Effects of Smartphone Use on Behavior While Walking

Syuji Yoshiki*, Hiroshi Tatsumi*, Kayoko Tsutsumi*, Toru Miyazaki**, Takuya Fujiki**

Abstract

There is an annually increasing trend in the number of people who must be taken to a hospital by ambulance following an accident related to smartphone use while walking, making this practice a significant social issue. In recent years, location information games using augmented reality have grown in popularity around the world, and so the risk of collisions or accidents arising from smartphone use while walking is increasing. For the present study, we focused on changes in the behavior of those who walk while using a smartphone to quantitatively verify the increased risk of collision, and conducted walking experiments using an eye mark recorder and an accelerometer. We first looked at the movement of the walkers' point of visual focus, and found that those who walk while web browsing or texting visually confirm the path ahead only about 30% of their total walking time, and that for the visual field, their lateral range in particular was greatly decreased. Further, this tendency did not change with increases or decreases in pedestrian traffic, which revealed that those who walk while using a smartphone do not adjust their level of forward visual confirmation regardless of changes in pedestrian traffic density. Next, analyses were conducted of walkers' avoidance and speed reducing behaviors. It was found that, as pedestrian traffic density increased, a greater acceleration was seen in the lateral and forward directions. It was clarified that, particularly when walking while texting, accelerations in the lateral direction and forward direction at 0.2 persons/m² were 1.6 times and roughly twice as high respectively than acceleration at 0.0 persons/m².

Keywords: distracted walking, dual-task, eye mark recorder, accelerometer

1. Introduction

The spread of smartphones in recent years has been remarkable, and ownership of the devices is rapidly increasing worldwide. Despite their obvious convenience, negative impacts associated with the spread of these devices have been pointed out almost everywhere, and traffic accidents related to smartphone use have become a noted problem in the field of transportation planning. In Japan, the numbers of persons taken to a hospital by ambulance due to causes involving use of a smartphone or other electronic communications device while walking are trending upwards every year¹⁾. Characteristically, most of these cases involve those walking while using a smartphone, and 80% of all such accidents occur on the street or at traffic facilities. Recently, location information games using augmented reality are globally booming, and the potential for collisions or accidents related to smartphone use while walking is ever increasing.

With these circumstances in mind, a number of studies focused on smartphone use while walking are being carried out. We conducted reviews mainly of studies based on observational

*Fukuoka University, **Former student, Fukuoka University
Email: syoshiki@fukuoka-u.ac.jp

surveys and on walking experiments. For the studies with observational surveys, Hatfield et al.²⁾, Walker et al.³⁾, and Thompson et al.⁴⁾ conducted studies that elucidated behavioral characteristics of those who use a smartphone while walking across an intersection. For the studies with walking experiments, Nasar et al.⁵⁾ and Lim et al.⁶⁾ clarified the levels of situational awareness, Lamberg et al.⁷⁾ illustrated walking behavior, and Schabrun et al.⁸⁾ used a 3-axis gyroscope. In addition to these, a virtual space was created to address street crossing behavior in a series of studies by Stavrinou et al.⁹⁾¹⁰⁾¹¹⁾¹²⁾, and studies by Neider et al.¹³⁾¹⁴⁾. In these studies, they examined the likelihood of being hit by a car, etc. when crossing a street, which is obviously difficult to assess in experiments based on real environments.

As shown above, the risks of using a smartphone while walking are being quantitatively clarified. Yet, we have observed that many of the studies focus on the risks at intersections or when crossing the street, and the main risks addressed involve being struck by an automobile. However, in order to verify the risks of smartphone use while walking in all locations, assessing the risk only at intersections is insufficient. Elucidating the risks at non-intersection traffic locations, as well as the increased risk of collision with other pedestrians is also needed.

Here, if we regard such a *collision* as human error, the causes of human error can be generally classified as a three-stage process of human behavior, namely, error of cognition, error of judgment and error of action. It is assumed that, compared to those who do not use a smartphone while walking, those who are using one would likely experience cognitive decline, leading to errors or delays in judgment, and resulting in errors of action such as collisions, or abrupt movements of avoidance or speed reductions.

Based on this hypothesis, the present study quantitatively verifies increased collision risks at locations other than intersections. We evaluate cognitive decline by examining changes in the visual field using an eye mark recorder, as cognition during walking depends largely on visual information. We also quantitatively evaluate changes in behavior, such as collisions, or abrupt avoidance or speed-reducing movements, by using an accelerometer. The objective of the study is to clarify how often people visually confirm their path ahead while walking and using a smartphone, and how abruptly the resulting movements in avoidance or speed reduction are made, by focusing on the movement of their point of visual focus and their avoidance and speed-reducing behaviors.

2. Overview of Experiments

2.1 Overview of experiments

2.1.1 Subjects

According to the results of a survey on the use of smartphones conducted by the Ministry of Internal Affairs and Communications in 2014¹⁵⁾, usage rates were 68.6% for teenagers (10-19), 94.1% for those in their 20s, 82.2% for those in their 30s, and 72.9% for those in their 40s. As a majority of those who were brought to a hospital by ambulance because of an accident involving the use of a smartphone or other electronic communication device between 2010 and 2014 were in the age groups from the 20s to 40s¹⁾, we decided to conduct experiments with 32 university students (27 males and 5 females) in their 20s. All subjects used smartphones on a daily basis, and they used their own smartphones during the walking experiments.

2.1.2 Experiment environment

Since the present study addresses the risk of collision with other pedestrians at non-intersection locations as explained in the study background, walking experiments were conducted in pedestrian-only zones. Specifically, the experiments were carried out on a 3-meter wide pedestrian walkway on the campus of Fukuoka University in western Japan. The schematic diagram of the walking environment is shown in Fig. 1. Since public entry to the walkway during the experiments was not controlled, the subjects walked among a spontaneous flow of pedestrians.

Figure 1 Schematic diagram of walking environment

2.1.3 Experiment details

The subjects walked in four different patterns: walking while not using a smartphone (hereafter *not using*), walking while talking (*talking*), walking while web browsing (*web browsing*), and walking while texting (*texting*). On the walkway described above, the subjects walked back and forth along a 30 meter path, making two round trips in respective patterns wearing an eye mark recorder (explained later) on the head and an accelerometer on the body. The walkway has significant temporal variations in pedestrian traffic. The reason the subjects walked two round trips was to collect data from varied traffic situations. The order of the four walking patterns was randomly set per subject.

For *web browsing*, the subjects walked while reading a news website that we specified. For *talking* and *texting*, the subjects walked while answering predetermined questions asked by research staff. The questions asked are shown in Table 1.

With these conditions, walking experiments were carried out from October 5 to November 24, 2015. The experiment overview is given in Table 2.

Table 1 Questions asked when subjects were walking while *talking* or *texting*

<i>Talking</i>	<i>Texting</i>
<ul style="list-style-type: none"> • What are your hobbies? • Have you seen a movie lately? →Who was in the film? →What was the story about? • What book have you read recently? →What was the book about? • What is your part-time job? • What subject are you good at? • What is your weak subject? • What are your career plans? 	<ul style="list-style-type: none"> • Your name • School name, faculty, year in school • Gender • Date of birth • Favorite foods • Name of a professor of the department you belong to

Table 2 Experiment overview

Experiment period	October 5, 2015 – November 24, 2015
Time	10:20 – 16:20
Weather conditions	Sunny or cloudy
Experiment venue	Pedestrian walkway on Fukuoka University campus
Subjects	32 university students (27 males and 5 females)
Walking patterns	Randomly used from among <i>not using</i> , <i>talking</i> , <i>web browsing</i> , and <i>texting</i> while walking

2.2 Quantification of walking environments

An objective of the present study is to clarify the increase of collision risk caused by walking while using a smartphone by studying changes in the behavior of those who use a smartphone while walking. Naturally, the collision risk largely depends on congestion in the walking area. In order to quantify congestion during the times the subjects walked, the pedestrian traffic density was determined. A 15-meter portion of the walkway was designated as the area for analyses. A video camera was set up on the roof of a building adjacent to the walkway, as shown in Fig. 1, to record each subject's walking behavior. From the video footage, still images were stored at a frequency of one per second for each subject during the time of his or her walking through the 15-meter analysis area. The pedestrians in the analysis area on each still image were counted, and the total number of pedestrians was divided by the number of seconds each subject took to walk through the analysis area to find the mean number of pedestrians (persons) walking in the area. Further, the total number of pedestrians was divided by 45 m², the size of the analysis area (15 m × 3 m), to determine the mean pedestrian traffic density (persons/m²). The following is the formula of derivation.

$$D_{ij} = \frac{\sum_{k=1}^{t_{ij}} x_k}{t_{ij}} \cdot \frac{1}{S}$$

D_{ij}	Pedestrian traffic density (persons/m ²) when the walking pattern of subject i was j
t_{ij}	Time (seconds) required for the subject i to walk through the analysis area when the walking pattern was j
x_k	The number of pedestrians (persons) within the analysis area at the time of k seconds
S	The size (m ²) of the analysis area

The obtained pedestrian traffic density values were rounded off, and the walking conditions of the subjects were separated into three classifications, 0.0 (persons/m²), 0.1 (persons/m²) and 0.2 (persons/m²). To calculate pedestrian traffic density and pedestrian behavior, a complete walk through the analysis area by a subject was defined as one sample, and the pedestrian traffic density and subject's behavioral data from each sample were sorted and used for the analyses below.

3. Movement of Point of Visual Focus

3.1. Eye mark recorder

In this section, we used an eye mark recorder (EMR-9) manufactured by NAC Image Technology Inc., which can capture a subject's eye movements to clarify the effects of using a smartphone while walking on the movement of his or her point of visual focus. This device detects the point of visual focus by using the pupil and cornea reflection, and allows the extraction of still images at a frequency of 30 frames per second to identify where in the visual field the eyes are directed. The detection range is +/- 31 degrees horizontally, and +/- 16.5 degrees vertically.

3.2. Rate of viewing

First we tried to determine how often the walkers were looking at their smartphone screens while walking (or conversely, how little they were looking ahead at the path in front of them). To find the percentage of time spent looking at the smartphone screen (rate of viewing), for each subject, we counted the number of still image frames in which his/her eyes were directed at the smartphone screen when walking while web browsing, as well as when walking while texting, and divided that number by the total number of frames the subject needed to complete walking through the analysis area. The percentage of viewing time for each walking pattern by pedestrian traffic density is shown in Figure 2. The figure shows that the rate of viewing was around 70% with both *web browsing* and *texting*, indicating that they were looking at their smartphone screens for a large part of their walking time. In addition, a one-way analysis of variance was applied to the data for each of the two walking patterns to clarify the relationship of rate of viewing to pedestrian traffic density. As a result, no statistically significant difference was found either with *web browsing* or *texting*. This result indicates the walking subjects did not increase the amount of time they kept their eyes ahead even when pedestrian traffic density increased.

Figure 2 Smartphone-viewing rate by pedestrian traffic density

3.3. Range of visual field

Next, to clarify the effects of using a smartphone while walking on a visual field, we divided the field into a 16×16 grid. As people generally require 0.15 seconds (5 frames) for visual confirmation, we sought vision field segments toward which eyes were directed consecutively for 5 frames or more as shown in Figure 3. Then, defining the maximum range of angles in leftward and rightward (lateral) and upward and downward (vertical) movements as the range of the view field in this study, we sought a value for each subject. Figures 4 and 5 show the mean values by pedestrian traffic density for each walking pattern in the lateral and vertical directions, respectively.

Figure 3 Range of visual field in this study

For the lateral range of the visual field, *not using* and *talking*, and *web browsing* and *texting*, respectively had identical widths, with *web browsing* and *texting* around 10 degrees narrower than *not using* and *talking*. In the vertical direction, the range was wider by 5 to 6 degrees when a smartphone was used than when it was not used, with the range being 14 degrees with *not using*, and about 20 degrees with *web browsing* and with *texting*. This may suggest that the subjects had a wider vertical range of visual field because they were confirming the path directly in front of them while using their smartphones.

To examine the relationship between pedestrian traffic density and range of visual field, a one-way analysis of variance was performed for each walking pattern. No statistically significant difference was presented with any of the walking patterns. From this result, we cannot conclude that walkers using their smartphones increased their range of field toward which they directed their eyes in accordance with any growth in pedestrian traffic density.

In this section, using the eye mark recorder, we analyzed the movement of the point of visual focus among those who were using their smartphones while walking. The results showed that those who were walking while web browsing or texting visually confirmed their path ahead during only around 30% of their total walking time. Furthermore, it was clear that their range of visual field, particularly in the lateral direction, greatly decreases, and that this tendency does not change even with changes in pedestrian traffic density. This means that the risk of collision is likely to increase. We will quantitatively clarify the risk using an accelerometer in the next section.

Figure 4 Range of visual field by walking pattern (lateral direction)

Figure 5 Range of visual field by walking pattern (vertical direction)

4. Avoidance and Speed-reducing Behaviors

4.1 Accelerometer

Section 3 made it clear about those who are using a smartphone while walking that 70% of the walking time they are looking at their smartphone screens, their lateral range of visual field is greatly narrowed, and they do not change their frequency of forward visual confirmation to respond to changes in pedestrian traffic volume. It is thus assumed that their risk of collision is particularly higher as pedestrian traffic density increases. In our experiments, no actual collision was observed. It is assumed that, though they avoided actually colliding, those who were using a smartphone while walking in our experiments made abrupt movements of avoidance or speed reductions to avert collisions. To quantify the abrupt avoidance and speed reduction movements these walkers make, this section focuses on acceleration. For measurement of acceleration, we used a compact wireless multifunctional sensor (TSND121) manufactured by ATR-Promotions, Inc., which is capable of measuring acceleration in three axes of x, y and z. In addition, as the data from the accelerometer is under the influence of gravitational acceleration, the data was compensated for based on the inclination angle of the accelerometer.

4.2 Relationship between pedestrian traffic density and walking speed

First, the walking speed was obtained from video footage, and mean speeds by pedestrian traffic density for each walking pattern are shown in Figure 6. The results of applying a one-way analysis of variance are also shown in Figure 6.

As a result of the analysis, a statistically significant difference was noted only with *not using*. This can be interpreted to mean that those who were walking without using a smartphone adjusted their pace of walking according to the surrounding conditions, and their walking speed reduced as pedestrian traffic density increased. On the other hand, with other walking patterns, no changes in walking speed following an increase in pedestrian traffic density were observed. The reason for this would be that, in addition to their already slow walking speed with 0.0 persons/m² pedestrian traffic density, they did not adjust their pace of walking in response to changes in surrounding conditions.

Figure 6 Walking speed by walking pattern

4.3. Changes in acceleration

4.3.1 Acceleration in the lateral direction

To determine the extent of the subjects' abrupt movements of avoidance, accelerations in the lateral direction were analyzed. Acceleration data from every 0.2 seconds was obtained for each subject, from which the maximum acceleration in the lateral direction recorded in the analysis area was extracted. A greater value for this indicated a more abrupt lateral movement while walking. Figure 7 shows the mean acceleration in the lateral direction by pedestrian traffic density for each walking pattern.

The figure indicates that, as pedestrian traffic density grows, acceleration in the lateral direction tends to increase. A one-way analysis of variance was performed on pedestrian traffic density by walking pattern to identify the effects of pedestrian traffic density on acceleration in the lateral direction. According to the results, a statistically significant difference was noted with *texting*, and the P value for *web browsing* was 0.074. These results suggest that walkers who are operating their smartphones while walking conduct insufficient visual confirmation of their path ahead, as indicated in the previous section. As a result, they veer in the lateral direction more as pedestrian traffic density grows.

Now, for each walking pattern, we examine how abrupt movements in the lateral direction were made with a growth of pedestrian traffic density, as compared with such movements at 0.0 persons/m² density. Figure 8 shows the ratio of acceleration with increased pedestrian traffic density to the mean acceleration at 0.0 persons/m². Acceleration in the lateral direction at 0.2 persons/m² increased 1.6 times with *texting* and 1.4 times with *web browsing* as compared with the reference values. On the other hand, the increase when *not using* was 1.2 times, which means that, with this pattern, veering movements were not so abrupt partly because the walkers were visually confirming their path ahead while walking.

Figure 7 Acceleration in the lateral direction by walking pattern

Figure 8 Increased rate of acceleration in the lateral direction

4.3.2. Acceleration in the forward direction

The previous paragraphs focused on acceleration in the lateral direction. Here we analyze acceleration in the forward direction. As with acceleration in the lateral direction, each subject's acceleration data of every 0.2 seconds was obtained, from which the minimum acceleration in the forward direction recorded in the analysis area was extracted. A greater value indicates a more abrupt speed reduction. Figure 9 shows the mean value by pedestrian traffic density for each walking pattern.

The results show that, as with acceleration in the lateral direction, acceleration in the forward direction tends to increase as pedestrian traffic density grows. With a one-way analysis of variance, a statistically significant difference was found only with *texting*. While both web browsing and texting walkers are looking at their smartphone screens while walking, *texting* also involves the task of thinking and typing in answers to questions. Therefore, when walking while texting, walkers' visual confirmation of the path ahead is even less adequate than when *web browsing*. It is considered that, as a result, a statistically significant difference was presented in acceleration with *texting*, not only in the lateral direction but in the forward direction as well.

In addition, as with acceleration in the lateral direction, we examined how abrupt speed

reductions in the forward direction were made in response to a growth of pedestrian traffic density, as compared with acceleration at 0.0 persons/m². Figure 10 shows the ratio of acceleration with increased pedestrian traffic density to the mean acceleration at 0.0 persons/m². With *not using*, *talking*, and *web browsing*, no great speed reduction was seen, with changes in acceleration being around 1.2 times those at 0.0 persons/m². However, with *texting*, the acceleration ratio was higher, roughly twice the reference value. This suggests that, as presented in Section 3, those who were using a smartphone while walking did not change the frequency of their forward visual confirmation even if pedestrian traffic had increased, and as a result, abrupt speed reductions were often made when *texting* to avoid collision.

Figure 9 Acceleration in the forward direction by walking pattern

Figure 10 Increased rate of acceleration in the forward direction

5. Conclusion

In order to study the potential risk of using a smartphone while walking, which has been an emerging problem recently, we examined the movement of the point of visual focus and avoidance and speed-reducing behaviors of people using their smartphones while walking. By conducting walking experiments using an eye mark recorder and accelerometer, we have clarified how little such people visually confirm the path ahead, and how abrupt changes are made in their movements as a result.

With regard to the movement of the point of visual focus, those who were using their smartphones while walking looked at their smartphone screens roughly 70% of their total walking time. Their lateral range of visual field was around 20 degrees, which was roughly 10 degrees narrower than when they were walking without using a smartphone. Meanwhile, their vertical range of visual field was found to be 5 to 6 degrees greater when walking while using their smartphones than when walking without a smartphone, as they were visually confirming the path directly in front of them while using their smartphones. Then, we identified the range of visual fields by pedestrian traffic density and performed a one-way analysis of variance. The results reveal that the visual field range does not broaden with an increase in pedestrian traffic density. These findings indicate that those who use their smartphones while walking do not change their degree of visual confirmation of the path ahead in response to changes in the surrounding pedestrian traffic density.

Subsequently, avoidance and speed-reducing behaviors were analyzed. The results revealed that those who were using their smartphones while walking accelerated more in both the lateral and forward directions as pedestrian traffic density increased. When subjects were walking without using a smartphone, even if the walking environment has a pedestrian traffic density of 0.2 persons/m², their acceleration in the lateral and forward directions was only around 1.2 times the acceleration value at 0.0 persons/m². In contrast, when *texting* while walking, their acceleration was 1.6 times greater in the lateral direction and as much as 2 times greater in the forward direction when compared with the values at 0.0 persons/m².

As stated above, we analyzed the potential risk of using a smartphone while walking by concentrating on the movement of the point of visual focus as well as on avoidance and speed-reducing behaviors. However, as the pedestrian traffic density we were able to examine only rose to 0.2 persons/m², the effects on walking behavior in more crowded conditions needs to be elucidated. In addition to density, other conditions of pedestrian traffic flows (walking against the flow and walking with the flow, for example) will need to be considered. This study examined patterns of *talking*, *web-browsing*, and *texting* while walking. It will also be necessary to clarify the effects of walking while playing a location information game based on augmented reality, as these games have been rapidly gaining popularity in recent years. These are the issues to be addressed in future research.

References

- 1) Tokyo Fire Department. *Aruki Sumaho-nado ni kakawaru Jiko ni Chui!* (Warning –Smartphone use while walking is dangerous!)
<http://www.tfd.metro.tokyo.jp/lfe/topics/201503/mobile.html>
- 2) Hatfield, J., Murphy, S., 2007. The effects of mobile phone use on pedestrian crossing behaviour at signalised and unsignalised intersections. *Accident Analysis & Prevention* 39, 197-205.
- 3) Walker, E.J., Lanthier, S.N., Risko, E.F., Kingstone, A., 2012. The effects of personal music devices on pedestrian behavior, *Safety Science*, 50, 123-128.
- 4) Thompson, L.L., Rivara, F.P., Ayyagari, R.C., Ebel, B.E., 2013. Impact of social and technological distraction on pedestrian crossing behavior: an observational study, *Injury Prevention*, 19, 232-237.
- 5) Nasar, J., Hecht, P., Wener, R., 2008. Mobile telephones, distracted attention, and pedestrian safety. *Accident Analysis & Prevention* 40, 69-75.
- 6) Lim, J., Amado, A., Sheehan, L., Van Emmerik, R.E.A., 2015. Dual task interference during walking: The effects of texting on situational awareness and gait stability, *Gait & Posture*, 42, 466-471.
- 7) Lamberg, E.M., Muratori, L.M., 2012. Cell phones change the way we walk, *Gait & Posture*, 35, 688-690.
- 8) Schabrun, S.M., van den Hoorn W, Moorcroft A, Greenland C, Hodges P, 2014. Texting and Walking: Strategies for Postural Control and Implications for Safety, *PLoS ONE*, e84312.
- 9) Stavrinou, D., Byington, K.D., Schwebel, D.C., 2009. Effect of Cell Phone Distraction on Pediatric Pedestrian Injury Risk. *Pediatrics* 123(2), e179-e185.
- 10) Stavrinou, D., Byington, K.W., Schwebel, D.C., 2011. Distracted walking: Cell phones increase injury risk for college pedestrians, *Journal of Safety Research*, 42, 101-107.
- 11) Schwebel, D.C., Stavrinou, D., Byington, K.D., Davis, T., O'Neal, E.E., de Jong, D., 2012. Distraction and pedestrian safety: How talking on the phone, texting, and listening to music impact crossing the street, *Accident Analysis & Prevention* 45, 266-271.
- 12) Byington, K.W., Schwebel, D.C., 2013. Effects of mobile internet use on college student pedestrian injury risk, *Accident Analysis & Prevention*, 51, 78-83.
- 13) Neider, M.B., McCarley, J.S., Crowell, J.A., Kaczmariski, H., Kramer, A.F., 2010. Pedestrians, vehicles, and cell phones. *Accident Analysis & Prevention*, 42, 589-59
- 14) Neider, M.B., Gaspar, J.G., McCarley, J.S., Crowell, J.A., Kaczmariski, H., Kramer, A.F., 2011. Walking and talking: dual-task effects on street crossing behavior in older adults, *Psychology and Aging*, 26, 260-268.
- 15) Institute for Information and Communications Policy, Ministry of Internal Affairs and Communications. *Heisei 26-nen Johotsushin Media no Riyojikan to Johokodo ni kansuru Chosa* (2014 Survey of Usage Time and Information Behavior Regarding Information and Communications Media)