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INCREASING DANGER AT PEDESTRIAN CROSSINGS: THE IMPACT OF MOBILE PHONES ON PEDESTRIAN SAFETY

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Abstract

This study focuses on the increasing danger posed by pedestrians using mobile devices at signalized crossings in urban areas. Conducted in Kielce, the research involved detailed observations at five high-traffic crossroads to assess the frequency and impact of distracted pedestrian behavior. The findings show a concerning rise in the use of mobile phones while crossing the street. Specifically, 32% of pedestrians were observed using their phones, whether for texting, browsing, or making calls. This behavior significantly contributed to unsafe situations, with 4% of those observed crossing against a red light, creating potentially hazardous conditions for both pedestrians and drivers. The study highlights how mobile phone use impairs pedestrians' ability to concentrate on their surroundings, reducing their awareness of traffic signals, oncoming vehicles, and other potential hazards. These distractions can lead to longer reaction times and poor decision-making when crossing roads, which increases the risk of accidents. In response, the research emphasizes the need for immediate action to improve pedestrian safety at urban crossings. Potential solutions include public awareness campaigns, stricter enforcement of traffic laws, and even technological solutions, such as signal systems that alert pedestrians when they are distracted. Addressing this issue is crucial to reducing the growing number of accidents related to mobile device use at pedestrian crossings.

Keywords: pedestrian safety; distraction related to mobile devices; pedestrian crossings; road behaviour; road safety

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1. Introduction

The rapid development of mobile devices has brought significant changes in various aspects of life, including pedestrian behaviors in urban areas. While these devices offer convenience and the ability to stay connected, their improper use, particularly by pedestrians crossing busy streets, poses serious risks. The phenomenon of "distracted walking" has become a zsignificant problem, leading to an increase in accidents and near-miss situations at crosswalks. This growing concern has prompted researchers and policymakers to investigate the scale of the problem and seek potential solutions.

Pedestrian safety in Poland remains a serious issue, particularly at crosswalks where traffic signals regulate the movement of both pedestrians and vehicles. From 2020 to 2023, the number of accidents involving pedestrians showed a slight decrease; however, the problem of pedestrians entering crosswalks at inappropriate times still persists. In 2020, there were 8,461 pedestrian accidents, with 1,683 cases involving inappropriate crossings, accounting for 19.87% of all pedestrian accidents. In 2021, the number of pedestrian accidents slightly decreased to 8,390, with 1,647 cases involving inappropriate crossings, representing 19.66% of the total. In 2022, the number of pedestrian accidents decreased to 8,352, but 1,646 cases involved inappropriate crossings, which accounted for 19.70% of all accidents. In 2023, there was a slight percentage increase, with 8,300 accidents and 1,646 cases of inappropriate crossings, accounting for 19.83% of all pedestrian accidents [19]. In the European context, the number of road accidents involving pedestrians in the European Union also remains high. In 2021, there were 22,700 fatal accidents on EU roads, with approximately 21% involving pedestrians [8]. In Poland, although the number of accidents is decreasing, the issue of ensuring safety at crosswalks requires further attention and intervention.

Research on the impact of pedestrian distraction caused by mobile phone use has been a subject of intense interest among numerous experts worldwide for years. This phenomenon, known as "distracted walking," has been thoroughly analyzed in the context of road safety, as increasing reliance on mobile devices creates new challenges for traffic management in cities. Studies indicate that using phones while navigating roads and sidewalks significantly increases the risk of accidents by limiting awareness of the surroundings and slowing reactions to hazards. Consequently, experts continuously advocate for greater awareness of this issue and the implementation of solutions aimed at minimizing the associated risks. An observational study presented in [10] conducted in Kielce showed a significant increase in distracting behaviors among pedestrians, correlating with a higher number of near-miss situations at crosswalks. In [12], Gądek-Hawlena (2012) stated that as many as 15% of pedestrian accidents in Poland were related to mobile device usage, leading to delayed reactions and misjudgments while crossing the street.

In [34], Stefański (2017) analyzed the effectiveness of legal regulations prohibiting mobile phone use by drivers, noting a 12% decrease in accidents after these laws were introduced.

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Although the study focused on drivers, the results suggest that similar regulations for pedestrians could enhance their safety. In [14], Gierszewski and Bajorski (2018) presented detailed statistics on pedestrian accidents, indicating that mobile device usage was a contributing factor in many cases where pedestrians ignored traffic signals. In [33], Sosik and Pawłowska (2019) focused on pedestrian behaviors at signalized intersections, noting a 7% decrease in accidents after educational campaigns discouraging mobile phone use among pedestrians were implemented. In [43], Zielińska and Skoczyński (2023) reported a 6% decrease in pedestrian accidents after stricter regulations prohibiting mobile device usage at crosswalks were introduced, although challenges related to widespread violations still exist.

In [38], the authors analyze pedestrian safety distracted by mobile phones at street crossings in Nanjing. Field studies show that pedestrians using smartphones make riskier decisions on the road, leading to increased collision risk. The authors suggest implementing preventive measures in the form of education and infrastructure to improve safety. In [20], the authors focus on understanding the risky behaviors of pedestrians distracted by smartphones. Field studies indicate that both visually and physically demanding tasks on the phone increase the likelihood of making dangerous decisions while navigating the streets. In [3], the authors conducted virtual reality studies to assess the effectiveness of various interventions aimed at reducing accidents among pedestrians using phones. The results suggest that visual notifications can significantly enhance pedestrian attention, thereby reducing accident risk. In [28], the authors analyze the impact of phone usage on the risk of accidental falls among young adult pedestrians. Studies show that smartphones increase fall risk, especially in challenging terrain, suggesting the need for educational campaigns targeting young individuals.

In [24], the author examines how smartphones influence the way pedestrians experience urban space. It was found that phone usage decreases pedestrians' spatial awareness, leading to a higher risk of accidents in urban environments. In [13], the authors describe the development of a monitoring system based on neural networks that tracks pedestrians using phones and headphones. This technology aims to improve pedestrian safety by monitoring and warning them of potential threats. In [23], the authors study how different smartphone tasks and traffic complexity affect pedestrian awareness and their ability to identify objects on the road. The results suggest that smartphones significantly diminish pedestrians' capacity to accurately assess their surroundings, increasing collision risk. In [6], the authors conducted a controlled study assessing the impact of phone usage while walking on pedestrians' moods. The findings indicate that while smartphones may improve mood, they also lead to reduced attention, increasing accident risk. In [42], the authors conducted a meta-analysis showing that phone tasks affect pedestrian movement patterns, with varying impacts based on age. Older adults are more susceptible to changes in gait and increased fall risk.

In [39], the authors investigate how beliefs and attitudes influence pedestrian mobile phone usage in India. It was found that personal beliefs significantly affect whether pedestrians choose to use phones in safe or risky ways. In [36], the authors explore the relationship

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between pedestrian phone usage and their risky behaviors while crossing the street. The results show that individuals using phones are more likely to ignore traffic signals and make dangerous decisions on the road. In [21], the authors present an evaluation of various interventions aimed at reducing accidents involving pedestrians using phones. Studies show that visual notifications can effectively reduce accident numbers. In [22], the authors analyze the impact of smartphone usage by "digital natives" while walking in realistic environments. Research shows that individuals raised in the digital age have more difficulty assessing the risks associated with phone usage while walking. In [25], the authors investigate how smartphone usage affects pedestrian behavior in open spaces. The results show that phone use leads to changes in movement patterns, increasing the risk of collisions.

In [32], the authors state that the risk of accidents among pedestrians using phones depends on the type of task and the environment in which the pedestrian is located. Tasks requiring greater concentration lead to increased distraction. In [42], the authors analyze the impact of various tasks on phones on pedestrian behavior in different urban environments. Studies show that the more complex the urban environment, the greater the risk associated with phone-related distraction. In [35], the authors present the development of a mobile application aimed at improving the safety of pedestrians using phones. The app monitors pedestrians and alerts them to approaching hazards to reduce accident numbers. In [40], the authors conduct a systematic review of studies on the impact of phone-related distraction on pedestrian behavior while crossing streets. The results show that pedestrians using phones are more vulnerable to vehicle collisions.

The aim of this study is to provide a comprehensive analysis of the impact of mobile device usage on pedestrian safety at signalized crosswalks in urban areas. The article is based on existing literature, presenting current data from Poland, comparing current trends with historical data, and proposing potential remedial measures to reduce the identified risks. The structure of the article is as follows: the next section describes the materials and methods used in the study, followed by detailed results, an interpretation of these results in the context of existing research, and finally, conclusions and recommendations for improving pedestrian safety.

2. Implementation of research

The study aimed to assess the impact of mobile device use by pedestrians on their behavior at signalized pedestrian crossings in Kielce, Poland. It was conducted at five major crossroads in the city center, known for high pedestrian and vehicle traffic. The selected crossroads were: the junction of Warszawska Street with Tysiąclecia Państwa Polskiego Avenue, the crossroads of Świętokrzyska Street with Warszawska Street, the crossroads of Warszawska Street with Świętokrzyska Street, the junction of Świętokrzyska Street with Solidarności Avenue, and the crossroads of Solidarności Avenue with Świętokrzyska Street. These loca-

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tions were chosen due to their high traffic conflict rates, making them ideal for observing pedestrian behavior.

In total, 1,498 pedestrians were observed as they crossed at these crossroads. Observations were made during different times of the day to capture various traffic conditions, with each crossroadsmonitored for three weekdays between 10:00 and 12:00. A team of nine researchers, divided into three groups, conducted the observations. Two groups positioned on opposite sides of the crosswalk recorded whether pedestrians used mobile devices, such as smartphones, and what activity they were performing (e.g., talking, texting, listening to music). The third group tracked the duration of traffic signals and pedestrian crossing times.

A specially designed observational questionnaire was the primary research tool used in the study. This questionnaire categorized pedestrian behaviors and crossing situations, recording whether pedestrians entered on a green light, flashing green, or red light, and whether they crossed during vehicle movement. Pedestrian behaviors were divided into categories such as using a phone, walking with a bicycle or scooter, wearing headphones, talking on the phone, actively using a phone (looking at the screen), and pedestrians not using any devices.

A total of 51 traffic light cycles were observed at each intersection, allowing for the collection of representative data. The data were analyzed statistically to evaluate the relationship between different pedestrian behaviors and their likelihood of violating traffic regulations. The analysis included comparing the percentage of pedestrians using mobile devices while crossing to those not using such devices, assessing how phone use affected crossing time, and examining the number of violations (e.g., crossing on a red light) in relation to mobile device use.

The study was conducted in full compliance with research ethics guidelines. Observations were anonymous, with no personal data collected. The results were presented in aggregate form, ensuring no individual participants could be identified.

3. Observation of pedestrians crossing

As part of the research, they were divided into five stages, corresponding to five selected pedestrian crossings in the centre of Kielce. Each step involved a detailed observation of pedestrian behaviour at one of the selected crossroads, enabling comparison of results and analysis of the impact of different locations on pedestrian behaviour. In each stage, pedestrian traffic at the crossing was monitored for three working days at specific times, which allowed data to be collected in different traffic conditions. Figures 1 to 5 below present satellite images of each of the examined pedestrian crossings.

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Fig. 1. Pedestrian crossing at the crossroads of Warszawska Street and Tysiąclecia Państwa Polskiego Avenue

Fig. 2. Pedestrian crossing at the crossroads of Świętokrzyska Street and Warszawska Street

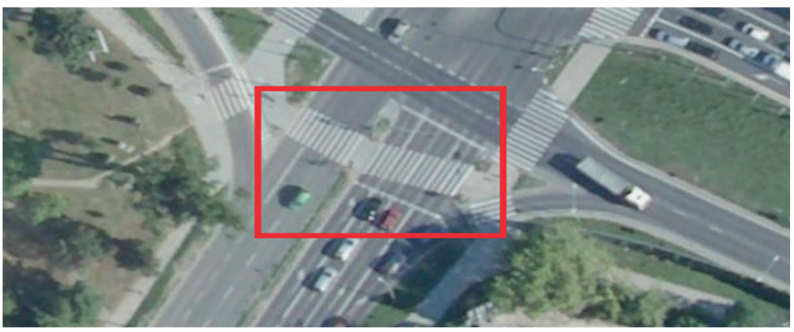

Fig. 3. Pedestrian crossing at the crossroads of Warszawska Street and Świętokrzyska Street

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Fig. 4. Pedestrian crossing at the crossroads of Świętokrzyska Street and Solidarności Avenue

Fig. 5. Pedestrian crossing at the crossroads of Solidarności Avenue and Świętokrzyska Street

The study conducted at five high-conflict pedestrian crossings in Kielce provided valuable data on pedestrian behavior in relation to traffic signals. These results allow for a better understanding of how pedestrians react to different phases of the signals and what decisions they make regarding crossing.

The first location studied was the pedestrian crossing at the crossroads of Warszawska Street and Tysiąclecia Państwa Polskiego Avenue. This crossroads is a key point in Kielce road network, and its location near a university, numerous service points, shops, and public transport stops generates significant pedestrian traffic, including various age groups. The study, conducted on March 13, 2023, showed that 304 people used the crossing during 51 signal cycles. The vast majority, 268 people, crossed on the green signal. Another 24 individuals crossed on the flashing green signal, which may suggest that some pedestrians feel time pressure or are unwilling to wait for the next light change. Only 12 people took the risk of crossing on a red light when vehicle traffic was closed, while no one crossed on a red signal when vehicle traffic was open. The number of pedestrians crossing at the crossroads of Warszawska Street and Tysiąclecia Państwa Polskiego Avenue is shown in Figure 6.

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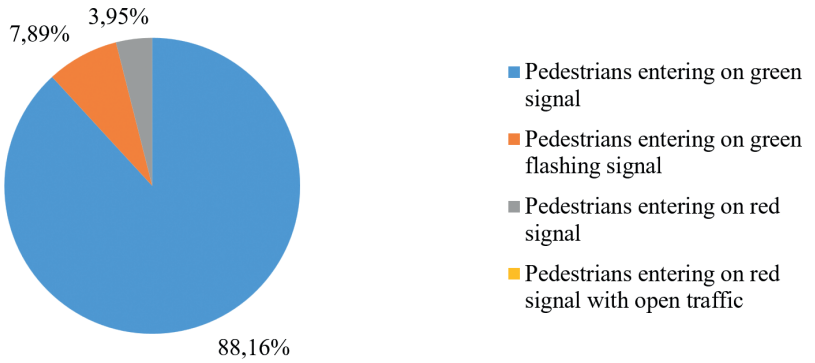

Fig. 6. Number of pedestrians crossing at the crossroads of Warszawska Street and Tysiąclecia Państwa Polskiego Avenue

The second location studied was the pedestrian crossing at the crossroads of Świętokrzyska and Warszawska Streets. This intersection, due to the transit traffic heading toward the S74 expressway, experiences a high volume of vehicle traffic. Increased pedestrian traffic is driven by the presence of a secondary school, a shopping mall, and other nearby facilities. The study, conducted on May 22, 2023, revealed that 326 people used this crossing, with 288 individuals crossing on the green signal. The number of people crossing on the flashing green signal was 29, which is higher than at the first intersection, possibly due to a greater sense of time pressure at this location. Only 9 people crossed on the red light when vehicle traffic was closed. The number of pedestrians crossing at the crossroads of Świętokrzyska and Warszawska Streets is shown in Figure 7.

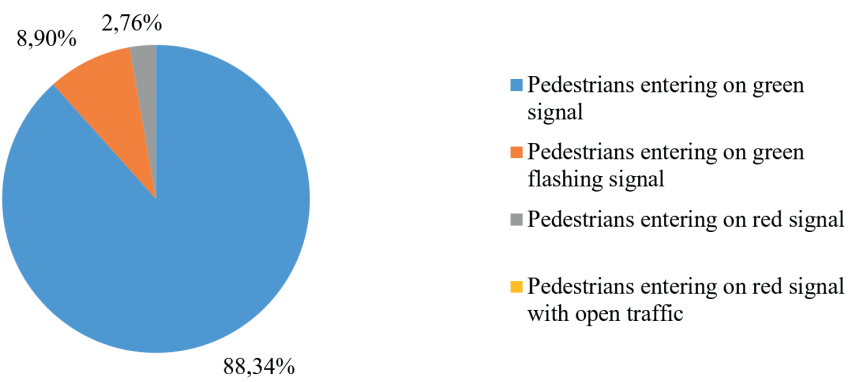

Fig. 7. Number of pedestrians crossing at the crossroads of Świętokrzyska and Warszawska Streets

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The third study, also conducted at the crossroads of Warszawska and Świętokrzyska Streets, revealed that 225 people crossed on the green signal. The number of individuals choosing to cross on the flashing green signal was significantly lower, with only 4 people, and only 2 people took the risk of crossing on the red signal when vehicle traffic was closed. The number of pedestrians crossing at the crossroads of Warszawska and Świętokrzyska Streets is shown in Figure 8.

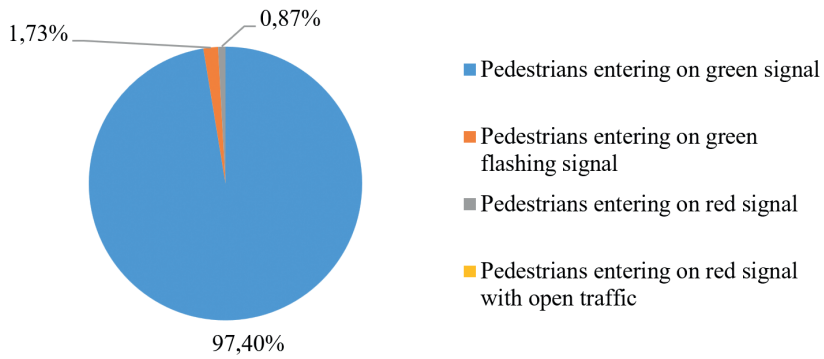

Fig. 8. Number of pedestrians crossing at the crossroads of Warszawska and Świętokrzyska Streets

The fourth study, conducted at the crossroads of Świętokrzyska Street and Solidarności Avenue, showed that 367 people used the crossing, with 288 individuals crossing on the green signal. In this case, there was a noticeable increase in the number of people (75) crossing on the flashing green signal, which may be due to the characteristics of the intersection, where pedestrians may feel more inclined to take risks. Only 4 people chose to cross on the red signal when vehicle traffic was closed. The number of pedestrians crossing at the crossroads of Świętokrzyska Street and Solidarności Avenue is shown in Figure 9.

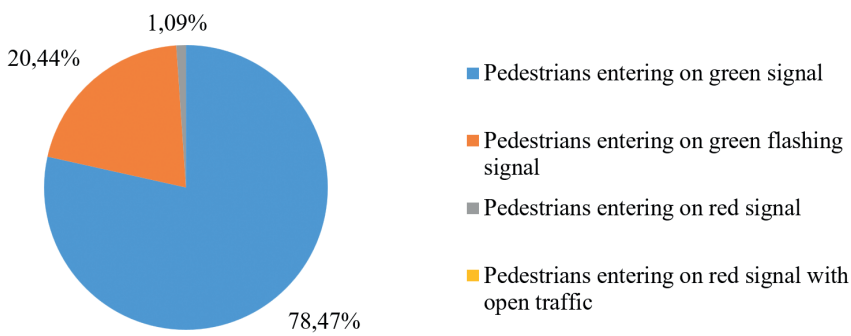

Fig. 9. Number of pedestrians crossing at the crossroads of Świętokrzyska Street and Solidarności Avenue

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The last, fifth study, conducted at the crossroads of Solidarności Avenue and Świętokrzyska Street, showed that 270 people used the crossing, with 261 individuals crossing on the green signal. Only 8 people chose to cross on the flashing green signal, and just 1 person took the risk of crossing on the red signal when vehicle traffic was closed. The number of pedestrians crossing at the crossroads of Solidarności Avenue and Świętokrzyska Street is shown in Figure 10.

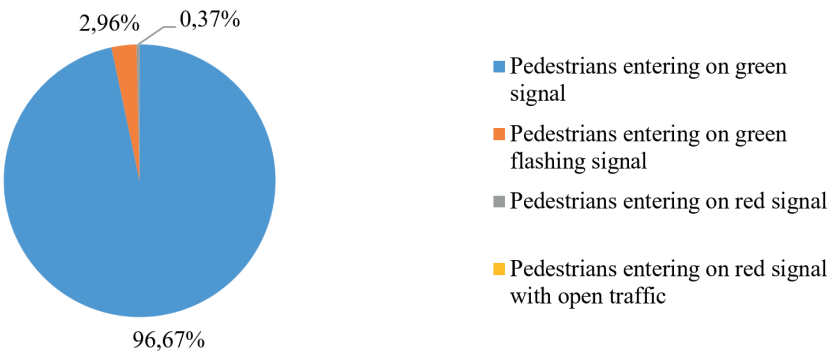

Fig. 10. Number of pedestrians crossing at the crossroads of Solidarności Avenue and Świętokrzyska Street

At the crossroads of Warszawska Street and Tysiąclecia Państwa Polskiego Avenue, the majority of pedestrians (68%) did not use any additional devices while crossing, indicating that they were more focused on the traffic. Among those who used devices, 51 pedestrians carried a phone, and 14 of them actively used it while crossing. Additionally, 20 people wore headphones, which could have affected their ability to perceive surrounding sounds, and 8 people were talking on the phone. A low number of pedestrians were observed pushing a bicycle or scooter, suggesting limited use of these modes of transportation at this location. The ratio of pedestrians to those using additional devices at the crossroads of Warszawska Street and Tysiąclecia Państwa Polskiego Avenue is shown in Figure 11.

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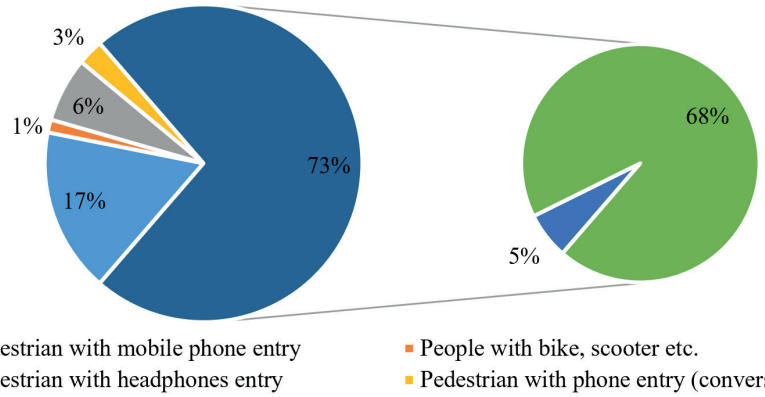

Fig. 11. Characteristics of the ratio of pedestrians to those using additional devices at the crossroads of Warszawska Street and Tysiąclecia Państwa Polskiego Avenue

At the crossroads of Świętokrzyska and Warszawska Streets, the percentage of pedestrians not using any additional devices was 41%, indicating that a larger portion of pedestrians were engaged in using mobile devices. Among this group, 42 people carried a phone, with 7 actively using it, which could have affected their concentration. Additionally, 32 people wore headphones, and 12 were talking on the phone, potentially limiting their ability to assess the road situation. A higher number of pedestrians pushing bicycles or scooters (98 people) was also noted at this intersection, which may be due to the nature of the area attracting younger road users. The ratio of pedestrians to those using additional devices at the crossroads of Świętokrzyska and Warszawska Streets is shown in Figure 12.

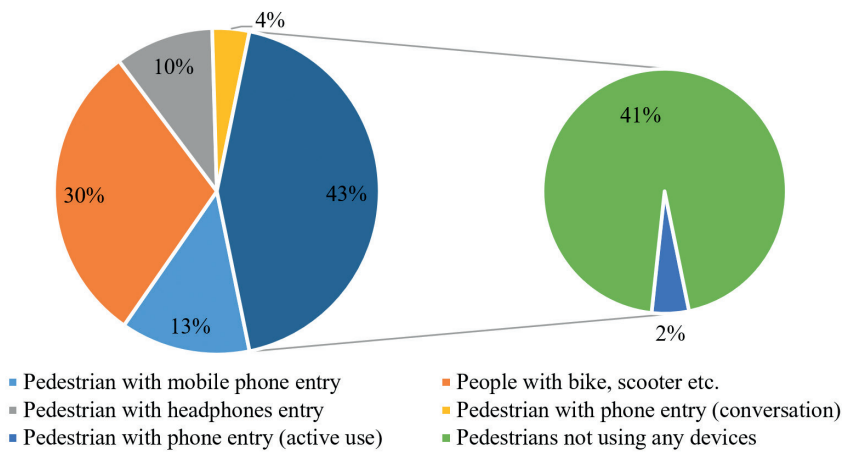

Fig. 12. Ratio of pedestrians to those using additional devices at the crossroads of Świętokrzyska and Warszawska Streets

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At the crossroads of Warszawska and Świętokrzyska Streets, 57% of pedestrians did not use any additional devices, suggesting a higher level of focus on traffic. Among the remaining pedestrians, 20 carried a phone, with 8 actively using it while crossing. Additionally, 23 people wore headphones, and 3 were talking on the phone. At this location, 46 people were observed pushing a bicycle or scooter, indicating moderate use of these modes of transportation. The ratio of pedestrians to those using additional devices at the crossroads of Warszawska and Świętokrzyska Streets is shown in Figure 13.

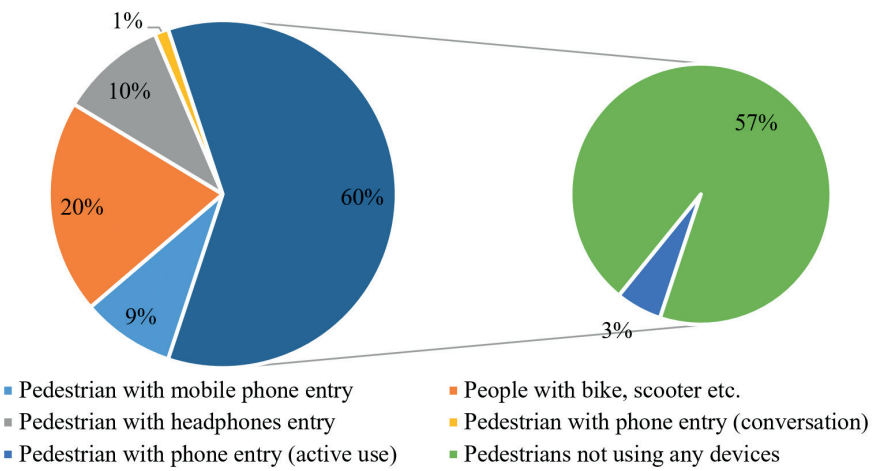

Fig. 13. Ratio of pedestrians to pedestrians using additional devices at the crossroads of Warszawska and Świętokrzyska Streets

At the crossroads of Świętokrzyska Street and Solidarności Avenue, 52% of pedestrians did not use any additional devices, indicating that the majority were focused on traffic. Among the remaining pedestrians, 37 carried a phone, with 14 actively using it while crossing. Additionally, 45 people wore headphones, potentially limiting their ability to perceive surrounding sounds, and 19 were talking on the phone. This crossroads also saw a higher number of pedestrians pushing bicycles or scooters (60 people), likely due to the proximity of a shopping mall and residential areas. The ratio of pedestrians to those using additional devices at the crossroads of Świętokrzyska Street and Solidarności Avenue is shown in Figure 14.

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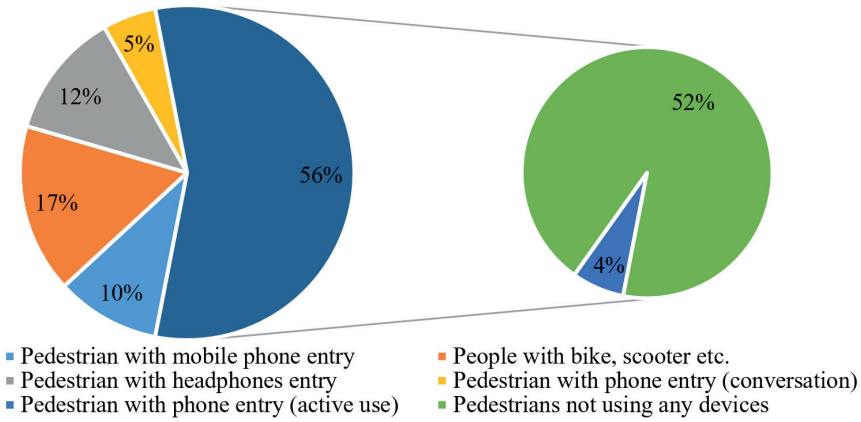

Fig. 14. Ratio of pedestrians to pedestrians using additional devices at the crossroads of Świętokrzyska Street and Solidarności Avenue

At the crossroads of Solidarności Avenue and Świętokrzyska Street, 40% of pedestrians did not use any additional devices, which is the lowest percentage among all the studied locations, possibly indicating greater distraction in this area. Among the remaining pedestrians, 69 carried a phone, with 15 actively using it while crossing. Additionally, 24 people wore headphones, and 18 were talking on the phone. It was also noted that 36 people crossed the crossroads while pushing a bicycle or scooter, likely due to the residential nature of the area. The ratio of pedestrians to those using additional devices at the crossroads of Solidarności Avenue and Świętokrzyska Street is shown in Figure 15.

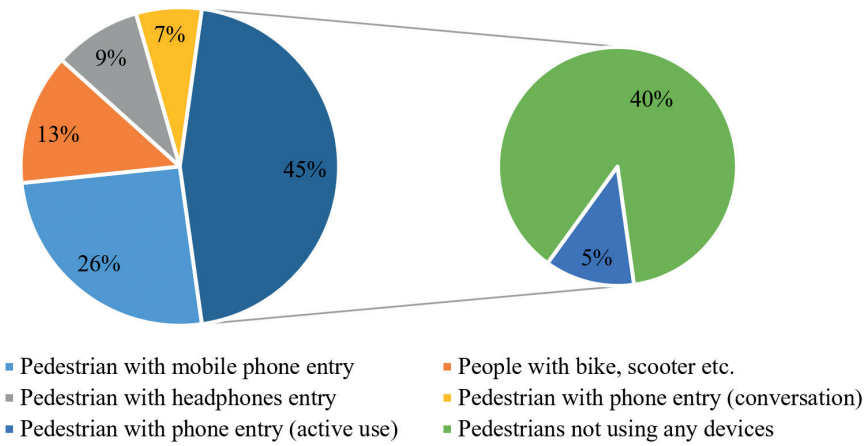

Fig. 15. Ratio of pedestrians to pedestrians using additional devices at the crossroads of Solidarności Avenue and Świętokrzyska Street

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The study at five pedestrian crossings in Kielce analyzed pedestrian behavior in relation to traffic signals. Key findings showed that most pedestrians crossed during the green signal, with some locations seeing a high use of mobile devices while crossing. For example, at the crossroads of Solidarności Avenue and Świętokrzyska Street, 69 pedestrians used phones, and 15 were actively distracted by them, increasing safety risks. The study also noted the use of bicycles and scooters at crossings. The results emphasize the need for educational efforts and infrastructure improvements to enhance pedestrian safety, particularly in reducing mobile device distractions.

4. Analysis of the results of observation of pedestrian behavior

The statistical significance coefficient of p=0.0001 (Table 1) clearly indicates a significant impact of the type of crossroads on pedestrian behavior. A summary of pedestrian behavior at individual crossroads is presented in Figure 16. Data analysis shows that at the crossroads of Solidarności Avenue and Świętokrzyska Street, the most pedestrians were using mobile phones – 69 people, which constitutes 26% of all pedestrians at this intersection. This is the highest percentage among all the locations studied. The same crossroads also had the highest number of pedestrians actively using their phones – 15 people (6%), as well as the highest number of people talking on the phone – 18 people (7%).

At the crossroads of Świętokrzyska and Warszawska Streets, 42 people (15%) were observed using their phones, which also represents a significant proportion. In this location, 12% of pedestrians were using headphones, noticeably higher than at other crossroads. Meanwhile, at the crossroads of Warszawska and Świętokrzyska Streets, where 34% of pedestrians were pushing a bicycle or scooter, this group had the highest percentage compared to other locations. Interestingly, at the crossroads of Świętokrzyska Street and Solidarności Avenue, 12% of pedestrians were using headphones, which may indicate a higher level of distraction at this location. The same crossroads also recorded the highest percentage of people talking on the phone – 5%.

Overall, across all locations studied, 15% of pedestrians used mobile phones while crossing. It is noteworthy that 10% of all pedestrians used headphones, which could significantly limit their ability to respond to their surroundings. One in four pedestrians, or 16% of those surveyed, was pushing a bicycle or scooter, which, in the context of road safety, requires special attention.

However, the most striking conclusion from the analysis is that 52% of pedestrians did not use any distracting devices. This indicates that the majority of pedestrians, despite the availability of mobile devices, try to maintain focus while crossing the street. Nevertheless, the high percentage of pedestrians using mobile devices at certain crossroads suggests the need

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for preventive and educational measures to raise awareness of the risks associated with distraction in traffic.

Tab. 1. Summary of pedestrian behaviour at individual crossroads

Parameter	Crossroads 1		Crossroads 2		Crossroads 3		Crossroads 4		Crossroads 5		Sum	
	n	%	n	%	n	%	n	%	n	%	n	%
Pedestrian with phone	51	17	42	15	20	7	37	10	69	26	219	15
Pedestrian with headphones	20	7	32	12	23	8	45	12	24	9	144	10
Pedestrian with bicycle, scooter	4	1	48	17	96	34	60	16	36	13	244	16
Pedestrian talking on the phone	8	3	12	4	3	1	19	5	18	7	60	4
Pedestrian actively using the phone	14	5	7	3	8	3	14	4	15	6	58	4
Pedestrian not using any devices	207	68	135	49	131	47	192	52	108	40	773	52
Chi-square	χ^2=188.06				df=20				p=0.0001			

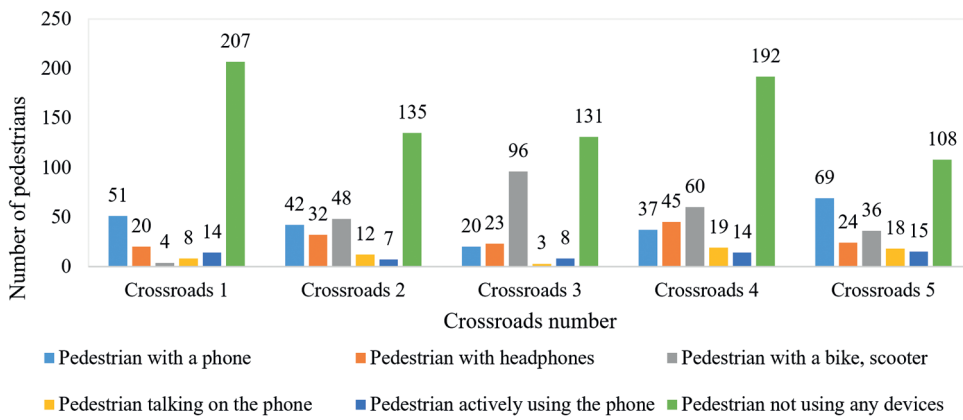

Fig. 16. Summary of pedestrian behaviour at individual crossroads

The statistical significance coefficient of p=0.0001 (Table 2), which is smaller than the accepted significance level (0.05), clearly indicates that the type of crossroads has a significant impact on how pedestrians use signalized crossings. Data analysis shows that the vast majority of pedestrians at each of the studied crossroads crossed during the green signal — a total of 1,330 such cases were recorded, representing 89% of all observations. The highest

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percentage of pedestrians crossing on the green light was observed at the crossroads of Warszawska Street and Solidarności Avenue, where as many as 97% of pedestrians complied with the signal. On the other hand, the highest number of pedestrians crossing during the flashing green light was noted at the crossroads of Świętokrzyska Street and Solidarności Avenue — 75 people, accounting for 20% of all pedestrians at this crossroads. This may suggest that pedestrians at this location felt time pressure or were willing to take the risk to cross before the signal changed to red.

The highest number of cases of crossing a red light was recorded at the crossroads of Warszawska Street and Aleja Tysiąclecia Pana Polskiego – 12 people, which is 4% of all pedestrians in this location. This result may be related to the short duration of the green light, which does not always allow pedestrians to cross the crossing safely, prompting some to behave riskily.

It is also worth noting that at none of the crossroads studied, no cases of pedestrians crossing a red light with open traffic were observed, suggesting that pedestrians in Kielce are aware of the risks associated with such behavior. A breakdown of pedestrian behaviour in relation to traffic lights at individual crossroads is presented in detail in Figure 17, which allows for a better understanding of how various factors affect pedestrian decisions when crossing the road.

Tab. 2. Summary of pedestrian behaviour in terms of compliance with traffic lights

Parameter	Crossroads 1		Crossroads 2		Crossroads 3		Crossroads 4		Crossroads 5		Sum	
	n	%	n	%	n	%	n	%	n	%	n	%
Pedestrian entry at the green signal	268	88%	288	88%	225	97%	288	78%	261	97%	1330	89%
Pedestrian entry on green flashing signal	24	8%	29	9%	4	2%	75	20%	8	3%	140	9%
Pedestrians entering at a red signal	12	4%	9	3%	2	1%	4	1%	1	0%	28	2%
Pedestrian entry at a red signal with open traffic	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%
Chi-square	χ^2=97.501				df=12				p=0.0001			

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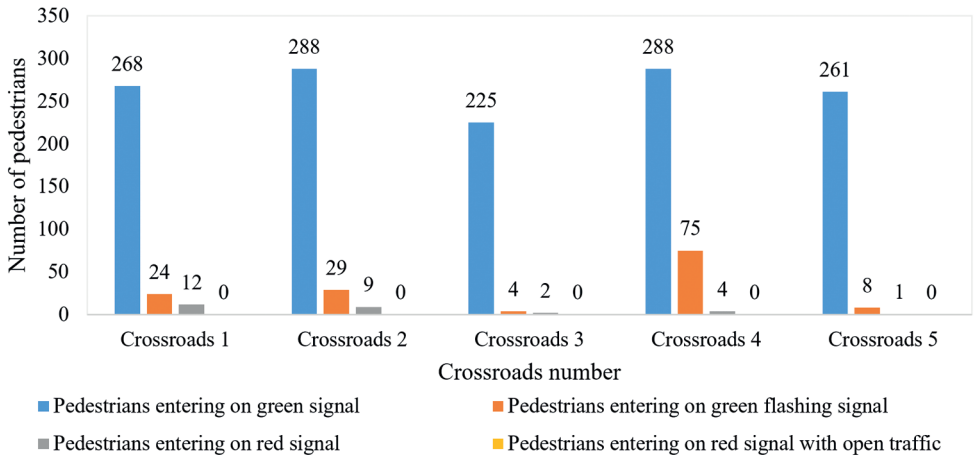

Fig. 17. Summary of pedestrian behaviour in terms of compliance with traffic lights at individual crossroads

In the article, the influence of crossroads type on pedestrian behavior is highlighted, particularly concerning mobile device use and compliance with traffic signals. The analysis reveals a clear pattern of riskier behaviors, such as crossing during flashing green signals, suggesting time pressure or a willingness to take risks. The article also emphasizes the significant role of mobile devices in reducing pedestrian attention, thereby increasing safety risks. Despite these concerns, most pedestrians adhered to traffic signals, and no cases of red-light crossings with open traffic were observed. The findings suggest the need for targeted educational campaigns and infrastructure adjustments to address pedestrian distractions and improve overall road safety.

5. Discussion

The results of the conducted studies are consistent with findings presented in the scientific literature analyzing pedestrian behavior at signalized crossroads. Specifically, the use of mobile devices, particularly mobile phones, is a significant factor affecting pedestrian behavior and their ability to properly respond to traffic signals. In literature it was noted that mobile phone use significantly affects pedestrians' attention and can lead to dangerous situations at pedestrian crossings. The results of this study confirm these findings, especially at the crossroads of Solidarności Avenue and Świętokrzyska Street, where the highest number of pedestrians using phones (69 people) and actively using phones (15 people) was observed. Similarly, in literature, it was emphasized that mobile phone use by pedestrians can lead to delayed reactions to traffic signals and increase the risk of inappropriate behavior, such as

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crossing on a red light. The study at the crossroads of Warszawska Street and Tysiąclecia Państwa Polskiego Avenue, where the highest number of red-light crossings (12 people) was recorded, aligns with these results [9, 10].

Wang and Co-authors [39] conducted a study in Nanjing, where they found that 10% of pedestrians using phones crossed at a red light, increasing the risk of collisions. In contrast, in their own study, it was observed that 2% (n=28) of all pedestrians crossed at a red signal. At the intersection of Warszawska Street and Tysiąclecia Państwa Polskiego Avenue, the highest percentage of such behaviors was recorded – 4% (n=12). Although this percentage is lower than in Wang's study, it is worth noting that phone usage may have influenced pedestrians' decisions. For example, at the intersection of Solidarności Avenue and Świętokrzyska Street, where 26% of pedestrians used phones, instances of crossing at a red light were also noted.

Krishna and co-authors [20] found that 12% of pedestrians using phones made risky decisions, such as crossing at a red light or ignoring signals. In their own study, it was noted that at the intersection of Świętokrzyska Street and Warszawska Street, 15% (n=42) of pedestrians used phones, and 3% (n=7) actively used them while crossing. Additionally, at this intersection, 9 individuals (3%) crossed at a red signal. This suggests that phone usage influences the tendency to take risks, aligning with Krishna's findings.

Arafat and Co-authors [3] evaluated the effectiveness of interventions, such as visual notifications, in reducing risky behaviors among pedestrians using phones, achieving a 15% reduction in risk. In their own study, it was noted that at the intersection of Solidarności Avenue and Świętokrzyska Street, where 26% (n=69) of pedestrians used phones, implementing the interventions suggested by Arafat could reduce the number of distracted pedestrians by approximately 10 individuals (15% of 69). This could potentially lead to a decrease in the number of pedestrians engaging in risky behaviors, such as crossing at a blinking green or red light.

Pelicioni's Study [28] examined the impact of phone usage on the risk of falls among young adult pedestrians, finding that 20% were more prone to falls. In their own study, as many as 10% (n=144) of pedestrians used headphones, which could limit their perception of surrounding sounds. At the intersection of Świętokrzyska Street and Solidarności Avenue, as many as 12% (n=45) of pedestrians used headphones. Although the user did not directly study fall risk, the use of headphones and phones can affect the ability to respond to unforeseen situations, consistent with Pelicioni's observations.

Lu's Study [24] analyzed the impact of smartphones on pedestrians' experience of urban space, finding that phone usage reduces spatial awareness by 30%. In their own study, at the intersection of Warszawska Street and Świętokrzyska Street, 47% (n=131) of pedestrians did not use any devices, meaning that 53% could potentially be distracted. The high percentage of pedestrians using mobile devices can lead to reduced awareness of the surroundings, confirming Lu's conclusions about the impact of smartphones on the perception of urban space.

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Ghosh and Roy's Study [13] developed a monitoring system for pedestrians using phones, finding that 18% of them ignored traffic signals. Implementing monitoring systems, such as the one proposed by Ghosh and Roy, could help identify and educate these pedestrians.

Lin and Cheng's Study [23] found that pedestrians using phones were 20% less aware of their surroundings and the presence of vehicles. In their own study, as many as 15% (n=219) of pedestrians used phones. At the intersection of Świętokrzyska Street and Warszawska Street, 12% (n=32) of pedestrians used headphones, further limiting their auditory perception. Reduced awareness of the surroundings could influence decisions to cross at a blinking green or even red light, aligning with Lin and Cheng's findings.

Collin and Broadbent's Study [6] demonstrated that using a phone while walking increases the risk of crossing at a red light by 25%. Although in their own study only 2% (n=28) of pedestrians crossed at a red light, at the intersection of Warszawska Street and Tysiąclecia Państwa Polskiego Avenue, where 17% (n=51) of pedestrians used phones, the highest percentage of red light crossings was recorded (4%, n=12). This suggests that phone usage may increase the risk of ignoring signals, consistent with Collin and Broadbent's results.

Zhang's Study [42] conducted a meta-analysis, showing that pedestrians using phones walked 15% slower and were more susceptible to distraction. In their own study, the speed of pedestrians was not directly measured, but it was noted that at the intersection of Solidarności Avenue and Świętokrzyska Street, 6% (n=15) of pedestrians actively used phones, which could affect their walking pace and decision-making when crossing at a blinking green signal. Slower pace and distraction may increase the risk of remaining on the crossing during signal changes, confirming Zhang's conclusions.

The article [4] presents the development of a VR-PSCT task assessing the perception of hazards and acceptance of the gap in pedestrians. Compared to our study, which focuses on the impact of mobile distraction on pedestrian behavior in real-world settings, the VR-PSCT study uses virtual reality to analyze risk perception. Our approach, based on field observations, allows us to assess the actual behavior of pedestrians and their decisions, which may differ from the reactions simulated in VR. The article [29] analyzes design practices in Bangladesh using co-design and the COM-B model. Compared to our study, which focuses on pedestrian education and the need to improve infrastructure to reduce risky behavior, the findings from Bangladesh point to the benefits of working with local stakeholders. Our study also suggests the need for infrastructure interventions to increase pedestrian safety at crossings.

The article [11] analyzes the behavior of pedestrians and electric cyclists at two-way crossings. Our study, while not including e-bikers, points to similar findings about the risk of increased congestion and delays associated with pedestrian use of mobile devices, which could have a similar impact on safety and traffic flow at crosswalks. In the paper [15], the authors used

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trajectory data from LiDAR sensors to assess pedestrian safety at uncontrolled crossings. In contrast, our study is based on manual observations, which, although less precise, allows for the analysis of a variety of pedestrian behaviours in real time. The results of both studies confirm the importance of infrastructure, such as asylum islands, in increasing pedestrian safety.

The article [16] presents a model of two-stage pedestrian crossing using PINN neural networks. In our study, we focus on the impact of mobile phones on pedestrian decisions at signaled crossings. While our approach does not include advanced neural models, real-world observations complement the modeling and show how the use of phones affects pedestrian behavior.

The article [5] evaluated the effectiveness of training to improve the safety of pedestrians for seniors. These findings can serve as inspiration for educational activities aimed at all age groups in our study, where we noted the need to increase pedestrians' awareness of the risks associated with using phones at crossings.

Article [26] compares the behaviour of children and adults when crossing the road in conditions of one- and two-lane traffic. Our study found that younger people are more likely to use mobile devices, which increases the risk of collisions at crossings, especially at busy intersections. The conclusions of both studies highlight the need to adapt prevention measures to different age groups.

The article [18] evaluated the effectiveness of visual and audible warning signals at crossings with traffic lights. Similarly, in articles [7, 17], virtual reality was used to test pedestrian behavior. Similar to our study, where we call for education and social campaigns, these interventions can help improve safety by increasing pedestrians' awareness of the risks.

The article [2] reviewed pedestrian speed and acceptance of traffic gaps in Asian countries. Our research also indicates that the use of phones influences pedestrians' decisions about crossings, but focuses on their behaviour at signalled crossings rather than in places without signals. The article [31] analyzed the behavior of pedestrians at unsignaled crossings using machine learning algorithms. Our study does not include algorithms, but it provides data on risky pedestrian behaviour at signalled crossings, which could provide a basis for the development of such technologies.

The article [30] presents a method for predicting pedestrian behavior when crossing the road using the MISO model. Unlike our study, which is based on direct observation, MISO enables automatic monitoring of groups of pedestrians, which can be a valuable complement to monitoring behavior at busy intersections. In the article [37], the impact of mobile phone usage on pedestrian crossing behavior was analyzed using video data collected from various intersections in Nanjing. Different types of distractions (e.g., voice calls, screen gazing, listening to music) as well as factors like age, gender, and companion presence were examined. The findings confirmed that phone usage increases accident risk, underscoring the

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need for measures to reduce pedestrian distraction. A paper [38] analyzed the effects of mobile phone distractions on pedestrians in Nanjing. Our results are consistent with Wang's findings, showing that phone use increases the risk of risky decisions at crossings. In addition, our study looks in detail at different forms of phone use, including hand-holding, active screen use, and the use of headphones, allowing for a deeper understanding of how different types of distraction affect pedestrian behavior.

In the article [1], the authors analyse the effectiveness of various warning signs at rail-pedestrian crossings. Similar to our research, which suggests the need for visual and audible warning signals for pedestrians using mobile devices, the results of this article indicate that appropriate signage can increase pedestrian awareness and improve their safety at crossings.

In the article [27], Osuret, et al. analyze the behavior of children at crossings in school zones in Uganda. Our study, like their analysis, points to the need for preventive measures, especially in places with heavy pedestrian traffic, such as intersections or school crossings, to reduce risky behaviour.

In the article [41], Yadav, et al. investigate the impact of smartphone distraction on pedestrian behavior in India. Our study found similar relationships between mobile use and an increase in the risk of risky behaviors at crossings. The authors' findings that men and younger people are more likely to take risks correspond with our observations, indicating the need for profiled safety campaigns.

6. Conclusions

Studies conducted in 2023 at five pedestrian crossings in Kielce revealed a significant increase in the number of pedestrians using mobile phones and other electronic devices while crossing the street. Compared to earlier ITS studies, where only 7% of pedestrians were using phones, current research indicates a dramatic rise in this behavior. At some crossings, the percentage ranged from 14% to as high as 60%, meaning the number of people engaging in risky behaviors has increased two to nine times. This trend can be attributed to the growing popularity of smartphones and various devices that work with them, such as wireless headphones.

One of the key findings of the study is that at certain crossroads, such as Solidarności Avenue and Świętokrzyska Street, the highest number of pedestrians using phones (69 people) and actively using phones while crossing (15 people) was recorded. In contrast, at the crossroads of Warszawska Street and Tysiąclecia Państwa Polskiego Avenue, 12 instances of crossing on a red light were observed, likely due to the short duration of the green light, which does not always allow pedestrians enough time to cross safely. The analysis also showed that pedestrians using mobile phones often step onto the crossing without proper attention, following

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the crowd, which increases the risk of dangerous situations. These pedestrians walk slower and do not pay attention to oncoming vehicles, potentially leading to collisions. These findings are consistent with previous research, which indicates that mobile device use at pedestrian crossings significantly reduces the ability to properly assess road conditions.

Another interesting conclusion is the decrease in the number of red-light crossings compared to ITS studies, where this rate was 7%. In 2023, this figure dropped to between 0.3% and 4%, possibly reflecting greater awareness of the dangers associated with crossing on a red light. However, the number of pedestrians stepping onto the crossing during the flashing green signal, often finishing their crossing on a red light, has increased. This occurred in 2% to 26% of cases, indicating the need for further educational efforts. The study also showed that the percentage of pedestrians using bicycles, electric scooters, or other personal transportation devices while crossing ranged from 13% to 30%. This is the first time such data has been collected, as previous ITS studies did not include this aspect. These figures highlight the need to consider new forms of mobility in road safety improvement strategies.

Based on data analysis from 2020–2023, the number of pedestrian-related accidents in Poland has decreased, but the percentage of incidents involving pedestrians entering crossings inappropriately has remained stable at around 19–20%. This suggests that despite overall improvement, the issue of inappropriate pedestrian behaviors, including mobile phone use, remains a significant challenge. It can be concluded that the rise in risky pedestrian behaviors at crossings can be partly attributed to the psychological effects of extending pedestrian right-of-way. This may lead to a false sense of security, where pedestrians assume that drivers bear full responsibility for their safety. Therefore, there is an urgent need to strengthen educational initiatives directed at pedestrians, emphasizing their responsibility for their own safety, especially when using mobile devices while crossing the street. Additionally, road infrastructure, including traffic signals, may need to be adjusted to better meet the real needs of pedestrians to reduce accident risks and improve overall road safety.

The research carried out on five pedestrian crossings in Kielce showed significant threats resulting from the use of mobile devices by pedestrians. The results highlight the impact of these devices on the behaviour of people crossing crossings and point to the need to implement measures to improve safety. There was an increase in the number of pedestrians using mobile devices. At selected crossings, up to 26% of pedestrians used a mobile phone or other electronic devices such as e-scooters, which affected their ability to judge the traffic situation and led to an increased risk of collisions.

A research novelty is the detailed division of pedestrians according to the way mobile devices are used. There were pedestrians holding a phone in their hand, talking on the phone, actively using the phone (staring at the screen, which limited their ability to observe the surroundings), using headphones and pedestrians on electric scooters. Thanks to this division, it is possible to analyse in more detail how various forms of using mobile devices affect the safety

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of pedestrians. Studies have shown that people who use phones were more likely to walk through a flashing green or even red light, which increased the risk of dangerous situations. In addition, pedestrians distracted by mobile devices moved more slowly, which affected their risk of remaining on the crossing when the traffic lights changed.

The research also showed differences in pedestrian behaviour depending on the location. At intersections with higher pedestrian traffic, especially in places with numerous retail and service outlets, a higher percentage of pedestrians using mobile devices was observed, which may be associated with various transport needs and a greater sense of time pressure.

The aim of the study was to investigate the impact of the use of mobile devices by pedestrians on their behavior at crossings with traffic lights and to assess the frequency of this phenomenon and risky behaviors associated with it. The tasks included observations at selected crossings and data analysis, taking into account the diversity in the ways of using mobile devices, which allowed to formulate recommendations for improving road safety.

The limitations of the study are the fact that it was carried out on a limited number of pedestrian crossings in one city, which may not reflect the nationwide situation. In addition, the lack of demographic structure in the form of data on the age and gender of pedestrians makes it impossible to more fully assess the impact of these factors on risky behavior. In addition, the research was limited to crossings with traffic lights; extending them to crossings without signalling could provide additional relevant information.

Currently, work is being carried out on an advanced machine learning algorithm that will enable the detection of pedestrians using mobile phones. Such a system, which would inform pedestrians about the need to put down their phone when crossing the road, would significantly contribute to improving safety. The introduction of this solution could reduce the risk of collisions resulting from distraction, which is crucial for the safety of pedestrians at crossings.

To better understand pedestrian behavior and assess the risks associated with mobile device use, the authors plan to conduct further studies focused on unsignalized pedestrian crossings. These crossings pose specific challenges for road safety, as the lack of signals forces pedestrians to independently assess the traffic situation. The planned research will specifically analyze the extent to which mobile phone users are more exposed to risk in such situations and what other factors may influence their behavior. The conclusions from these studies could provide valuable insights for the further development of road safety strategies and actions aimed at reducing the number of pedestrian-related accidents at unsignalized crossings.

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