Effects on Space Recognition of Walking Through Augmented Reality

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Abstract

The widening use of smartphones, which can be used anytime and anywhere, has made daily life more comfortable and convenient. Nevertheless, traffic collisions involving pedestrians using smartphones have become a noteworthy social problem. In recent years, augmented reality (AR) technology has been developed. Applications using AR have increased. Accordingly, a new use pattern of smartphones to portray real space surrounding the device has arisen: The use differs from traditional walking while looking at one hand held smartphone. This study specifically examines distraction during walking while using a smartphone, especially when using AR. To examine the changes of movement of the pedestrian’s point of visual focus and those changes’ effects on spatial recognition, we conducted walking experiments using an eye mark recorder. We examined whether users noticed the check objects addressed in this study. The walking patterns included walking while web browsing, while using the AR applications of two kinds (Point View, Map Fan AR Global), and while not using a smartphone. Actually, the uses of AR in smartphones are diverse. The technology is used for various applications such as games, navigation, and photography. Among them, two AR applications described above were selected in this study because we specifically examined "situations in which the AR technology is used for pedestrian navigation," which are often used while walking. (Point View displays information about a place (name, address, etc.) on the smartphone screen when it is held in the direction of a building or other object. Map Fan AR Global displays information about the destination direction on the smartphone screen it is held along a road or other landmark.). First, we analyzed movements of participants’ point of visual focus, which revealed that those who were walking while using smartphones viewed surroundings for only 20%–40% of the walking duration. Moreover, the share of duration gazing around while walking using an AR was higher than that for Web browsing. Additionally, with regard to the range of the visual field in the lateral direction, we demonstrated that the Point View is about 90%, Map Fan AR Global is 80%, and Web browsing is only 70% of the figures found for Not using. Examining characteristics of walking by AR to assess the effects on spatial recognition revealed a high rate of those who noticed a “standing pedestrian” ahead, but no significant difference was found. However, the rate of those who noticed other objects, especially a signboard set on the roadside, was low. Results show that walking while looking at real space through AR is as dangerous as walking while web browsing. Apparently, arranging attention information related to the road surface or the roadside is ineffective for pedestrians who are walking while using a smartphone.

Keywords: distracted walking, eye mark recorder, spatial recognition, visual focus

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http://dx.doi.org/10.14398/urpr.6.84
1. Introduction

With the spread of smartphones, people have become increasingly able to exchange information anytime and anywhere, even when they are outdoors. Daily life is more comfortable using them. Unfortunately, traffic collisions involving pedestrians using smartphones have become a noteworthy social problem. The number of persons transported to a hospital by ambulance for causes related to the use of smartphones or other electronic communications devices while walking is trending upward every year in the Tokyo Fire Department jurisdiction.

Recently, augmented reality (AR) technology has been developed with digital information displayed on the scene or video portraying real space. AR is also applied to portable devices such as smartphones. Therefore, digital information (e.g., location information obtained by GPS or for restaurants and landmarks as maps) can be added to images of real space portrayed through the camera. In recent years, smartphone applications such as location information games and those by which the direction of walking is navigated using augmented reality have increased. Accordingly, a new pattern of using smartphones to portray real space surrounding the device has occurred. That usage differs from traditional walking while looking at one handheld smartphone.

With these circumstances in mind, several studies have been conducted to assess the use of smartphones while walking. We conducted reviews below with particular emphasis on conditions for using smartphones. Many studies related to mobile phones usage while walking have specifically examined several conditions: walking while talking on the cellphone (talking and calling) or walking while entering characters such as text chat with the cellphone (texting). Some studies have emphasized only talking or calling. Nasar et al. investigated space recognition while having a telephone conversation, and compared the dangers of pedestrian behavior of talking and calling and listening to music during street crossing based on observational surveys. Tapiro et al. compared crossing behaviors during calling by adults and by children. Stavrinos et al. examined pedestrian safety of cell phone conversations for college students by clarifying the effects of individual difference factors and three forms of distraction. Kao et al. examined gait stability and variation during a cell phone dialing task. They administered tests to assess attention abilities. For texting only, Lim et al. reported effects of texting on situational awareness and gait stability during visual tasks of various conditions using a treadmill. Plummer et al. examined the ability of young adults to prioritize attention flexibly between texting and walking in each environment. For talking and calling, and for texting, Lamberg et al. conducted a study based on walking experiments, which revealed the influence on walking stability from its relation with working memory. For studies based on observational surveys of pedestrian crossing behavior at intersections, observations were made in a study by Hatfield et al. Pešić et al. assessed the effects of listening to music along with these walking conditions.

In other studies, to assess kinematic gait characteristics of people using smartphones, Niederer et al. used basic cognitive tests to assess attention abilities and walking experiments under five conditions: talking/calling, reading a message, internet searching, taking a self-photograph or selfie, and no use. Haga et al. investigated reaction times at which participants detect auditory and visual signals under four conditions for smartphone use while walking: texting, watching a video, playing a game, and the control condition of holding a cell phone. Lin et al. reported the effects on pedestrians’ awareness of roadside events in a virtual...
space under three conditions: texting, picture-dragging, and reading news. With particular
attention to pedestrian behavior, Schwebel et al. and Yoshiki et al. examined the effects of
smartphone use while walking. The former conducted experiments under several conditions:
talking and calling, texting, listening to music, and not using a smartphone. The latter assessed
web browsing without listening to music.

Although the effects of smartphone use on recognition decline and pedestrians behavior
during walking have been clarified quantitatively, many studies have targeted talking and calling
and texting as the conditions for smartphone use. Some researchers have examined spatial
recognition using walking experiments. Others have conducted analyses to assess basic
attention while performing cognitive tasks. Several methods have been used. However, as
described above, some smartphone applications that use AR as it has developed are premised on
walking. Therefore, elucidating the effects of such new patterns using smartphones is necessary.
A few reports have described studies that have specifically examined the influence of AR on
pedestrians. For instance, Chung et al. reported a mindful navigation system with the
assistance of an AR interface. They found that the system increased the navigation performance
and experience, decreased travel time, errors, and confusion, and found that it increased the
number of landmarks noticed. Haarman et al. observed 20 participants walk on a treadmill
and compared their AR and VR performance. Nevertheless, no report of the literature has
described research conducted to clarify the influence on gaze behavior while using AR.

This study was conducted to clarify the effects of walking through AR on spatial
recognition, especially visual tasks. We conducted analyses using an eye mark recorder during
walking to assess effects on spatial recognition. We also attempted to evaluate phenomena from
checks of awareness for objects. Regarding the effects on spatial recognition, if we can ascertain
what surrounding information pedestrians visually confirm while using smartphones, then we
can obtain fundamental knowledge indicating smartphone users' focus of attention.

2. Method

2.1 Uses of AR analyzed in this Study

As described in Chapter 1, AR has diverse uses in smartphones. The technology is used in
various applications such as games, navigation, and photography. Among these applications,
using AR technology while walking must be analyzed because this study specifically examines
the use of smartphones while walking. Specifically, we addressed "situations in which the AR
technology is used for pedestrian navigation." The AR applications used for the experiment are
discussed in the next section.

2.2 Overview of Experiments

An outline of the experiment presented in Table 1. Only on sunny days during
November–December 2017 did we conduct walking experiments with 62 university students
who used smartphones in everyday life. According to results of a survey of the use of
smartphones conducted by the Ministry of Internal Affairs and Communications in 2016, the
usage rate was highest for those in their 20s in Japan. Moreover, most of those who were
taken to a hospital by ambulance because of an accident involving the use of a smartphone or
the other electronic communication device were in their 20s to 40s. We therefore examined
university students in their 20s.

Each participant walked while wearing an eye mark recorder (EMR-9; NAC Inc.). The conditions for smartphone use included walking while not using a smartphone (Not using), walking while web browsing (Web browsing), walking while using the Point View AR application\(^9\) (Point View), and walking while using the AR app called Map Fan AR Global\(^{20}\) (Map Fan AR Global). Each participant walked in one of these conditions. Table 2 presents an outline of the applications used for the experiment and an explanation of instructions given to participants. Figure 1 portrays examples of pictures of smartphone display that the participants viewed.

Figure 2 presents an example of the image recorded by the eye mark recorder when the participant walked while using the Point View AR application. The square mark in the figure shows the position of the view obtained when just moving. The line shows the trajectory along which the eye has moved.

Here, the participants walked among a spontaneous flow of pedestrians because public entry to the sidewalk during the experiments was not controlled. Regarding the flow of pedestrians, we counted pedestrians who were standing, those who passed the participant, and those who were overtaken by the participant on the sidewalk. We conducted a test to find

| Table 1 Overview of Experiments |
|---------------------------------|
| **Experiment period** | November 23, 2017 – December 23, 2017 |
| **Experiment venue** | Sidewalk on the Fukuoka University campus |
| **Participants** | 62 university students (39 men, 23 women) |
| **Conditions for smartphone use** | Not using, Web browsing, AR app (Point View), AR app (Map Fan AR Global): each participant walked in one of these conditions. |

| Table 2 Outline of the applications and instructions to participants |
|-----------------------------|-------------------------------------------------|--------------------------------------------------|
| **Conditions** | **Details** | **Instructions to participants** |
| Not using | Walking while not holding a smartphone. | Participants are instructed to walk only along the experiment route. |
| Web browsing | Reading articles of web news\(^1\) | Participants are instructed to walk along the experiment route while reading one article selected randomly from web news on the experiment day. |
| Point View\(^9\) | This application displays information about a place (name, address, marks, etc.) on the screen when the smartphone is held in the direction of a building or the like. | Participants are instructed to walk along the experimental route while collecting building information by holding the smartphone in the direction of a building. |
| Map Fan AR Global\(^{20}\) | Navigation, an application by which the direction of walking is navigated on the screen by holding a smartphone to the road. | We set "Fukudai-mae Station" shown in Figure 3 as the destination of Map Fan AR Global. Participants are instructed to walk along the experiment route while checking the navigation screen of the smartphone. |
outliers among them for each walking experiment. Thereby, we were able to assess differences among the experiments. Therefore, the following analysis was performed except for one instance judged as pedestrian traffic different from the others. The average pedestrian traffic was 2.9 pedestrians among the 61 participants.

For checks of spatial recognition, we selected several areas: The scene ahead, the road surface, and the roadside. From these areas, we have selected several objects ranging from easy to find objects to difficult to find objects. Specifically, a person standing on the sidewalk and signs of road markings were selected as objects that are easy to find because pedestrians using a smartphone mainly walk while gazing at a smartphone in a frontward and downward direction. From the roadside area, they are regarded as less attentive, we selected a signboard that is easy to find even in the roadside area and a handkerchief that is difficult to find. Immediately after the walking experiment, we asked participants whether they had noticed a pedestrian standing on the sidewalk (set by investigators), signs of road markings (for pedestrians, for bicycles), a handkerchief on a plant, and a signboard. A schematic diagram of the road inside Fukuoka University campus used for the experiments is portrayed in Figure 3. It also shows the locations of checks on spatial recognition. Furthermore, Table 3 presents the check contents. The number in Figure 3 corresponds to the number in Table 3. We told participants only about the experimental walking route. We did not tell them about these objects in advance.

Figure 1 Examples of smartphone display images. (Left, Point View19; Right, “Map Fan AR Global20”)
2.3 Overview of analyses

Using the eye mark recorder for this study, we analyzed the path traced by moving of the point of visual focus, the rates of gazing at the surrounding environment, and the range of visual field. Based on understanding of human visibility characteristics observed while using a smartphone during walking, we clarified how users recognize their surroundings from the survey assessment of whether participants noticed the presence of objects.

The trajectory of the participant viewpoint was visible in the image recorded by the eye mark recorder. We used analysis software (EMR-dFactory ver. 2.7; nac Image Technology Inc.).

Next the visual field was divided into two areas: a smartphone screen and the other surrounding environment. We counted the instances of a participant looking at each areas for each frame (1/30 s). People generally require 0.15 s (5 frames) for visual confirmation. Therefore, we calculated the percentage of duration and that of number of times viewing the surroundings to which eyes were directed consecutively for 5 frames or more as gazing. The number of frames during which the participant viewed surroundings was divided by the number of frames that elapsed when walking through the experimental walking routes. Using this

Figure 3 Experiment venue and locations of checks on spatial recognition.

Table 3 Checks of spatial recognition

| Ahead                  | Road surface       | Roadside          |
|------------------------|--------------------|-------------------|
| ① Standing pedestrian | ② Signs for bicycles | ④ Handkerchief on a plant |
| ③ Signs for pedestrian |                   | ⑤ Signboard       |

| Ahead                  | Road surface       | Roadside          |
|------------------------|--------------------|-------------------|
| ① Standing pedestrian | ② Signs for bicycles | ④ Handkerchief on a plant |
| ③ Signs for pedestrian |                   | ⑤ Signboard       |
analysis, the data for which the percentage of eye marks not recorded in the image was 30% or less were excluded from the analytical targets.

Next, to clarify smartphone use effects while walking on the visual field, we divided the field into a $16 \times 16$ grid. Because people generally require $0.15$ s (five frames) for visual confirmation, we sought vision field segments toward which eyes were directed consecutively for five frames or more, as shown in Figure 4. 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 participant. Finally, the percentages of participants who answered "noticed" for the respective objects were calculated for each condition for smartphone use based on responses to spatial recognition assessments conducted immediately after the walking experiment.

3. Movement of the Point of Visual Focus

As described in this section, we quantitatively examined how often participants were gazing at the surrounding area and narrow view. We did so using images recorded by the eye mark recorder to assess pedestrian visibility characteristics while using a smartphone.

3.1 Rate of gazing

To clarify how often the participants looked at the surrounding area, we calculated the rates of the duration and the number of times of viewing surroundings, not the smartphone screen, when walking. Results demonstrate that the rates obtained when using a smartphone are less than half of those obtained for Not using.

Figure 5 presents percentages of duration viewing surroundings other than the smartphone during the experiment. With respect to the rate of duration of gazing around, a significant
difference was found according to the three conditions of walking while using a smartphone (one-way analysis of variance, ANOVA: $P=0.007$). The respective shares for **Point View** and **Map Fan AR Global** were 24.0% and 39.0%, whereas that for **Web browsing** was only 16.3%. Results demonstrate that participants who were walking while web browsing gazed at their smartphone during most of their total walking time without viewing the surroundings. In fact, the results show that the percentage for **Web browsing** was the lowest. Others were walking with **Map Fan AR Global**, an application related to the direction of walking. This application was viewed the most in the three conditions using a smartphone. Still others were walking while using **Point View**, an application that displays information about a place.

The rates of number of times gazing at the surroundings were 37.8% for **Web browsing**, 36.8% for **Point View**, and 43.8% for **Map Fan AR Global**. Accordingly, the numbers of times of viewing the surrounding environment were about 40%. No significant difference was found (one-way ANOVA: $P=0.424$). Figure 6 presents percentages of the number of times viewing surroundings. In addition to checking whether differences exist in the number of gazing at the surroundings, even for real numbers rather than rates, their average values were calculated for each of three conditions of walking while using a smartphone. Results show that the average numbers of gazing at surroundings were 26.1 times for **Web browsing**, 33.2 times for **Point View**, and 41.3 times for **Map Fan AR Global**. The result of one-way ANOVA was $P = 0.126$. Figure 6 shows that no significant difference in the rates of number of gazes at surroundings or the average number was found among the conditions of walking while using a smartphone.

### 3.2 Range of visual field

Next, we clarified the narrow view using a smartphone while walking. Mean angles of the

![Figure 5: Viewing the surrounding environment: share of total duration.](image)

[One-way ANOVA $P=0.007$]

![Figure 6: Viewing the surrounding environment:](image)

[One-way ANOVA $P=0.424$] [One-way ANOVA $P=0.126$]

Figure 6 shows that no significant difference in the rates of number of gazes at surroundings or the average number was found among the conditions of walking while using a smartphone.
visual field in the lateral direction and in the vertical direction are presented in Table 4.

Results show no difference depending on the condition in the vertical direction (one-way ANOVA: \(P=0.650\)), but some difference was found in the lateral direction (\(P=0.022\)). Regarding the lateral direction, \textit{Point View} was about 90\%, \textit{Map Fan AR Global} was 80\%, and \textit{Web browsing} was only 70\% of \textit{Not using}. Therefore, walking while using AR application has a characteristic by which eyes looked at the surrounding environment through the smartphone screen that is moved using a hand holding it. Walking while web browsing shows that the eye gaze is concentrated on the handheld smartphone screen at a fixed position.

4. Effects on space recognition

Section 3 included the explanation that those who were walking while using a smartphone viewed surroundings other than their smartphone screens for only 20\%–40\% of the walking time. Moreover, those participants exhibited more narrowing in their lateral range of the visual field. It is therefore assumed that attention to the surroundings decreases when walking while using a smartphone. Considering the visibility properties explained in the previous section, this section presents a description of quantitative clarification of the effects on spatial recognition based on a survey asking participants whether they noticed the presence of objects while walking in the condition.

The percentage of participants who answered that they noticed is presented by the condition in Figure 7. Results of independent chi-square tests for the respective objects are included. Overall, the rate of participants who noticed a “standing pedestrian” was higher than those who noticed other objects. The rate of those who noticed other objects was low. Among these lower four objects, the rate of participants who noticed the “signs for bicycles” tended to be higher than “signs for pedestrians,” presumably because "signs for pedestrians" has only one marking, whereas "signs for bicycles" has two markings (Table 3). The recognition of “handkerchief” is low even when participants were “Not using.” We infer that it was difficult to notice because it was placed in the roadside area and because it was small.

In terms of the conditions for smartphone use, the recognition was low for all objects for \textit{Web browsing}. However, regarding walking by AR, the rate of those who noticed a “standing pedestrian” was high; other objects were low. Particularly it is clear, based on results of statistical analyses that the rate of those who noticed a “signboard” is lower than that of participants who were \textit{Not using}, which suggests that using smartphones affects spatial recognition. This evidence confirms that walking while using an AR application, while holding a smartphone forward, has characteristics by which recognition of the front is as high as when \textit{Not using}, although the recognition of other objects, especially the “signboard” set at the roadside, was as low as when participants were \textit{Web browsing}.

| Walking condition     | Lateral (deg) | Vertical (deg) |
|-----------------------|---------------|----------------|
| Not using             | 60.0          | 35.7           |
| Web browsing          | 43.6          | 40.0           |
| AR (Point View)       | 53.6          | 39.1           |
| AR (Map Fan AR Global)| 49.1          | 37.1           |
| One-way ANOVA (\(P\) value) | 0.022        | 0.650          |
5. Conclusion

This study specifically addressed walking while using a smartphone, which has come to pose a noteworthy social problem recently, especially when walking through AR. We evaluated the movement of the point of visual focus of the pedestrians and the effects on spatial recognition by comparing four conditions for smartphone use while walking: Not using, Web browsing, Point View (AR), and Map Fan AR Global (AR). To elucidate the visibility characteristics during walking while using a smartphone, we used an eye mark recorder to conduct walking experiments for quantitative examination of how little pedestrians visually confirm the surrounding environment and how narrowly they view their surroundings when using a smartphone. Subsequently, we clarified the effects of spatial recognition based on a survey administered immediately after the walking experiment: we asked participants whether they noticed objects in the condition.

First, regarding movement of the visual focus, we calculated the respective shares of duration and the number of times they were gazing at surroundings other than the pedestrian’s smartphone screen for three conditions when using smartphones. A significant difference was found among the three conditions for the rate of gazing duration, which revealed that walking through AR visually confirmed the surroundings because the highest rate of duration of gazing at surroundings was found for Map Fan AR Global, followed by Point View and by Web browsing. Additionally, we found a narrow view of the visual field. No significant difference was found among the three conditions in the vertical direction, although significant difference was found in the lateral direction. The lateral range of the visual field while Web browsing was 30% smaller than when Not using. Walking while using AR applications of two kinds is not associated with as narrow a view as Web browsing, but the view was decreased by 10%–20%.

Secondly, the overall effects on spatial recognition are that the share of participants who noticed the “standing pedestrian” was higher than the share of those who noticed other objects. The share of those walking through AR who noticed the “standing pedestrian” ahead was high, although no difference was found. However, the rates found for the other objects were low. A significant difference was found in the share of those who noticed the “signboard.” Particularly, results show that using a smartphone while walking probably affects spatial recognition.

As described above, we demonstrated effects of the movement of the pedestrian point of

![Figure 7 Percentages of participants who noticed objects.](image-url)
visual field and the effects on spatial recognition, particularly addressing walking while using a smartphone through AR. Specifically, the duration of gazing at surroundings when walking through AR was shorter than when Not using, as shown in Figure 5. Table 4 shows that the lateral range of visual field narrowed. Based on that evidence, we inferred that the recognition of the “signboard” set at the roadside is low, as shown in Figure 7. Additionally, walking while looking at real space through AR is as dangerous as walking while web browsing. Results suggest that arranging the designs of attention information used in this experiment (shown in Table 3) on the road surface or at the roadside is ineffective for pedestrians who are walking while using a smartphone.

For this study, we examined walking through AR and especially its influence on spatial recognition. Future tasks are described below.

- This study examined influences on the recognition of stationary objects. It is also necessary to analyze people’s recognition of moving objects (e.g., cars, bicycles, and pedestrians).
- We conducted experiments using only AR applications playing forward, but future research must clarify effects of phone use for other purposes.
- Each participant walked while wearing an eye mark recorder, but this device might have influenced their walking behavior. Walking experiments must be conducted without using an eye mark recorder to assess its effects, if any.
- Influences of different designs of attention information related to pedestrian recognition must be clarified.
- Analyzing the screens of pedestrians using AR can elucidate processes related to recognition of objects, such as whether pedestrians recognize objects directly from the surrounding environment without the screen, or recognize objects through screen use.
- For this study, experiments were conducted using three conditions for smartphone use: Web browsing, Point View and Map Fan AR Global. However, participants’ purposes for looking at their smartphone differ among these three conditions because Map Fan AR Global and Point View are designed for pedestrian navigation, but Web browsing is designed for reading web news. Conducting comparative experiments with applications limited to pedestrian navigation purposes can elucidate means of showing attention information to pedestrians according to the information from their smartphones.

Notes

(1) Analyzing the influence of AR on pedestrians necessitates comparison of the behavior of people looking forward through AR and the walking behavior of people who are not looking forward because of smartphone use. Table 2 shows that participants’ purposes for looking at a smartphone differ among the three smartphone use conditions: web browsing and two AR apps. To unify the purposes, web browsing, not web news, should have been required for walking while checking route navigation information. However, it is unlikely that the participants would have walked while maintaining their gaze at their smartphone. Observing walking behavior when not looking to the front would have been difficult because the experiment walking route was simple. The participants did not need to keep checking route navigation information. Therefore, we chose ‘walking while reading web news’ as more appropriate for this experiment than ‘walking while checking route navigation information.’

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