Investigation of Traffic and Safety Behavior of Pedestrians Texting or Web-Surfing

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ABSTRACT

The objective of this research is to examine pedestrians' traffic and safety behavior while texting or web-surfing, when crossing signalized intersections. In order to achieve this objective and compare the behavior of distracted and non-distracted pedestrians, an experimental process through video recording was carried out in real road conditions, in three signalized intersections in the center of Athens in Greece. For the analysis, two multiple linear regression models were developed to investigate the association of pedestrians' speed and distraction caused by mobile phone use. Additionally, binary logistic regression models were developed in order to determine the influence of distraction on pedestrians' safety characteristics (near misses and conflicts among pedestrians). This research pointed out that in high pedestrian traffic, mobile phone use not only decreases pedestrians' speed, regardless of their age, but also increases their probability of being involved in a crash with an oncoming vehicle. The results indicated that distraction caused by texting or web-surfing had a negative impact on pedestrians' main traffic and safety characteristics.

Keywords: distraction, pedestrians, traffic and safety behavior, signalized intersection, mobile phone use

INTRODUCTION

Despite considerable efforts and noteworthy progress, road safety still remains a major issue that concerns the majority of countries worldwide, as road traffic injuries are the eight leading cause of death for people of all ages. More specifically, it is estimated that about 1.35 million people lost their lives as a result of road crashes in 2016 (*1*). An important aspect of the problem is vulnerable road users such as pedestrians, cyclists and motorcyclists. Pedestrians suffer, due to their vulnerability to the speed of vehicles and increased exposure to multiple vehicles in high traffic volumes, and thus are at increased risk of serious injury or even death when involved in road crashes. It is estimated that in 2017 there were 5,220 pedestrian fatalities due to road crashes in the EU, which account for 21% of all road fatalities. However, a significant decrease of 36% has been observed in pedestrian road fatalities during the last decade (*2*). It is also remarkable that pedestrian actions and behavior may account for 15% of pedestrian fatalities (*3*).

Another factor that needs to be investigated is the association of pedestrian crashes with the use of mobile phone. Going through an era in which technology is evolving rapidly, it is now a given that mobile phone use is an integral part of people's lives. This expansion of mobile phones has caused a rising number of pedestrians who use mobile phones in their daily traffic activities by the roadside or even when crossing the street. A recent survey conducted in six major European capitals found that a significant proportion of pedestrians crossing the street made use of their mobile phone (*4*). According to a recent observational study in China, one third of pedestrians displayed mobile phone distracted activity while crossing the street (*5*). Another research conducted in the USA using data from 2004 through 2010, showed that the number of pedestrian injuries due to mobile phone use increased relative to total pedestrian injuries (*6*).

Furthermore, many surveys have been conducted in order to analyse traffic and safety behavior of distracted pedestrians with focus on texting or web-surfing distraction. Distracted behavior is common among pedestrians and it was observed that technological and social distractions increase crossing times, with text messaging being associated with the highest risk (*3*). Another study tested how talking on the phone, texting, listening to music may influence pedestrian safety and it was observed that participants distracted by music or texting were more likely to be hit by a vehicle in the virtual pedestrian environment than were non-distracted participants (*7*). An outdoor-environment experiment was conducted in China and the results showed that mobile phone distractions cause different levels of impairment to pedestrians' crossing performance, with the greatest effect from text distraction (*8*). Another study showed that pedestrian behavior was riskier when pedestrians were using the Internet and crossing the street at the same time (*9*). Moreover, pedestrians who use mobile phones while crossing the street behave less safely and pedestrians who text or view content on the phone have higher chances not to finish at the marked pedestrian crossing than non-distracted pedestrians (*10*).

Researchers have also examined the way in which pedestrian crossing speed is affected by texting or web-surfing distraction. The results of an indoor experiment in Japan indicated higher risk of crashes among pedestrians who are using mobile phones and lower speed of pedestrians who are texting in comparison with the speed of the control group (*11*). Regarding non-distracted pedestrians, it has been observed that it was higher than the speed of distracted pedestrians, which leads to larger exposure to conflicts with vehicles (*12*). However, the results of a recent survey pointed out that talking and texting while walking were not statistically significantly associated with walking speed, indicating that pedestrians may be accustomed to walking while talking or texting and do not significantly slow or increase their walking speeds (*13*).

Based on the above, the objective of this paper is to investigate traffic and safety behavior of pedestrians who are texting or web-surfing when passing through signalized pedestrian crossings. To that end, a pedestrian outdoor-environment experiment in real road conditions was carried out at three signalized pedestrian crossings in the center of Athens in Greece, in order to examine the differences between the behavior of distracted and non-distracted pedestrians.

DATA COLLECTION

For the purpose of this research, an experimental process through video recording was carried out in real road conditions, in three signalized intersections in the center of Athens in Greece. The selection of the road sections for the experiment and consequently the selection of the pedestrian crossings were based on the high pedestrian volumes typically found in the area, ensuring sufficient sample size, and the presence of a pedestrian traffic light on each crossing. Taking into account these criteria, the locations chosen for this experiment were namely:

- Pedestrian crossing on Akadimias Street in the intersection with Ippokratous Street (A)
- Pedestrian crossing on Ippokratous Street in the intersection with Akadimias Street (B)
- Pedestrian crossing on Skoufa Street in the intersection with Filikis Eterias Square (C)

Figure 1: Overhead views of the examined pedestrian crossings

The data utilized for this study were extracted from the video analysis and the extracted data are the following:

- Pedestrian distraction, recorded as one of four discrete categories: texting or web-surfing on mobile phone, talking on the phone, listening to music using headphones, no distraction.
- Pedestrian gender: male or female
- Pedestrian age estimate using four discrete age groups: age 0 to 17 (child), age 18 to 34 (young), age 35 to 64 (middle) and age 65 or older (old).
- Pedestrian crossing length and width
- Crossing time

- Pedestrian speed
- Number of road lanes
- Pedestrian volume: number of pedestrians crossing the street at the same time
- Pedestrian was accompanied by someone else: yes or no
- Pedestrian traffic light: green or red
- Pedestrians' trajectory while crossing the street: direct or not direct
- Conflict with other pedestrian: yes or no
- Illegal vehicle passing: yes or no
- Vehicle on crossing: yes or no
- Weekday
- Waiting time for pedestrian green light
- Near miss (temporal headway between pedestrian and vehicle less than two seconds): yes or no

The analysis of the videos revealed that 142 pedestrians were texting or surfing the Internet, 113 were talking on the mobile phone, 124 were listening to music using headphones and 1,901 pedestrians were non-distracted. All the pedestrians who were using their mobile phone for texting or web-surfing were included in the pedestrian sample. Concerning the non-distracted pedestrians, a random sample was selected in the following manner. Firstly, the respective average speed was calculated for each non-distracted pedestrian who was added in the database. At the point where the average speed stopped changing significantly, the recording of the non-distracted pedestrians sample was stopped. At that moment, the non-distracted pedestrians in the database were 412 and this number was considered representative of the behavior of all non-distracted pedestrians. Thus, the examined sample for this research is consisted of 142 distracted pedestrians who were texting or web-surfing and 412 non-distracted pedestrians as a control group.

The videos were examined frame by frame with the ability to pause and rewind all the pedestrian times and the calculation of pedestrian speed in meters per second (m/s) were cross-checked by multiple researchers. **Table 1** presents summary statistics for pedestrian observations in the three examined pedestrian crossings regarding distraction.

TABLE 1 Summary Statistics for Pedestrian Observation Regarding Distraction

Distraction	Count	Percentage
Distracted Texting	142	6.2%
Distracted Music (headphones)	124	5.4%
Distracted Talking	113	5.0%
Non-Distracted	1,901	83.4%
Total	2,280	100.0%

According to **Table 1**, it can be observed that texting or web-surfing on the mobile phone was the most common distraction activity among the pedestrian sample. (As it has been also reported previously, the examined sample size for this research includes 142 distracted pedestrians who were texting or web-surfing and the control group of 412 non-distracted pedestrians). In **Table 2** additional summary statistics for the examined pedestrians' characteristics are also presented.

TABLE 2 Summary Statistics for Pedestrian Gender and Age

Variable	Frequency	Percent
Gender		
Male	286	51.6%
Female	268	48.4%
Total	554	100.0%
Age		
0-17 y.o. (child)	32	5.8%
18-34 y.o. (young)	242	43.7%
35-64 y.o. (middle)	187	33.8%
>65 y.o. (old)	93	16.8%
Total	554	100.0%

METHODOLOGY

Data obtained from the videos were analysed using Microsoft Excel and IBM SPSS Statistics (version 21). Afterwards, statistical analyses were carried out using two modelling approaches; multiple linear regression and binary logistic regression models. The basic equation of the multiple linear regression model is the following equation (**Equation 1**):

$$Y_i = \beta_0 + \beta_1 * X_{1i} + \beta_2 * X_{2i} + \ldots + \beta_v * X_{vi} + \varepsilon_i \qquad (1)$$

The main assumption of the multiple linear regression is that there is no correlation among the independent variables ($\rho\ (x_i, x_j) \rightarrow 0$, for each $i \neq j$). The accuracy of the model is assessed through the coefficient of determination R squared (R^2). R^2 shows the percentage of the variability of the dependent variable Y explained by the independent variables X included in the model. R^2 has values between 0 and 1, with 1 indicating that the variable Y is fully explained by the variables X.

Linear regression models have the assumption that the dependent variable is continuous. However, in many cases the dependent variable is not continuous and discrete outcome models should be applied instead. When there are two discrete outcomes, binary logistic regression models can be applied. The goal remains the same as in simple linear regression. The best fitting model which describes the linear relationship between a binary (dichotomous) dependent variable and a number of explanatory variables (predictors) is pursued. If the “utility function” is given by **Equation 2**, then the probability P is given by **Equation 3**:

$$U=\beta_0+\beta_i * X_i \qquad (2)$$

$$P=e^U/(e^U+1) \qquad (3)$$

Most of the tests for goodness of fit of a model are carried out by analyzing residuals, however, such an approach is not feasible for a binary outcome variable. In this case, the goodness of fit of the model can be assessed with the Hosmer & Lemeshow Test (*14*).

In the case of this study, six statistical models were developed. More specifically, two multiple linear models with pedestrian speed as the dependent variable and two binary logistic regression models for each of the following dependent variables: near misses and conflict among pedestrians.

RESULTS AND DISCUSSION

A high number of regression model tests were conducted for different combinations of variables and this procedure resulted in the final statistical models that capture the correlation between dependent and independent variables.

The selected independent variables were exactly the same for each one of the following models with the same dependent variable in order to ensure comparability between the models for distracted and non-distracted pedestrians. The dependent variables of the models are:

- Models 1a, 1b: Pedestrian Speed (The logarithm of pedestrian speed).
- Models 2a, 2b: Near miss (Binary: Yes/No)
- Models 3a, 3b: Conflict among pedestrians (Binary: Yes/No)

Table 3 summarizes the results of Models 1a and 1b for distracted and non-distracted pedestrians with pedestrian speed as the dependent variable.

TABLE 3 Statistical Model for Pedestrian Speed

	Distracted Pedestrians			Non-Distracted Pedestrians		
Independent Variables	**β_i**	**t**	**Sig.**	**β_i**	**t**	**Sig.**
Age	-0.018	-1.781	0.077	-0.033	-6.562	0.000
Accompanied	-0.052	-2.093	0.038	-0.063	-6.194	0.000
Crossing length	0.021	7.676	0.000	0.026	15.231	0.000
$(\text{Pedestrian Volume})^2$	-6.056E-005	-2.662	0.009	-3.627E-005	-3.200	0.001
Adjusted R^2	0.638			0.556		

All the parameters are statistically significant at 95% confidence intervals for both models except age for the distracted pedestrians' model which is statistically significant at 90% confidence interval. The adjusted R^2 are 0.638 and 0.556 respectively, which lead to the acceptance of these models as robust. Regarding the modelling results, it can be observed that the independent variables affect the speed of distracted and non-distracted pedestrians in the same manner, as the signs of the β coefficients are the same in both cases. More specifically, results indicate for both models the following:

- The variable "Age" has a negative relationship with the dependent variable, showing that as pedestrian age increases, the speed of the pedestrian decreases. In other words, elderly people move at lower speeds.
- The negative sign of "Accompanied" variable shows that if someone else accompanies the examined pedestrian, pedestrian speed decreases.
- The variable "Crossing length" has a positive relationship with the dependent variable, showing that as crossing length increases, the speed of the pedestrian increases as well. In other words, pedestrians feel the need to hasten their crossing, possibly fearing that they will not have enough time.
- Pedestrian speed is lower for higher pedestrian volumes.

Sensitivity analyses were also conducted for the findings of the previous models and Figures based on sensitivity analysis were also developed to better understand the influence of the independent variables on the speed of the two types of pedestrians. As it can be observed in **Figure 2**, in low pedestrian volumes distracted children move at higher speeds than non-distracted young pedestrians, as children are very familiar with the use of the mobile phone and their speed is not greatly affected. Moreover, at high pedestrian volumes, distracted pedestrians who were texting or web-surfing on their mobile phone present lower speed than non-distracted pedestrians, regardless of their age, as they may be not aware of traffic conditions due to distraction and therefore they have higher crossing times.

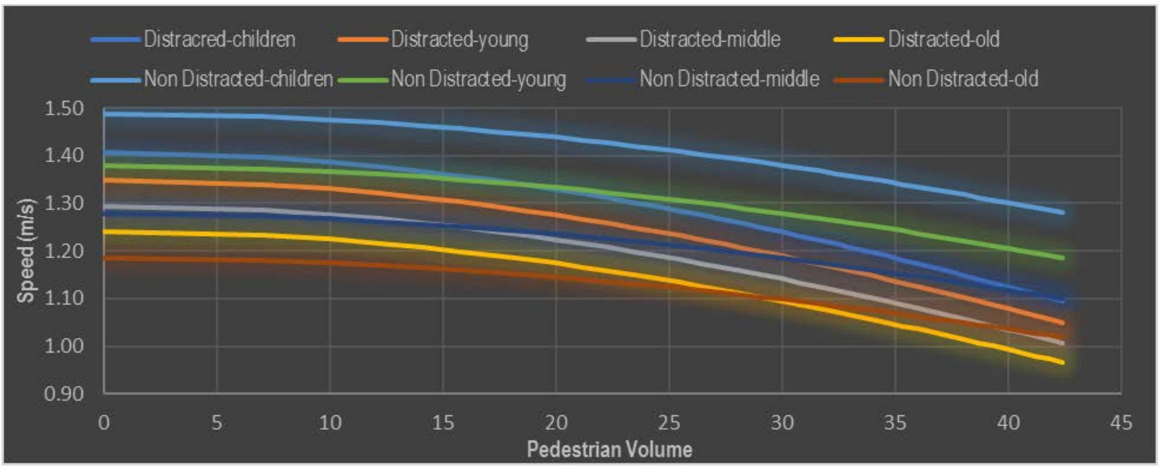

Figure 2: Sensitivity Analysis: Pedestrian Speed to Pedestrian Volume (Non Accompanied)

The association between independent variables and the probability of a near miss to occur (temporal headway between pedestrian and vehicle less than two seconds) was investigated using binary logistic regression. In these statistical models the occurrence of a near miss is the dependent variable; this variable takes two values (0: no near miss and 1: near miss happened). The explanatory variables are the sign of traffic light for pedestrians, the logarithm of pedestrian speed, the pedestrian volume and the crossing length. The results of these binary logistic regression models are presented in **Table 4**.

TABLE 4 Statistical Model for Near Misses

	Distracted Pedestrians				Non-Distracted Pedestrians			
Independent variables	β_i	**Wald**	**Sig.**	**Exp(β_i)**	β_i	**Wald**	**Sig.**	**Exp(β_i)**
Red Pedestrian Traffic light	3.287	11.399	0.001	26.756	2.269	8.095	0.004	9.671
Pedestrian Volume	0.083	3.711	0.054	1.086	-0.074	4.328	0.037	0.928
Log(Speed)	6.158	2.354	0.125	472.401	3.866	1.860	0.173	47.742
Crossing Length	-0.820	19.907	0.000	0.441	-0.543	25.724	0.000	0.581
Hosmer & Lemeshow Test	0.954				0.578			

The p-value of Hosmer & Lemeshow Test for goodness of fit is higher than 0.05 meaning that the null hypothesis of the test is accepted for both logistic regression models. Additionally, Wald values are higher than 1.7 leading to the acceptance of these models. The results presented in the previous Table indicate the following:

- Both distracted and non-distracted pedestrians who started walking through the crossing when the pedestrian traffic light was red present higher probability of a near miss with a vehicle.
- The positive sign of pedestrian speed shows that there is an increase in the probability of a near miss, if pedestrian speed increases for both models.
- The probability of a near miss is higher for pedestrian crossings with lower crossing length.
- It can be observed that pedestrian volume does not affect in the same way the probability of a near miss for distracted and non-distracted pedestrians. More specifically, the positive sign of the variable in the distracted pedestrians' model shows that as pedestrian volume increases, the probability of a near miss for distracted pedestrians with a vehicle is higher. However, the sign of pedestrian volume in the non-distracted pedestrians' model is negative indicating that an increase in pedestrian volume leads to lower probabilities of a near miss.

The following figure (**Figure 3**) shows the change in the probability of a near miss depending on the pedestrian volume for both distracted and non-distracted pedestrians who started crossing the street with red pedestrian traffic light. Regarding distracted pedestrians the probability of a near miss increases with increasing pedestrian volume as the more pedestrians who occupy the pedestrian crossing the more difficult is for them to observe carefully the rest traffic. On the contrary, the probability of a near miss for non-distracted pedestrians decreases with increasing pedestrian volume. This may be attributed to the fact that non-distracted pedestrians are fully aware of the traffic conditions and they can perceive the danger early by observing the behavior of other pedestrians. Another remarkable conclusion that derived from the sensitivity analysis is that the probability of a near miss for non-distracted pedestrian remains very low and almost equal to zero when pedestrian volume increases, while for distracted pedestrians it presents an increasing trend.

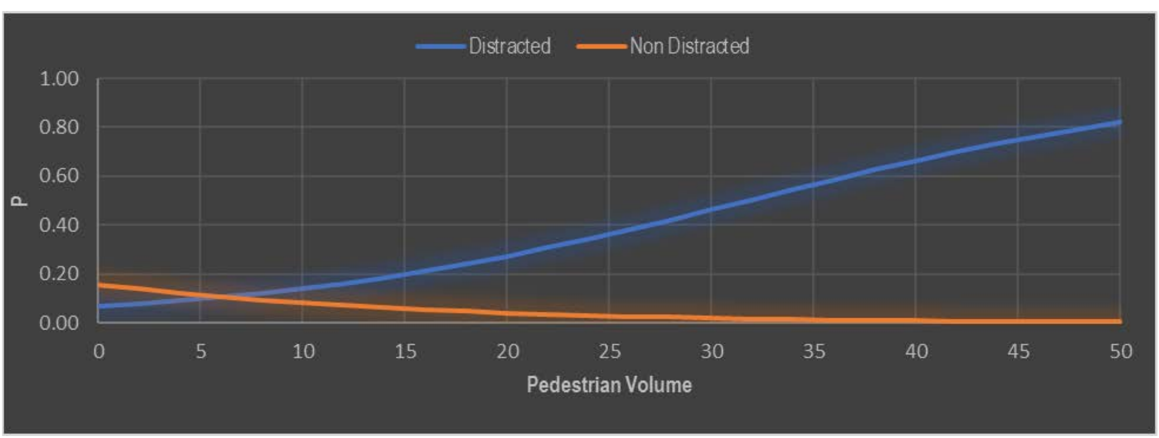

Figure 3: Sensitivity Analysis: Probability of a Near Miss to Pedestrian Volume (Red Pedestrian Traffic Light)

Two additional binary logistic regression models were developed in order to investigate the association of explanatory variables and the probability of a conflict among pedestrians to occur. In these models the conflict among pedestrians is selected as the dependent variable it takes two values (0: no conflict among pedestrians occurred and 1: a conflict among the pedestrians occurred). As explanatory variables the following variables were selected: “Pedestrian Volume”, “Accompanied” and “Vehicle on crossing”. Moreover, in these two statistical models a constant is also included in the results. The results of these two models are presented in **Table 5**.

TABLE 5 Statistical Model for Conflicts among Pedestrians

	Distracted Pedestrians				**Non-Distracted Pedestrians**			
Independent variables	**β_i**	**Wald**	**Sig.**	**Exp(β_i)**	**β_i**	**Wald**	**Sig.**	**Exp(β_i)**
Constant	-7.877	17.638	0.000	0.000	-3.598	42.292	0.000	0.027
Pedestrian Volume	0.122	13.149	0.000	1.129	0.116	39.185	0.000	1.123
Non Accompanied	2.509	3.927	0.048	12.293	-0.900	10.591	0.001	0.407
Weekend	1.041	3.203	0.073	2.831	-0.409	1.656	0.198	0.664
No Vehicle on crossing	1.048	1.907	0.167	2.853	0.646	3.555	0.059	1.908
Hosmer & Lemeshow Test	0.856				0.696			

The p-value of Hosmer & Lemeshow Test for goodness of fit is higher than 0.05 meaning that the null hypothesis of the test is accepted for both logistic regression models. All the Wald values are higher than 1.7 except for the “Weekend” variable in the non-distracted model which is 1.656 but it is very close to 1.7 and thus these two models are considered acceptable. The results of these two models show the following:

- As the variable of pedestrian volume increases, the probability of a conflict among pedestrians increases both for distracted and non-distracted pedestrians as well.
- The positive sign of the variable “Non Accompanied” for distracted pedestrians indicates that there is a higher probability of conflict among pedestrians for distracted pedestrians who are not accompanied by someone else. This may be explained due to the fact that distracted pedestrians’ attention is on their mobile phone’s screen and there is no one next to them to guide and show to them another route in order to avoid the conflict. On the other hand, the probability of a conflict among pedestrians for non-distracted pedestrians who are not accompanied by someone else is lower.
- Moreover, on weekends a conflict among pedestrians for distracted pedestrians is more likely to occur because the purpose of their trip is often for entertainment and not for work and they may send messages to people that they are going to meet. On the contrary, for non-distracted pedestrians the probability of a conflict among pedestrians is higher on working days may due to the fact that the purpose of their trip is related to work and they may be in a hurry or tired from their work and they are less careful.

- The probability of a conflict among pedestrians is higher when there is no vehicle on the pedestrian crossing.

Furthermore, based on the following sensitivity analysis figure (**Figure 4**) it can be observed that in the case of high pedestrian volume, distracted pedestrians who are texting or web-surfing and they are accompanied by other pedestrians tend to move away from others and avoid conflicts as they are guided by their companion while those who are non-distracted and accompanied have higher possibilities for a conflict with other pedestrians may due to the fact that they are talking with their companion and they are not so careful while crossing the street.

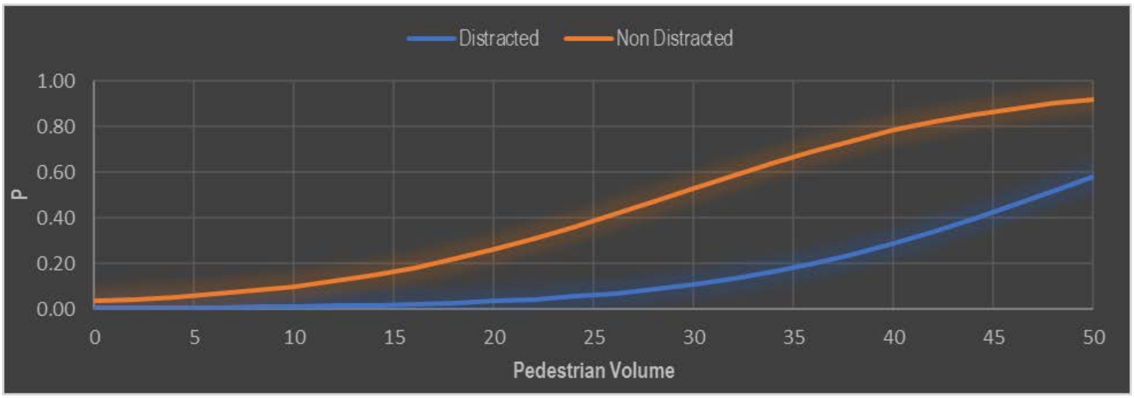

Figure 4: Sensitivity Analysis: Probability of a Conflict among Pedestrians to Pedestrian Volume (Accompanied Pedestrians, Weekend, No Vehicle on Crossing)

CONCLUSIONS

Cell phones are integral to contemporary daily life and their use and penetration is increasing rapidly as well. For this reason, it is crucial to investigate the impacts of distracted walking on pedestrians' traffic and safety behavior. Many studies have been conducted aiming to identify the dangers of distracted driving, however, not much emphasis has been placed in surveys with main topic the investigation of pedestrians' distracted walking. This study used data derived from an outdoor experimental process through video recording which was carried out in three signalized intersections in the center of Athens and the results of this paper shed light to the characteristics that affect traffic and safety behavior of distracted and non-distracted pedestrians. The analyses pointed out that in high pedestrian traffic, mobile use not only decreases pedestrians' speed, regardless of their age, but also increases their probability of being involved in a crash with an oncoming vehicle. Moreover, it was found that distraction caused by texting or web-surfing on the mobile phone affects negatively pedestrians' main traffic and safety characteristics.

Pedestrian distraction is a global problem, and to the extend of the authors' knowledge, there are typically no road safety measures to reduce pedestrian distraction in modern road networks. To counter this, various measures and strategies should be implemented. For example, targeted educational campaigns should be conducted in order to inform and sensitize pedestrians to the risks of texting or web-surfing on their mobile phone while crossing the street. A type of restriction on walking while using a mobile phone (as compared to the driver mobile phone prohibition) might also be foreseen in busy roads where road crashes involving pedestrians are a frequent phenomenon. Technology could also offer some solutions. More specifically, mobile applications which warn pedestrians that they are moving towards a pedestrian crossing or that a vehicle is approaching them could be developed. Additionally, the GPS of the mobile phones could recognize that the pedestrians are moving and disable some specific features while walking (especially in high risk situations). Lastly, engineering solutions in the design of road crossings and public places (e.g. green and red lights on the ground) may also contribute to distracted pedestrians' safety.

Regarding future research in this topic, it would be extremely interesting to expand this experiment in a larger sample of pedestrians and signalized intersections located in different areas, and to conduct a comparative analysis to see which pedestrians incur higher risks. Additionally, it would also be useful to carry out the same experiment during the nighttime in order to identify the differences in pedestrians' behavior between nighttime and daylight hours. Concluding, it is a fact that mobile technology continues to change rapidly. Our society should stay up to date with these changes to take advantage of the benefits and reduce the safety risks of distracted walking. To that end, the results of the present research allow for an overall assessment of pedestrians' safety in signalized intersections. Useful support is thus provided to decision makers working for the improvement of pedestrians' safety, who should take into account the particularities of distracted pedestrians and the different behavior patterns of all pedestrians.

AUTHOR CONTRIBUTIONS

The authors confirm contribution to the paper as follows: study conception and design: Marilia Ropaka Author, Dimitrios Nikolaou Author, George Yannis Author; data collection: Marilia Ropaka Author; analysis and interpretation of results: Marilia Ropaka Author, Dimitrios Nikolaou Author, George Yannis Author; draft manuscript preparation: Marilia Ropaka Author, Dimitrios Nikolaou Author, George Yannis Author. All authors reviewed the results and approved the final version of the manuscript.

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