Abstract. [Purpose] To elucidate factors that affect walking before and after direction changes and their effects on reaction time by investigating different angles of direction changes. [Participants and Methods] A total of 29 healthy young males and females participated in this study. The task was to walk along a 20-m path and perform three direction changes while walking: straight walking, 45° direction change, and 90° direction change. Step length and probe reaction time (P-RT) were measured before and after the point of direction change. A two-factor repeated measures analysis of variance was applied to measure P-RT and step length before and after direction changes. [Results] A significant effect was observed for step length and P-RT immediately before and after direction changes. An interaction was also observed between the angle of direction change and the step length before and after the direction change. When compared with the straight walk, a significant effect was observed at 45° and 90° direction changes. [Conclusion] While walking, 90° direction changes are suggested to be more difficult than 45° direction changes, and 45° direction changes are more difficult than walking in a straight line.

Key words: Walking, Turning, Probe reaction time

INTRODUCTION

Falls may occur among elderly people including those requiring long-term care or support, owing to various causes such as aging. These factors related to falls are primarily classified as internal and external factors. Internal factors include joint range of motion, muscle strength, and proprioception inside the body, whereas external factors include environmental aspects such as obstacles. In recent years, with the increase in aging population, various initiatives have been implemented to prevent falls. Among the causes of falls, 50% of falls is believed to occur while walking, 8% occurred while climbing up or down the stairs, and 14% occurred while standing up, suggesting that factors associated with falls while walking should be investigated and preventive measures implemented.

Walking includes not only in a straight line but also change-of-direction motion, which is said to account for approximately 35–50% of walking to a destination. The aim of change-of-direction motion includes avoiding contact with other people and obstacles and changing the course, one of the required motions when moving from one place to another.

Previous studies on change-of-direction motion have reported reduced walking speed, increased lateral shift of body balance, and joint torque examination for change-of-direction motion at different angles compared with walking in a straight line. In addition, with muscular activities of the supporting legs in change-of-direction motions, the muscle activity of the
upper fibers of the gluteus maximus is reportedly increased from the heel contact to the midstance in side steps and that of the gluteus medius and the tensor fascia latae muscle increased in cross steps{6}. According to Lee et al., long jumpers adjust their stride length as they approach a take-off board{9}. Krell et al. investigated motions to avoid obstacles and demonstrated that a movement is corrected several steps in advance while avoiding an obstacle{9}. This clearly shows that stride length is adjusted immediately before changing one’s direction in a change-of-direction motion.

In real life, in addition to just walking without involving any other motions, several scenarios where multiple tasking, such as walking while having a conversation and moving while holding a cup, are simultaneously performed. Particularly in elderly people, attention functions rather than motor functions are said to be strongly involved while walking under a double-task condition{10}. This suggests that attention functions should be considered to prevent falls.

In the field of psychology, attention capacity in humans is fixed and limited{10}. Probe reaction time (P-RT) is used as a means to quantify the distributed attention capacity. When a participant is performing a task (hereinafter primary task), by giving another task (hereinafter secondary task) and measuring the time taken to react to the secondary task, the distributed capacity is determined based on the duration. When more attention capacity is distributed to the secondary task, reaction time becomes shorter, indicating automation of the primary task. P-RT is considered an index to estimate attention capacity. In other words, it is possible to assess the level of attention capacity distributed to the primary task based on the length of the reaction time for the secondary task.

Previous studies on P-RT demonstrated the following results: P-RT was shortest while walking at a comfortable speed and prolonged while walking at a faster or slower speed{10}, the head reaction time preceded the lumber part reaction time in change-of-direction motion{11}, and P-RT was prolonged as the difficulty level of the task increased{12}.

Although some reports have investigated the kinesiological aspect of walking with change-of-direction motions, which occurs in a real life situation, only a few reports examined the cognitive aspect of attention capacity while walking. In addition, how attention capacity and walking factors change before and after a change-of-direction motion at different change-of-direction angles remains to be clarified.

This study aimed to elucidate the effects of different walking directions on factors and attention capacity before and after a change-of-direction motion in healthy adults. Moreover, because stride length is adjusted while changing motions{7}, this study aimed to clarify changes in stride lengths and P-RT immediately before and after a direction change as walking factors. The significance of this study in physiotherapeutics is to clarify the difficulty level of change-of-direction motion from the experimental psychological viewpoint as a basic research will be useful to provide motion guidance focusing on fall prevention in clinical settings.

PARTICIPANTS AND METHODS

The study participants included 29 healthy young adults (age: 23.3 ± 2.3 years, height: 1.6 ± 0.0 m, weight: 57.1 ± 10.3 kg), comprising 13 men (age: 22.8 ± 2.0 years, height: 1.7 ± 0.0 m, and weight: 65.0 ± 9.8 kg) and 16 women (age: 23.7 ± 2.6 years, height: 1.6 ± 0.0 m, and weight: 50.8 ± 4.9 kg). Exclusion criteria were as follows: history of orthopedic or neurological disease and extremely fast or slow walking speed during a 10-m walk.

The Institutional Review Board of the International University of Health and Welfare approved this study (approval number: 16-Ig-69). Adequate explanation with written documents using the research plan approved by the Institutional Review Board of the International University of Health and Welfare and the research explanation documents was provided to all participants. Those who consented and provided necessary information in the written informed consent were included in the study.

The following methods were used as measurement equipment. To measure the stride length in the walking task, the theme of this study, four digital cameras (Nikon, Tokyo, Japan) were set at each of the following four positions: before and at 0°, 45°, and 90° after the direction change. Tapes were placed at 1-m intervals at 3 m before and after each change-of-direction position. To measure the stride length, a video analysis software Dartfish Team Pro 5.5 (Dartfish, Fribourg, Switzerland) was used. Assuming the distance between the tapes placed at 1-m intervals was 1.00 cm, the distance between the left and right heel positions at the heel contact of one side was converted from centimeters to meters (Fig. 1). Next, the Multi-PAS II system (DKH, Tokyo, Japan) was used for P-RT measurement. PH-1211 (DKH, Tokyo, Japan) was used as an audio trigger device to cue the phonation task. PH-1131A1 (DKH, Tokyo, Japan) and Diversity Wireless Receiver WX-4200 (Panasonic, Osaka, Japan) were used for audio data conversion. A measurement headset microphone WH-4000A (TOA, Kobe, Japan) attached to a measurement wireless microphone WM-1320 (TOA, Kobe, Japan) was used to collect the audio during the phonation task.

Figure 2 shows the measurement environment. The measurement task comprised walking along a 20-m walking path and a change-of-direction motion while walking. In addition, the turning direction was the same side as the supporting leg used when kicking a soccer ball. A comfortable walking speed was used, and three measurement conditions were as follows: a straight direction and 45° and 90° change-of-direction angles from the straight line. The measurement order was randomized by making participants randomly draw cards with each condition written in advance. Measurements were obtained after a sufficient practice under each condition. Before starting each test, participants were given the following verbal instructions: “To walk at the usual speed, start walking at the initial audio cue, saying ‘Ah’ as soon as possible when hearing the second and subsequent audios, and change the direction not to cross the legs.” A participant started walking at the initial audio stimu-
lation, and the measurer presented him/her with one of the three measurement conditions: a straight direction and 45° and 90° change-of-direction angles from the straight line. The participant said “Ah” at every audio stimulation after the second time. The audio stimulation was randomly provided six times in total, i.e., three times each before and after the direction change, lasting 100 msec with 1.0–1.5-sec intervals. The change-of-direction position was set at 10 m from the starting position. The participant turned toward the presented direction at the change-of-direction position and continued walking toward the target through the direction of each angle. Measurements were obtained nine times in total: three times for each condition.

SPSS Statistics (ver. 23, IBM, Armonk, NY, USA) was used for statistical analysis. Okubo demonstrated that reaction times of 100 msec or shorter are based on the prediction\(^\text{13}\). Therefore, reaction times were shorter than 100 msec were excluded as outliers. The stride length and P-RT under each condition were analyzed using the Shapiro–Wilk test for normality. To compare the three-step stride length and average P-RT three times before and after the change-of-direction point under each condition, a repeated measures two-factor analysis of variance was performed with three levels for change-of-direction angles and two levels before and after the direction change. Subsequently, multiple comparisons were performed using the Bonferroni method.

Similarly, audio stimulation results immediately before and after the direction change were extracted from six measurements of audio stimulations, with three times each before and after the direction change as shown in Fig. 2. The one-step stride length and P-RT immediately before and after the direction change were similarly analyzed by a repeated measures

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**Fig. 1.** Measuring stride length.

**Fig. 2.** Measurement environment.
two-factor analysis of variance, and multiple comparisons were performed using the Bonferroni method. The significance level was set at 5%.

RESULTS

Results of the three-step stride length and each of the three measurements of the P-RT before and after the direction change under each condition are shown in Tables 1 and 2. Comparison of stride length before and after the change-of-direction with change-of-direction angles indicated a significant main effect on change-of-direction angles and stride length before and after direction changes. Multiple comparisons showed significant stride length shortening with change-of-direction angles of 45° and 90° compared with walking in a straight line (Table 1). In addition, an interaction effect was observed between the change-of-direction angles and stride length before and after the direction change (F-value: 3.72 and degree of freedom: 2, p=0.03). As an interaction effect was observed on stride length, subtests were conducted. Results showed significant shortening in stride length before the direction change at a change-of-direction angle of 90° (Table 2). No significant main effect was noted in comparisons of P-RT (Table 1).

The audio stimulation results for immediately before and after the direction change were extracted from six measurements of audio stimulations, three times for each variable before and after the direction change. The stride length and P-RT results are shown in Tables 3 and 4, respectively. Results of the stride length showed a significant main effect on the change-of-direction angles and before and after the direction change of, and an interaction effect was observed (F-value: 12.86, degree of freedom: 2, p=0.00). One-way analysis of variance was performed for each value before and after the direction change. A significant main effect was observed only before, but not after, the direction change (Table 3). Due to the interaction effect, subtests were performed. Significant shortening in stride length was observed before the direction change for the change-of-direction angles of 45° and 90° (Table 4). The P-RT analysis showed a significant main effect on the change-of-direction angles, and a significant delay was observed at the change-of-direction angles of 45° and 90° compared with walking in a straight line.

However, no interaction effects were observed on the change-of-direction angles and before and after the direction change (Table 3).

DISCUSSION

This study aimed to elucidate the effects of differences in change-of-direction angles on the stride length and reaction time, which are walking factors, before and after the direction change. This study was conducted based on our hypothesis that walking at the change-of-direction angles of 45° and 90° compared with walking in a straight line may show stride length shortening and P-RT delay. Similarly, stride length shortening and P-RT delay may be observed before the direction change compared with after the direction change.

Comparing the average stride length of the three steps before and after the direction change showed a significant main effect on the change-of-direction angles and before and after the direction change. Significant shortening was observed between the straight line and both change-of-direction angles of 45° and 90°. These results suggest that the stride length became shorter because the attention capacity was required before the direction change. However, no significant main effect was observed in analyzing the average of three P-RT measurements before and after the direction change. Therefore, to increase the detection power, values immediately before and after the direction change were extracted and analyzed.

Comparison of the stride length immediately before and after the direction change showed a significant main effect on the change-of-direction angles and before and after the direction change. These variables also showed an interaction effect, and results of the subtest showed a significant stride length shortening before the direction change of the angles of 45° and 90°. One-way analysis of variance performed on each value before and after the direction change indicated a significant main effect only on values shown before the direction change.

Results also showed that the stride length was shortened for the direction angle changes of 45° and 90° and walking in a straight line. However, for the P-RT, a significant main effect in the direction angle changes was observed between walking in a straight line and 45° as well as walking in a straight line and 90°, and a significant delay was found in the change-of-direction angles of 45° and 90° compared with walking in a straight line. However, no interaction effect was observed between the change-of-direction angles and before and after the direction change. Based on these findings, the stride length and reaction time values were extracted and analyzed immediately before and after the direction change. Results indicated that attention capacity was required before the direction change compared with walking in a straight line, suggesting that the presence of a certain psychological burden.

A previous study demonstrated that the change-of-direction motions at different angles decreased the walking speed and increased lateral shift of the body balance compared with walking in a straight line11. These changes occurred immediately before the change-of-direction motions. During motions taken to avoid obstacles, the stride length is adjusted several steps before changing the motions12. In addition, a previous study on P-RT, compared attention capacities during tasks of different difficulty levels based on P-RT delay with increased difficulty level of the task13. Nicolas et al. reported a comparison of attention capacities between gymnasts and other athletes in balance ability tasks under dual-task conditions, demonstrating
no considerable difference in the primary balance task, even in increased difficulty level. However, a difference was observed in the reaction time when the difficulty level of the tasks was increased\(^{15}\).

In this study, the stride length immediately before the motion changes was shortened for the change-of-direction angles of 45° and 90°, which was associated with the P-RT delay. From the start of walking until before the direction change, additional conditions to perform a motion to change the direction separately from walking increased the attention capacity in the change-of-direction motion, resulting in P-RT delay in the phonation task, which was a secondary task, to adjust the stride length. This result supports previous findings that the stride length was adjusted immediately before the motion change and that the reaction time was delayed when the difficulty level of the task was increased. However, no main effect was observed when comparing the P-RT before and after the direction change. Although a task to alter motion while walking is added before the direction change, altering the motion is completed after the direction change, with walking in a straight

**Table 1.** Average comparison of the three-step stride length and each of the three measurements of the P-RT before and after the direction change

| Change in direction angle | Stride length (m) | P-RT (msec) |
|---------------------------|-------------------|------------|
|                           | Before | After | Before | After |
| Straight                  | 0.69 ± 0.07 | 0.69 ± 0.07 | 386.3 ± 0.09 | 351.0 ± 0.10 |
| 45°                       | 0.67 ± 0.06 | 0.68 ± 0.07 | 374.5 ± 0.08 | 374.7 ± 0.10 |
| 90°                       | 0.66 ± 0.07 | 0.68 ± 0.06 | 387.9 ± 0.08 | 382.6 ± 0.11 |

Values are presented as the mean ± standard deviation (SD).
*\(p<0.01\).
Stride showed interaction (\(p<0.05\)).

**Table 2.** Comparison of the three-step stride length before and after the direction change under each condition

| Direction angle change (m) | Before | After | Significant difference |
|---------------------------|--------|-------|------------------------|
| Straight                  | 0.69 ± 0.07 | 0.69 ± 0.07 |             |
| 45°                       | 0.67 ± 0.06 | 0.68 ± 0.07 |             |
| 90°                       | 0.66 ± 0.07 | 0.68 ± 0.06 | *          |

Values are presented as the mean ± standard deviation (SD).
*\(p<0.01\).

**Table 3.** Comparison of the stride length and P-RT immediately before and after the direction change

| Direction angle change | Stride length (m) | P-RT (msec) |
|------------------------|-------------------|------------|
|                        | Before | After | Before | After |
| Straight               | 0.69 ± 0.07 | 0.70 ± 0.07 | 343.2 ± 0.09 | 334.7 ± 0.09 |
| 45°                    | 0.65 ± 0.07 | 0.69 ± 0.08 | 367.1 ± 0.10 | 389.3 ± 0.14 |
| 90°                    | 0.61 ± 0.08 | 0.68 ± 0.08 | 383.3 ± 0.10 | 409.0 ± 0.15 |

Values are presented as the mean ± standard deviation (SD).
*\(p<0.01\), **\(p<0.05\).
Stride showed interaction (\(p<0.01\)).

**Table 4.** Comparison of stride length immediately before and after the direction change at each turning angle

| Direction angle change (m) | Before | After | Significant difference |
|---------------------------|--------|-------|------------------------|
| Straight                  | 0.69 ± 0.07 | 0.70 ± 0.07 |             |
| 45°                       | 0.65 ± 0.07 | 0.69 ± 0.08 | *          |
| 90°                       | 0.61 ± 0.08 | 0.68 ± 0.08 | *          |

Values are presented as the mean ± standard deviation (SD).
*\(p<0.01\).
In the current study, tests were performed at a comfortable walking speed, and the change-of-direction motion was performed in a way not to cross legs. These conditions are considered the reasons why changes were observed in the stride length; however, the difference in difficulty levels of the tasks did not significantly alter P-RT between before and after the direction change.

In this study, stride length shortening was observed immediately before the direction change. Further, P-RT delay was observed depending on the change-of-direction angles. These results suggest that the duration of the reaction time can be used as an index to assess the difficulty level of the task and that in the change-of-direction task, change-of-direction angles of 45° and 90° are more difficult than walking in a straight line.

This study has the following limitations. This study was conducted in healthy young adults to examine the effects of differences in change-of-direction angles on the stride length and reaction time before and after the direction change. However, outcomes cannot be applied for elderly people or patients with diseases such as hemiplegia following cerebral apoplexy.

In addition, the direction change was performed toward the supporting leg side, which is considered a frequent movement. However, when considering fall occurrences, direction motion changes toward the non-supporting leg side could be more likely to cause falls. As the study participants were healthy young adults, the risk of falls was small. However, when participants include community-dwelling elderly people or patients with diseases, the risk of falls should be considered.

In the future walking factors and reaction times should be examined before and after the direction change using different direction sides in community-dwelling elderly people as study participants.

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None.

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