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GAIT PATTERN ANALYSIS FOR PEDESTRIANS USING A MOBILE DEVICE

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Abstract. *Widespread use of mobile device has changed a lot of things in our daily life, and one of the most salient changes is the gait behavior. Mobile device enabled information access anytime and anywhere, and using mobile devices while walking became very common. Thus, the gait pattern also has changed since the pedestrian should share the attention allocated for walking with other tasks using a mobile device, such as checking email, sending message, and searching on the web. An experiment conducted with 16 participants revealed that walking speed and average stride decrease as the secondary tasks become more difficult. The tested secondary tasks were simple phone call, complex phone call, and text-messaging. Among the three, text-messaging decreased walking speed and stride most (down to 84% of normal walking pattern).*

Keywords: Mobile phone use, Gait pattern analysis, Infrared motion capture system, Secondary task analysis

1. **Introduction.** Pedestrians represent a large proportion of road accident and casualties. Casualties in traffic crashes in the U.S. reach up to 4641 in the year of 2004, which is about 11% of total road fatalities [1]. Both pedestrian and driver behavior can contribute to traffic accidents, but it was known that 15% of pedestrian casualties are caused by the failure of attention on the pedestrian side. Especially younger populations may have elevated pedestrian injury risks because (1) they walk more than other population groups, (2) they may walk more frequently at night under the influence and (3) they may walk while distracted by mobile devices.

Mobile device has changed our daily life a lot. It enabled ubiquitous information access anytime and anywhere; thus, the gait pattern also has changed as pedestrians use mobile devices for checking email, sending message, searching on the web, etc., while walking. Whereas mobile devices offer substantial convenience, benefit, and entertainment to users, there have been worries expressed about the potential to distract individuals from safe engagement in hazardous environments including driving and walking. In spite of general awareness of the potential risk of using mobile phone, still many drivers use mobile phone while driving, for making a phone call and even sending a short message. In the United States, between 70% to 90% of users reported that they use mobile phones while driving [2]. An extensive literature indicates that using a mobile phone while driving increases crash risk and impairs driving performance. These effects have been explained by the driver distraction [3].

In terms of human information processing, the use of mobile phone while walking causes cognitive distraction, physical distraction, visual distraction, and auditory distraction in various ways. Traditionally walking is a fairly automatic task, involving minimal cognitive demand, and recent findings suggest that a substantial amount of attention is required to fluid and unaided postural control [3,4]. Cognitive distraction happens while walking in complex traffic environment. For example, crossing at non-signalized interaction needs several things to check including the distance from and speed of oncoming vehicles to evaluate gap safety. Several studies have found that the use of mobile phone while driving reduces the speed and this was interpreted as compensation for the secondary task [5,6]. Pedestrians also compensate by slowing in order not to trip. Physical distraction usually comes from the posture changes caused by holding a mobile device and supplemented motor actions when operating mobile devices, such as writing an SMS. Especially operating mobile device requires visual-motor coordination which increases the workload of visual tasks. To walk safely in a traffic environment, pedestrians should notice relevant signs and signals while looking for other approaching pedestrians and obstacles. When they are using mobile devices, the visual attention should be shared between the mobile device screen and road-related stimuli. If pedestrians failed to identify approaching unexpected dangers while looking at mobile device screen, they may get injured seriously [7,8]. Thus, it is necessary for them to develop strategies to effectively share limited visual attention with competing stimuli. Compared to other distractions, the effect of auditory distraction does not show a unanimous result. Some studies showed that comprehending a message and even simply listening to music can influence the driving performances, whereas other studies found that auditory tasks do not change the performance of driving. Pedestrians, however, are able to receive auditory stimuli in more direct manner compared to drivers, and the detection of approaching vehicle can exploit the auditory input if visual cue is not provided. Thus, making a phone call not only increases a cognitive workload, but also overrides subtle auditory inputs [4,5].

In this sense, using mobile devices while walking changes the gait pattern by causing distractions in several ways [9]. It increases cognitive load in perception, decision making, response selection and execution, which requires appropriate distribution of attentions on multiple tasks [9,10]. Thus, this study investigated the effect of using mobile devices on the behaviors of pedestrian in the viewpoint of human information processing model and divided attention. Following chapters are organized as follows. Chapter 2 describes the detailed procedures of experiments conducted in a motion analysis studio where the pedestrians' gait patterns were analyzed by a camera-type motion capture system. The result of experiment was presented in Chapter 3 which shows the differences in the gait pattern of pedestrians. The implications of the experimental result were discussed in the following Chapter 4. Chapter 5 states the practical meanings of the research findings and limitations of the experiments.

2. **Methods.** An experiment was conducted to test the changes in walking speed and strides according to the secondary tasks requested for the participants.

Participants

Total number of 16 university students (9 male; 7 female) participated in the experiment. All participants were volunteers and there were no specific screening criteria as long as they do not have injuries on legs or difficulties in walking. As a reward for participating in the experiment small monetary reward was provided at the end of the experiment.

The experiment was conducted in a research lab equipped with the infrared motion capture system. The motion capture system has 8 Vicon Camera, model T10 which covers an 8×8 meter space. Participants were asked to travel back and forth the runway about 8 meters long while performing tasks given according to the experimental conditions. The captured data was analyzed by Nexus 2 software package which can calculate the position, velocity and acceleration of each marker. Body model used in the analysis is plug-in gait full body which has 27 markers covering the whole body part.

Tasks.

There were four conditions in the experiments: baseline, easy phone call, hard phone call, and text messaging. In the baseline condition, participants walk normally at his/her

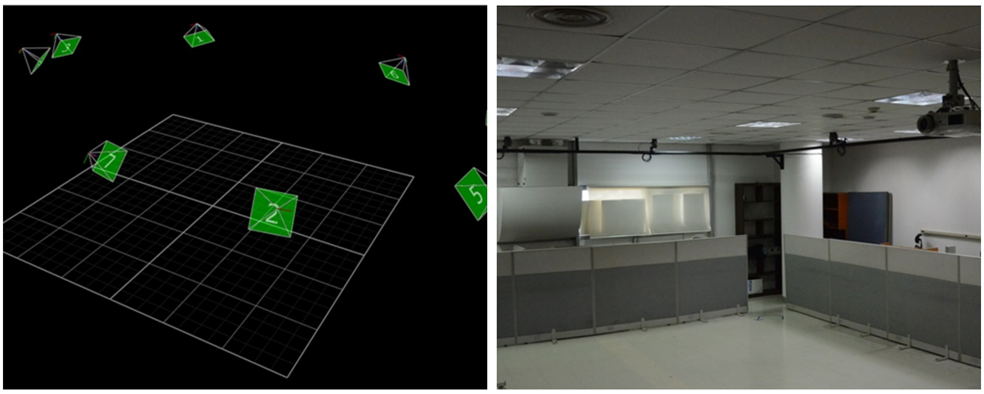

Figure 1. Experimental setup of the motion capture studio

Figure 2. Preparation for the experiment and the marker position

own speed without doing any specific tasks. Phone call tasks have two levels: easy and hard verbal tasks. For easy task, the experimenter makes a phone call to the participant and asks simple questions, such as weather and hobby. Hard phone call task is designed to impose high mental workload while walking. The experimenter asked complex questions, such as multiplying two digit numbers or reversing 5 digit numbers provided over the phone without any memory assistant. For both phone call tasks, participants started walking after receiving phone call from the experimenter, and the conversation was over when they finish two roundtrips on the path. Text messaging task starts when the experimenter sends a message to the participant. The message sent to the participant includes typos intentionally embedded, and the participant was requested to correct the message and sent it back to the experimenter while walking. In order to complete the given task, the participant had to operate the mobile phone with two hands.

Procedures.

On the arrival of the participants, the experimenter explained the objective of the study and experimental procedures. After signing the consent form for the experiment, the participant was asked to fill out a pre-experimental questionnaire asking demographic information. The performance of text-typing using a mobile phone was measured in a normal condition by recording the time taken for writing the sample message which was the same for all participants. Participants used their own mobile phone for the experiment in order to simulate their natural usage of mobile phone. After the completion of pre-experimental tasks, 14 mm markers were attached by the experimenter according to the guide of plug-in gait model [11].

The experiment was designed as within-subject; the participant completed all four conditions in a random order. For this experiment, only the treatment conditions were randomized. Starting from the baseline condition – walking without any additional tasks, three different conditions were randomized per each participant. Participants completed

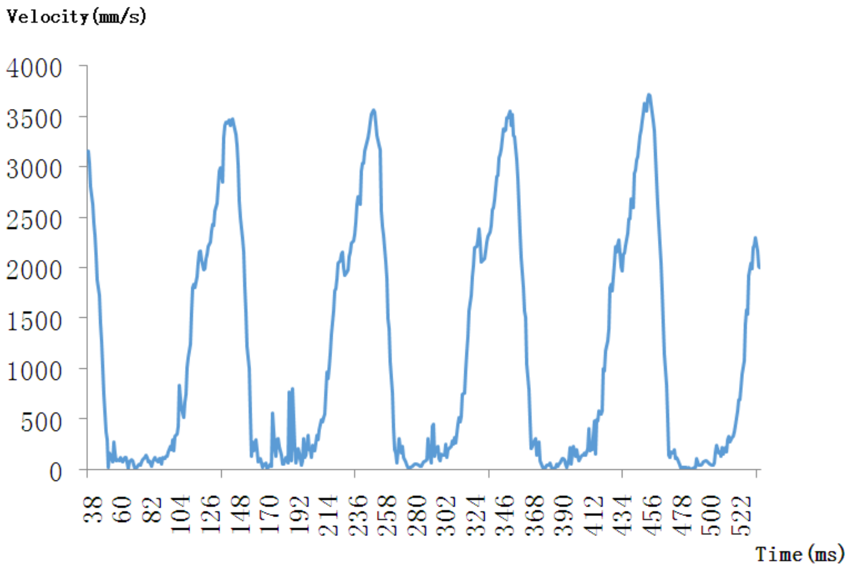

FIGURE 3. Example of velocity trajectory of a heel marker

two roundtrips per experimental conditions. During the task, participants were asked to keep walking while conducting the given tasks. Thus, the priority was given to the walking task.

Each session was recorded by the infrared motion cameras and analyzed. The markers on the heel, i.e., LHEE and RHEE in plug-in gait model were used to capture the movement of the foot. The step size was determined from the velocity profile of each heel marker since foot on the ground is not moving while the other foot is moving in the air. Figure 3 shows that the velocity profile is periodic and its peek is around 3500 mm/s. While the foot works as an anchor, there are some jitters in the velocity profile, but its location does not change much. At the stationary point the location of marker was captured and the distance between the two footprints of the same leg was measured.

3. **Results.** Since there are four conditions to compare the differences, the analysis of variance (ANOVA) was used to check whether there is a significant difference among the experimental conditions. ANOVA result showed that there were significant differences depending on the secondary tasks added on the simple walking task ($F_{3,1385} = 279.195$; $p < 0.0001$). In order to find out where the difference occurred, multiple comparison analysis was conducted by Tukey-HSD method. When conducting a multiple comparison test, it is important to reduce Type I error while maximizing the statistical power. Thus, one of the most frequently used methods, Tukey-HSD, was employed for the analysis. The result showed that four conditions are significantly different all another. As shown in Table 1, the stride decreases as the secondary task difficulty increases. The walking speed shows the same pattern as average stride (see Figure 4).

TABLE 1. Average stride per conditions

	N	Mean (mm)	Stdev
baseline*	303	1273	93.6
call	370	1165	77.1
math†	330	1110	95.1
text‡	386	1069	112.5

*baseline: simple walking without any given tasks; call: simple phone conversation; †math: solving simple math problems delivered over the phone; ‡text: sending a text message

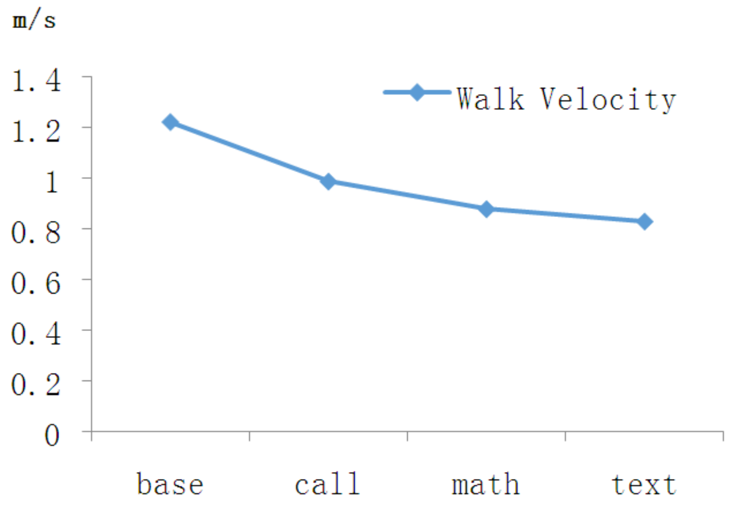

FIGURE 4. Walking velocity per conditions

4. **Discussion.** The experimental result showed that the stride and walking speed decreased as additional tasks were given to the participants. In view of task prioritization and workload management, the walking task was hindered by the given secondary tasks. The attentional resource used to perform multiple tasks cannot cover all the given tasks since the workload was too high especially for complex phone call and text-messaging. Thus, the participant finds a compromised point to handle both tasks simultaneously. When performing visual-motor tasks of sending a text message while walking, the stride decreases most (down to 84% of the baseline) and the variance of stride increases. This means that their gait pattern gets irregular while performing both tasks, which could be caused by mental overload. As the visual-motor task shares the same resources with walking, the impairment of performance was more salient compared to phone call tasks. For the phone call tasks, on the other hand, as the difficulty of question increases, stride and walking speed decreased. This is similar to the text messaging cases in a sense that the high workload caused by mental calculation interfered the walking task and the performance was influenced.

5. **Conclusions.** The present study investigated the influence of mobile device use on the gait patterns, especially the walking speed and strides. The result showed that as the mental workload increases by the secondary tasks introduced, the stride decreases significantly. Especially, the walking task was most influenced for the text-messaging tasks perhaps because the visual-motor task and walking use the same category of resources.

There are a couple of limitations in this study mainly caused by the experimental environment. Since the main objective of this study is to analyze the gait pattern quantitatively, the experiment was conducted in a controlled experimental environment which is different from the actual walking conditions. For the pedestrian walking there could be unexpected obstacles and other visual stimuli, but this was not well reflected in the experimental setting. For this reason, the difficulties of using mobile devices while walking may be underestimated. Another difference between the experimental and actual setting is that pedestrians tend to stop walking when the additional task workload increases. In other words, people may stop walking if they have to write a long message without making errors, but in this experimental setting, it was advised for the participants to keep walking while doing their tasks. Thus, it may not be able to replicate the actual use case precisely. However, the tendency of suboptimal performance was salient enough to consider redesign of pedestrian sidewalks or crossings to compensate the loss of walking performance.

To overcome the limitations explained above, future study collecting gait pattern in more realistic setting is in preparation. Walking on the street while wearing accelerometer-based motion capture system can provide the same precision movement data while maintaining the reality of actual walking on the street. However, the variability of walking pattern will increase if the fidelity of the experimental environment increases. Thus, finding a good balance between reality of walking environment and control of nuisance factor is crucial for successful data collection.

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