual-task methodology and assessing the attentional demands of ambulation with walking devices. Phys Ther, 1992, 72: 306–312, discussion 313–315. [Medline] [CrossRef]
11) Sparrow WA, Bradshaw EJ, Lamoureux E, et al.: Ageing effects on the attention demands of walking. Hum Mov Sci, 2002, 21: 961–972. [Medline] [CrossRef]
12) Tang Z, Wakayama S: Age-related changes in the auditory reaction time of healthy elderly person while walking. J Phys Ther Sci, 2011, 23: 185–188. [CrossRef]
13) Haridas C, Gordon IT, Misiaszek JE: Walking delays anticipatory postural adjustments but not reaction times in a choice reaction task. Exp Brain Res, 2005, 163: 440–444. [Medline] [CrossRef]

14) Tseng BY, Cullum CM, Zhang R: Older adults with amnestic mild cognitive impairment exhibit exacerbated gait slowing under dual-task challenges. Curr Alzheimer Res, 2014, 11: 494–500. [Medline] [CrossRef]
15) Lajoie Y, Teasdale N, Bard C, et al.: Attentional demands for static and dynamic equilibrium. Exp Brain Res, 1993, 97: 139–144. [Medline] [CrossRef]
16) Kurosawa K: Effects of various walking speeds on probe reaction time during treadmill walking. Percept Mot Skills, 1994, 78: 768–770. [Medline] [CrossRef]
17) Lajoie Y, Jehu DA, Richer N, et al.: Reaction time is slower when walking at a slow pace in young adults. J Mot Behav, 2016, 48: 153–154. [Medline] [CrossRef]
18) Sekiya N, Nagasaki H, Ito H, et al.: Optimal walking in terms of variability in step length. J Orthop Sports Phys Ther, 1997, 26: 266–272. [Medline] [CrossRef]
19) Sekiya N, Nagasaki H, Ito H, et al.: The invariant relationship between step length and step rate during free walking. Hum Mov Stud, 1996, 30: 241–257.
20) Nascimbeni A, Minchillo M, Salatino A, et al.: Gait attentional load at different walking speeds. Gait Posture, 2015, 41: 304–306. [Medline] [CrossRef]
21) Nagasaki H, Itoh H, Hashizume K, et al.: Walking patterns and finger rhythm of older adults. Percept Mot Skills, 1996, 82: 435–447. [Medline] [CrossRef]
22) Suzuki K, Yamada Y, Handa T, et al.: Relationship between stride length and walking rate in gait training for hemiparetic stroke patients. Am J Phys Med Rehabil, 1999, 78: 147–152. [Medline] [CrossRef]
23) Regnaux JP, David D, Daniel O, et al.: Evidence for cognitive processes involved in the control of steady state of walking in healthy subjects and after cerebral damage. Neurorehabil Neural Repair, 2005, 19: 125–132. [Medline] [CrossRef]
24) Lee SJ, Hidler J: Biomechanics of overground vs. treadmill walking in healthy individuals. J Appl Physiol 1985, 2008, 104: 747–755. [Medline] [CrossRef]
25) Rispens SM, Van Dieën JH, Van Schooten KS, et al.: Fall-related gait characteristics on the treadmill and in daily life. J Neuroeng Rehabil, 2016, 13: 12. [Medline] [CrossRef]