Design and Evaluation of a Smartphone-based Alarming System for Pedestrian Safety in Vehicular Networks

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Abstract. This paper proposes a depth-based alarming service for pedestrian's safety in streets. This service is based on attentional network in cognitive neuroscience field. For the detailed study, we developed an Android alarming App, letting a smartphone user be informed of risk in advance. The alarming App was evaluated with six types of alarm along with a remote control car. During experiment, four metrics were measured, such as response time, collision, disturbance, and satisfaction by recording and questionnaire. The results show that, among six sorts of alarm, providing pre-warning with colorful background was useful to a pedestrian's response time to a main warning, but transparency for background color was not useful. These results demonstrate that offering pre-warning alarm makes the users promptly avoid the collision with cars. On the part of preference, going against our assumption, people prefer an apparent warning to a transparent background-color warning for less disturbance. Participants expressed that the less clear notification message is provided with transparent background, the more disturbed they are. Through experiments, it is shown that the proposed two-level depth-based alarming service can significantly reduce a pedestrian's reaction time to a main warning message, leading to the provisioning of better safety for pedestrians.

Keywords: Smartphone · Alarming · Pre-warning · Distracted walking · Texting

1 Introduction

These days, when we walk around the street, we can often see people using their smartphone while walking. This scene means two aspects. One is how advanced our technology is and the other is the high possibility of collision beween a pedestrian and a car. Due to the highly advanced technology of smartphones, people can easily access the Internet for a variety of purposes (e.g., entertainment and

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email checking) anytime and anywhere. Now, this accessibility of a smartphone, however, puts people in danger. People lose their attention by smartphone and are exposed to the collision with a car. In the United States, 200,000 of people received hospital treatment, and approximately 4,000 people were killed because of distracted walking by smartphones in only 2009 [1]. According to the report of the US NSC (National Safety Council) in 2011, at least 1.6 million people suffered from accidents related to smartphones, and this trend has been increasing constantly [2]. Especially, in case of South Korea, the research of the impact of smartphone use on pedestrian safety risk was conducted by Transportation Safety Authority in 2013. This research reports that traffic accidents associated with smartphones have been steadily rising for the last four years. Korea has 1.7 times higher increase rate in smartphone-related accidents than the OECD [3]. Thus, the increase of smartphone users causes more traffic accidents related to smartphones, which is a global issue.

To the best of our knowledge, this paper is the first work to study a mobile alarm service for smartphone users, which is Smartphone-Assisted Navigation Application (SANA). The proposed alarm service is designed to ensure the safety of pedestrians with minimal disturbance. In particular, we choose a way of providing effective visual alarm to texting users while walking, which may encounter dangerous situations. The proposed alarm service takes a two-stage alarming, such as pre-warning and warning (called alarm). A pre-warning is an additional alarm generated before a warning so that a pedestrian can react to the warning within safety margin time to avoid an accident. After the delivery of the pre-warning, a warning is generated to let the pedestrian avoid an accident. In this paper, we design this two-stage alarming and evaluate our design in terms of user experience. Note that this paper is the enhanced version of our early paper [4]. The contributions of the paper are as follows:

- A design of a depth-based alarming service. The proposed alarming service consists of two-level alarms for effective user reaction, such as pre-warning and warning.
- The evaluation of the depth-based alarming service. The alarming service is implemented by Android App and the performance is statistically evaluated.

The remaining structure of the paper is as follows. Section 2 summarizes related work. Section 3 describes our design of SANA. Section 4 specifies our experiment method to evaluate our SANA. In Sect. 5, we conclude the paper along with future work.

2 Related Work

Nowadays, distracted walking has become an issue as one of major causes in road accidents. Smartphone users have been dramatically increasing for several years, and it is expected that one third of the worldwide population will use it by 2018 [5]. Distracted driving is now decreasing due to regulation and education, but distracted walking is increasing on the contrary. Some research indicates that distracted walking could be more dangerous than distracted driving [6]. In comparison to feature phone, smartphone would also be more dangerous. That is because various functions of smartphone make people spend their time more than before. Many people are using their smartphone for texting or music-listening while walking. Therefore, distracted walking needs to be studied as well as distracted driving for safety.

Visually distracted people tend to walk slower about 2 s in average than the undistracted person at the intersection, and also they tend to look around less [7]. In order to avoid distracted walking accident, smartphone users need to do less texting than other activities with smartphones.

In order to avoid distracted walking, both technology and education are explored. BumpFree is a service for preventing collision with obstacles is in progress [8]. That is, BumpFree is a service to prevent the indoor/outdoor collision caused by distraction from happening through a smartphone alarm in a passage or street. On the other hand, in this paper, we have more interest in collision avoidance between a pedestrian and vehicle rather than collision avoidance from stationary obstacles. Some movements to avoid distracted walking also have been started. There is an international movement toward improvement for the pedestrians safety. The Washington DC constructed a campaign for smartphone users in sidewalk lane [9], and in Korea, *distracted walking prevention campaign* was held for children [10]. However, even though these are good approaches, it seems still insufficient to avoid or prevent countless accidents throughout the world. The reduction of distracted walking, therefore, needs not only the method of education, but also that of technology. As a technology for accident prevention, we propose a smartphone-based alarming system, which informs pedestrians of the important moment in advance when they could be in danger because of distraction. Moreover, we investigate an effective design of alarm with minimal disturbance from the alarm. In this context, one natural research question is *how to provide pedestrians using smartphones with safety alarm effectively with minimal disturbance*.

In order to study a proper method for testing the effectiveness of an alarm on distracted walking, attentional network in cognitive neuroscience has been researched. Attentional network has three separable functional components, that is, alerting, orienting, and executive control [11]. *Alerting* can be described as a change in the internal state in preparation for perceiving a stimulus. *Orienting* can be defined as the aspects of attention that support the selection of specific information from numerous sensory inputs. *Executive control* can be meant as more complex, mental operations in detecting and resolving conflicts between computations occurring in different brain areas [12]. Among them, especially, orienting is affected if different conditions are given for an experiment, because giving an alarm while texting includes orienting as well as alerting. This is what we want to verify in this study, such as the effectiveness of visual alarm with depth when the alarm is given. In behavioral studies, orienting is often manipulated by presenting a *cue*, indicating where a subsequent *target* will (or will not) appear [12,13]. Therefore, for experiments in this paper, the revised attention network test (called ANT-R) is used, which is for testing the effects of alarms, including behavior using cue and target [12].

3 Design of SANA

In this section, we introduce the architecture, scenario, and implementation of our SANA.

3.1 Architecture

Our framework is based on wireless networks between a vehicle and pedestrian. Above all, the connection issue is on the consideration first. During the experiment of this study, we assume that wireless networks from each of mobile devices such as a vehicle and smartphone are available. That is, either Dedicated Short-Range Communications (DSRC) [14] or 4G-LTE [15] is used for the communications between the vehicle and pedestrian, as shown in Fig. 1. Actually, the vehicle and pedestrian can communicate with each other via Road-Side Unit (RSU) in DSRC or Evolved Node B (eNodeB) in 4G-LTE [16]. When the people set this application up at the smartphone, the network connection could be automatically built up and support data sharing.

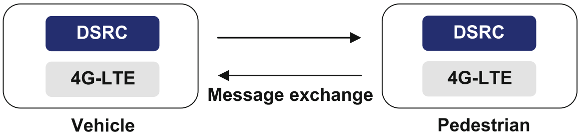


Fig. 1. Wireless communications for interaction between vehicle and pedestrian

In Fig. 2 shows the framework for user experience test in SANA. In Step (a) of the figure, Server determines time instants for alarm, and in Step (b), it sends an alarm to the smartphone App of both Participant (i.e., pedestrian) and Experimenter (i.e., vehicle driver). The figure also shows how Participant reacts to the alarm. In Step (c), Participant gets the alarm from the App and Experimenter provides stimulus (i.e., remote control car) to Participant at the same time. Finally, in Step (d), Participant reacts to the alarm.

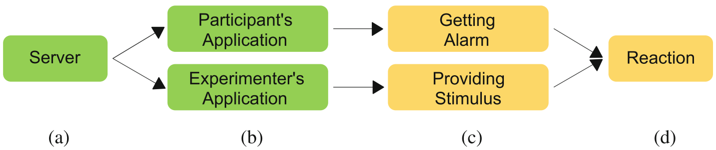


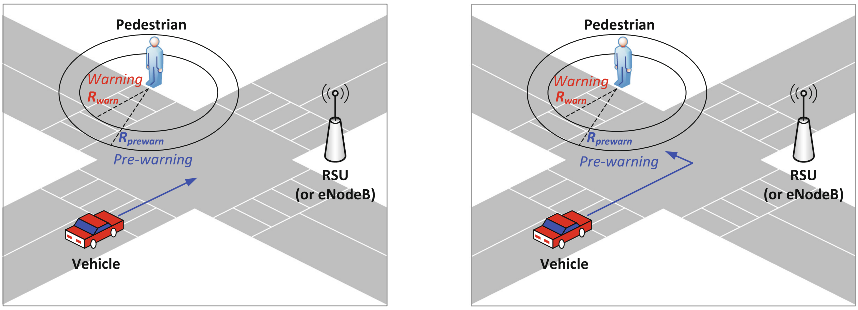
Fig. 2. The framework for user experience test in SANA

3.2 Scenario

Along with the basic steps for providing an alarm, we consider a useful method for alarming under two scenarios in a target environment (e.g., street) and the ways to use smartphones.

Basic Principle. Figure 3 shows the basic idea of providing alarming service. Two circles in the figure are used as the boundary for detecting a vehicle. When the vehicle is detected at the outer circle, pre-warning is delivered, and when it hits the inner circle, warning is provided. Our early work in [16] explains the details for detecting vehicles, filtering vehicles, and energy efficiency.

Surrounding Environments of Pedestrian. Pedestrian's surrounding environments include roadside, alley, and crosswalk. Roadside has a roadway and a sidewalk, and they can be easily located by using database for traffic information. When a pedestrian is in sidewalk, and a vehicle is in roadway, even though the vehicle and pedestrian are close to each other, this may not be a dangerous circumstance. Through using this information, false positive alarms in short distance can be filtered out to reduce the disturbance of pedestrians. The vector information of a user's smartphone is also a good way to increase the accuracy of the alarm. In Fig. 3(a), a vehicle goes straight, and, in Fig. 3(b), it turns left for a different direction. When the pedestrian crosses the street, he may encounter a collision. But if the directions of the vehicle and pedestrian are heading to each other, and they keep their position (pedestrian in sidewalk and vehicle in roadway), it is not dangerous at all. The combination of traffic information and direction of smartphone will block such false positive alarms. However, the street is narrow or the distance between the vehicle and pedestrian is too close, it could be a dangerous case. Especially, a street like alley has many blind spots. In this case, warning should be generated accurately for safety.



(a) No Overlap of Trajectories of Pedestrian and Vehicle

(b) Overlap of Trajectories of Pedestrian and Vehicle

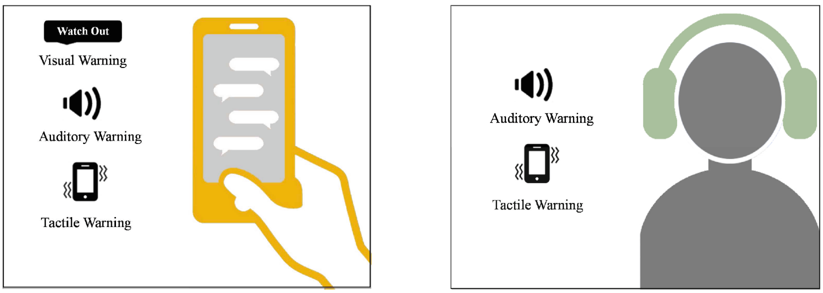
Fig. 3. Scenarios in target environment

Figure 4 shows two ways of using smartphone while walking. Those may cause visual and cognitive distraction, and cognitive distraction only [1]. The first case in Fig. 4(a) is related to screen, and the second case in Fig. 4(b) is not. When a pedestrian is watching screen while walking, the alarm could be given in visual, auditory, or tactile way. On the other hand, when a pedestrian walks with talking and listening, visual warning could not be an appropriate option. Also, in both cases, we can consider to give alarm not only in one way, but also in multiple ways. In this paper, we investigate the first case of the visual and cognitive distraction which is the most dangerous case in distracted walking, and we use visual warning among the three warning ways.

3.3 SANA Design

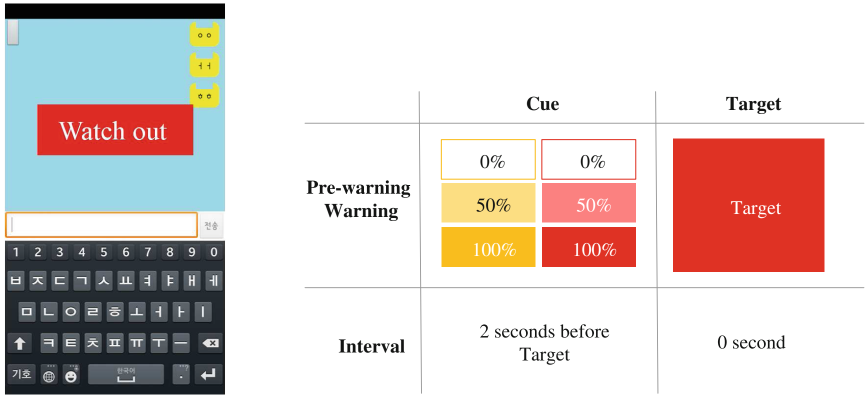
This section explains the design of user interface and user experience test for our SANA experiments, and the synchronization of devices used for the experiments.

Design of User Interface. This subsection explains our user interface design in SANA. For alarming, SANA provides a pop-up window with a warning message (e.g., Watch out) in red background, as shown in Fig. 5(a). SANA provides a pedestrian with depth-based alarming that consists of pre-warning (as cue) and alarm (as target) [12,13], as shown in Fig. 5(b). The background color for target is always red to draw attention from the pedestrian. On the other hand, the background color for cue is either yellow or red. Also, the transparency levels of the background is investigated, such as 0 % (as completely transparent color, that is, no background color), 50 % (as an half transparent color for less disturbing the pedestrian), and 100 % (as the solid color for strong attention). The interval between cue and target is 2 s [17]. In this paper, we investigate which combination is the most effective for alarm in terms of the pedestrian's response time and disturbance for the alarm.



(a) Text Messaging (b) Music Listening

Fig. 4. Scenarios of smartphone usage



(a) User Interface for Participant's Smartphone

(b) Depth-based Alarming with Cue and Interval

Fig. 5. Design of SANA user interface

Design of User Experience Test. There are three components for user experience test, as shown in Fig. 6. Those are experimenter, participant and server. Experimenter controls all of experiments. Experimenter starts experiment, stops experiment, and records a log file. Participant is the subject of the experiment. Participant gets warning alarm from server on time. Server waits for the command from experimenter. When experimenter orders to start an experiment, server generates a random time instant for collision event and sends it to both experimenter and participant. The devices of experimenter and participant know when a remote-control car will come. But the difference is that experimenter can see all time instants that server generates, but participant cannot. Thus, experimenter can control the car to collide with participant, as shown in Fig. 7.

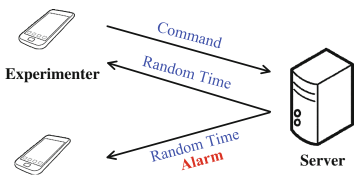
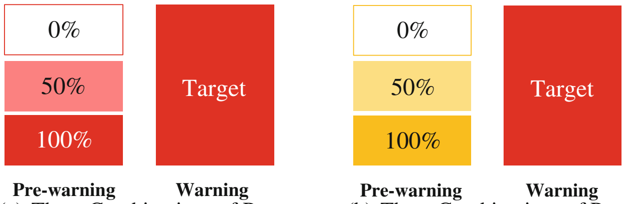


Fig. 6. Three components for experiment

Fig. 7. Experiment with remote-control car

Synchronization. For an accurate experiment, all devices and server must be synchronized. An easy way to synchronize is to use device time. All devices have different device time from a millisecond to more than 10 seconds at first. To correct this error, server sends its device time to other devices. Then experimenter sets the time of other devices to be the same with the received time from server.



(a) Three Combinations of Pre-warning with Yellow Color (b) Three Combinations of Pre-warning with Red Color

Fig. 8. Six combinations of pre-warning

4 Performance Evaluation

This section explains our experiment method to evaluate our SANA. This study conducts experiments to verify our research questions and hypotheses. The experiments use six combinations with different background color and transparency for alarm message. We categorize them into two kinds of experiments, such as (i) within-subject experiment with three options in transparency and (ii) between-subject experiment with two options in color. Participants were randomly assigned to have transparency options and were exposed to a warning stimulus more than 10 times. During the experiments, every single reaction of participant was recorded, and the results were calculated under operational definitions, specified in Sect. 4.1. We categorized the tests into three different types of transparency, 0 %, 50 %, and 100 %. After every single experiment, individuals answered questionnaires regarding to their disturbance and satisfaction through online survey. Each experiment was repeated 10 times and then questionnaire was given, which was based on Fig. 8. Total 29 (i.e., 21 males and 8 females) students using smartphone daily were recruited from the Natural Sciences Campus at Sungkyunkwan University (SKKU), Korea.

The experiments were performed by a remote-control car (called rc-car), such as M40S Volkswagen Touareg3, as a stimulus for a safety reason. The alarm stimuli were automatically provided by server to smartphone App of the participants, as shown in Fig. 6. The rc-car stimulus was manually provided from experimenter according to the time information given by the server, as shown in Fig. 7. The experiment was conducted in the lobby of the medical school auditorium at SKKU using a camcorder (i.e., Canon FS200) for recording the students' physical reaction, a laptop computer (i.e., LG ZD360-GD70K) for answering questionnaire, and mobile devices (i.e., Samsung SHV-250, SHV-160, and SHW-M380S) for recording experiments and operating rc-car.

4.1 Operational Definitions for Measurement

The operational definitions for this study are as follows.

Warning: Warning is an on-time alarm which indicates the probability of collision with rc-car within a second.

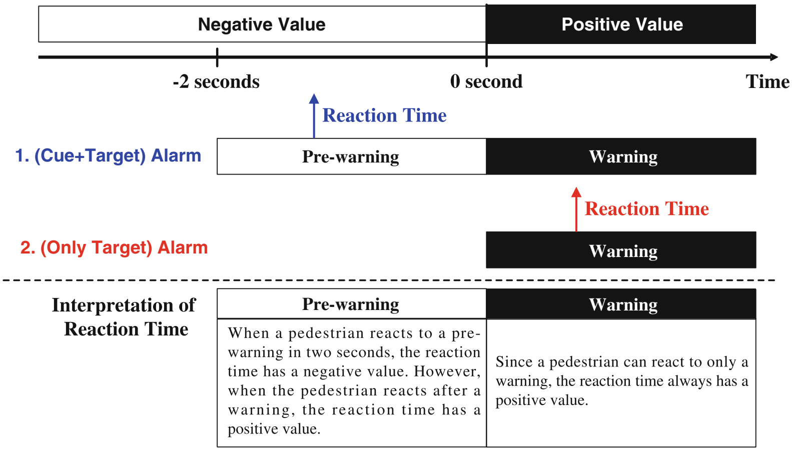


Fig. 9. Operational definitions on pre-warning and warning

Pre-warning: Pre-warning is a preceding warning which is provided two seconds earlier than a warning.

Reaction Time: Reaction time is relative time interval between the generating time of a warning and the response time of a pedestrian to a rc-car, as shown in Fig. 9. In the figure, for *(Cue+Target) Alarm* with both pre-warning and warning, the response time is negative, but, for *(Only Target) Alarm* with only warning, the response time is positive.

Collision: Collision is either a physical collision of the pedestrian and rc-car or the case where the distance between them is less than 20 centimeters. That is, when the pedestrian is within 20 centimeters of the rc-car, it is counted as a collision.

Disturbance: Disturbance is the value of disturbance questionnaire which is customized from *the development of the noise sensitivity questionnaire* [18]. A major factor is divided into two disturbances. One is the daily disturbance of the smartphone alarm, and the other is the disturbance of the smartphone alarm during the experiment. Participants responded to each item on 7-point Likert scale, ranging from 1 = "strongly disagree" to 7 = "strongly agree". The value of satisfaction questionnaire is customized from *the assessment of client/patient satisfaction* [19]. Satisfaction also uses the same Likert scale as the disturbance questionnaire.

4.2 Experimental Treatment Conditions

In the ANT-R experimental frame which was designed by Jin Fan, he considered interval as a cue-target onset asynchrony (ctoa) and alerting cue conditions (no-cue, temporal cue, and spatial cue) [12]. We considered one interval of 2 s in this study [17], because of the difference of individual response time which would be better to be considered later. We focused on alerting cue conditions, so the experiment was designed to test six kinds of independent variables with the combination of color and transparency. We combined two colors and three levels of transparency for pre-warning (i.e., 100 % red, 50 % red, 0 % red, 100 % yellow, 50 % yellow, and 0 % yellow), as shown in Fig. 8. The color for pre-warning was between-subject and randomly assigned, and the transparency for pre-warning was within-subject. Each case was repeated 10 times, and the interval between pre-warning and warning was set to 2 s. The interval of experiment repetition was a random value between 10 to 30 s.

4.3 Procedure

The task of participants is to react to the smartphone alarm and avoid rc-car while walking along the track and chatting with a chatting partner in the same time using a message application in smartphone that was provided by us. Also, the participants were asked to wear earplug in order not to react to any noise of the rc-car or anything else during the experiment. In order to establish a situation similar to the real case, we hired a chatting partner. The chatting topic was fixed to Korean thanksgiving holidays that would come soon. The experiment was processed for each individual and repeated 30 times (i.e., every 10 times for one of three random combinations). Right after each experiment, participants marked their disturbance and satisfaction on questionnaire. After the experiment, response time and collision were measured through the analysis of recording data. Reaction time was measured in millisecond. When participants reacted not to alarm but to a noise, the data were excluded from statistical analysis for more accurate measurement.

4.4 Data Analysis

SPSS 21 was adopted for the whole testing. ANOVA was conducted to investigate the effect of pre-warning and color. Generalized Linear Model (GLM) was used to test the effect of transparency and gender on pre-warning. Correlation analysis was conducted to test the correlation of response time and collision, and also the correlation of disturbance and satisfaction. Among the collected data, the data of a person who does not react to the given alarm or overreact to the stimulus were excluded from statistical analysis as an outlier.

4.5 Experiment Results

This subsection summarizes the results of user experience in the SANA alarming service. Table 1 shows the results of the statistical analysis about whether hypotheses were supported or not. Providing pre-warning has significant effect on response time and collision (see H1). Providing color pre-warning has significant effect on satisfaction and collision (see H2). Providing transparent pre-warning has significant effect on response time and collision (see H3).

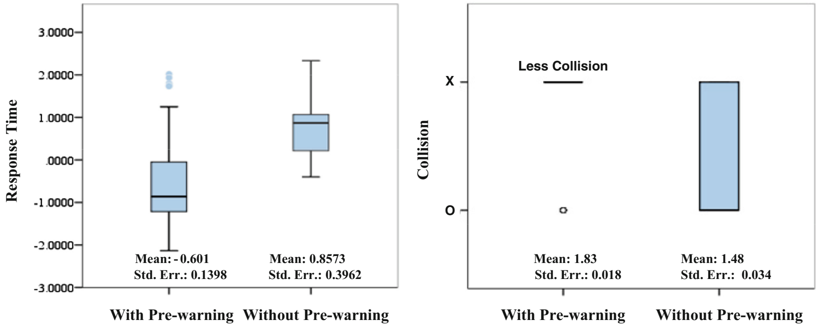
Table 1. Results of hypothesis test

Hypotheses			Supported
H1a	Providing pre-warning alarm will have positive effect on	(a) response time	**yes**
		(b) collision	**yes**
		(c) disturbance	**no**
H1b	Providing pre-warning alarm will have negative effect on	(d) satisfaction	**no**
H2a	In case of providing pre-warning alarm, different background-color alarm will have positive effect on	(c) disturbance	**no**
		(d) satisfaction	**yes**
H2b	In case of providing pre-warning alarm, different background-color alarm will have no effect on	(a) response time	**yes**
		(b) collision	**no**
H3a	In case of providing pre-warning alarm, providing transparency to alarm will have positive effect on	(c) disturbance	**no**
		(d) satisfaction	**no**
H3b	In case of providing pre-warning alarm, providing transparency to alarm will have no effect on	(a) response time	**no**
		(b) collision	**no**

Manipulation Check. A reliability analysis was conducted to check the consistency of the questionnaire. Disturbance questionnaire was reliable (Cronbachs $\alpha = 0.761$). Satisfaction questionnaire was also reliable (Cronbachs $\alpha = 0.894$). In the case of two factors of disturbance, the questionnaire about participant's daily disturbance was reliable (Cronbachs $\alpha = 0.629$), and also the disturbance questionnaire during experiment was reliable (Cronbachs $\alpha = 0.716$).

Statistical Validation. We performed one-way ANOVA to show the statistical validation of the effectiveness of our alarming system with pre-warning and warning.

To find out the effect of a pre-warning, one-way ANOVA was conducted. The result shows that there was a significant effect on response time with pre-warning (Mean (M) = −0.601, Standard Error (SE) = 0.1398) compared with no pre-warning (M = 0.8573, SE = 0.3962), and degree of freedom $F(1, 658) = 53.33$, p-value (p) < 0.5. The result also confirms that there was a significant effect on collision with pre-warning (M = 1.83, SE = 0.018) compared with no pre-warning (M = 1.48, SE = 0.034), $F(1, 658) = 104.18$, $p < 0.5$. However, there was no significant effect on disturbance with pre-warning, and also no significant effect on satisfaction. The difference on response time and collision with pre-warning and without pre-warning is shown in Fig. 10. The hypotheses in H1a were partially supported, however the hypothesis in H1b was not supported.



(a) Response Time according to Pre-warning (b) Collision according to Pre-warning

Fig. 10. The impact of pre-warning on reaction time and collision

To investigate the effect of the color and transparency for pre-warning, we performed one-way ANOVA in a similar way with the previous ANOVA test. For the color, the result shows that red pre-warning is more effective for both response time and collision avoidance than yellow pre-warning. Also, for the transparency, the result shows that either 100 % or 50 % tranparent pre-warning is more effective for both response time and collision avoidance than 0 % transparent pre-warning.

5 Conclusion

There are several fundamental outcomes in this research. First, providing alarm for distraced-walking pedestrians can improve safety. Second, notification with different depth of color and transparency provided to pedestrians can bring different reactions to a moving vehicle, so it can be helpful for collision avoidance. Third, the warning message with solid-background color allows collision avoidance with less disturbance for pedestrians. Finally, an alarming App for smartphone users seems a simple and effective method to bring safety in streets. As future work, we can design an audio-based alarming for the case where pedestrians are listening to music or having phone-call.

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