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Review Article

Interventions for Increasing Pedestrian Visibility to Prevent Injury and Death: A Systematic Review

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Background: Pedestrian visibility is a critical factor in reducing the number of pedestrian accidents on roads. A review of pedestrian visibility literature may reveal different types of interventions that are feasible for promoting pedestrian visibility. Therefore, this study aimed to identify the interventions to increase pedestrian visibility.
Methods: A systematic search was conducted on electronic databases including PubMed, Scopus, and Google Scholar for full-text articles published from 2003 to December 17, 2023. All interventions used for pedestrians to increase their visibility were considered for the review.
Results: Our systematic search identified 13,472 records, of which 5749 duplicated articles were removed. The remaining 7723 records were initially screened on the basis of title and abstract. After full reading of 804 articles, finally, 14 articles were eligible to be included in the review. The strategies for the visibility of pedestrians were categorized based on the nature of strategies intervened on pedestrians, components, and benefits. The categorizations highlight a diverse range of strategies employed to enhance pedestrian visibility, including technological solutions, wearable, nonverbal communication, detection-based warnings, and educational interventions.
Conclusion: The diverse range of strategies explored in the reviewed studies underscores the multidimensional approach required to enhance pedestrian visibility and safety. It highlights the need for effective interventions to improve detection and recognition of pedestrians by drivers, which is crucial for reducing accidents. The findings suggest that a combination of technological advancements, wearables, nonverbal communication, detection-based warnings, and educational interventions can contribute to a safer pedestrian environment. However, further research is needed to assess the long-term effectiveness and real-world applicability of these strategies.

Keywords: intervention; pedestrian; traffic accident; visibility

1. Introduction

Road accidents continue to be a grave global concern as they lead to a staggering toll of over one million deaths and approximately 10 million permanent disabilities annually. Disturbingly, almost three-quarters of these tragic incidents unfold in low- and middle-income countries, where vulnerable pedestrians bear the brunt of the injuries [1, 2].

Pedestrian visibility is a critical factor in reducing the number of pedestrian accidents on roads. Despite the importance of this issue, it remains a significant problem in many parts of the world. Motorists often fail to detect pedestrians, especially in low light or inclement weather conditions [3]. This issue has triggered the implementation of various interventions to increase the visibility of pedestrians on roads [4].

One of the fundamental errors drivers commit that frequently result in accidents is their failure to detect pedestrians on the road in a timely manner. Such lapses become even more perilous at night due to the reduced visibility that puts pedestrians at a higher risk of injury or death [5]. Statistics reveal that over 60% of all pedestrian fatalities happen between the hours of 8:00 p.m. and 4:00 a.m., highlighting the dire consequences of poor visibility during these hours [5–7].

One of the earliest interventions to increase pedestrian visibility was the development of reflective materials [8]. For many years, reflective materials have been used on clothing, footwear, and other personal items to make pedestrians more visible to motorists [9, 10]. However, reflective materials alone are not always sufficient, particularly during daylight hours or in brightly lit urban areas [11].

The visibility of objects is influenced by several factors, including object contrast, size, motion, brightness, background, and road conditions. Drivers' cognitive responses in detecting these elements also play a significant role [12, 13]. The efficacy of visual aids relies on their ability to warn drivers in sufficient time to prevent collisions. Longer preimpact times and intervals provide a crucial opportunity to identify and avert potential dangers on the road [14, 15].

New interventions have been developed to increase pedestrian visibility during the day. One such intervention is the use of bright-colored clothing, such as neon yellow or orange, to make pedestrians more visible to drivers. Another approach involves the use of lighted crosswalks, which use flashing lights or light-emitting diode (LED) technology to signal to drivers that pedestrians are present [16, 17]. Other interventions have focused on increasing pedestrian visibility through environmental changes. It is important to clarify that visibility at locations where vehicle and pedestrian flows conflict is not merely an optional strategy; it is a legal requirement. The law mandates a minimum level of stop visibility for vehicle movements, which must be adhered to without exception. At intersections, visibility is assessed and established for all traffic flows and participants, representing a legal obligation grounded in traffic safety regulations. Therefore, while "daylighting" strategies can enhance visibility beyond the legal minimum, it is crucial to recognize that the baseline visibility requirements are prescribed by law [18].

Kwan and Mapstone conducted a systematic review of interventions for increasing pedestrian and cyclist visibility in 2002 [12]. They found that red and orange colors improve pedestrian detection and recognition in the daytime, whereas lamps, flashing lights, and retroreflective materials in red and yellow increase pedestrian detection and recognition at night.

In light of the advancements in technology and changing urban landscapes, a contemporary review of interventions aimed at enhancing pedestrian visibility is imperative. Although Kwan and Mapstone' study [9] in 2004 laid the foundation for understanding interventions to promote pedestrian visibility, the field has evolved significantly since then. New technologies, innovative urban planning strategies, and an increased emphasis on pedestrian safety necessitate an updated review. By synthesizing recent research, this review aims to provide an up-to-date assessment of the effectiveness of interventions to enhance pedestrian visibility.

1.1. Objectives. The primary objective of this review is to assess the effectiveness of interventions designed to enhance pedestrian visibility, thereby reducing injuries and fatalities among this vulnerable road user group. Additionally, the review aims to identify gaps in research, promote evidence-based practices, and address public health concerns. By focusing on these objectives, this study intends to make a significant contribution to the field of pedestrian safety and public health, advocating for systemic changes that prioritize pedestrian visibility.

2. Method

The study design followed the Preferred Reporting Items for Systematic Review and Meta-Analysis 2009 guidelines [19].

2.1. Information Sources and Search Strategy. Published literature in the English language was searched using a search strategy by Khabiri and Jahangiry. A systematic search was conducted on electronic databases including PubMed, Scopus, and Google Scholar for full-text articles published from 2003 to December 17, 2023. All the research results were imported into the EndNote library. A combination of keywords related to pedestrian visibility, interventions, injury prevention, and traffic safety was used. This includes terms like "pedestrian visibility," "traffic accidents," "intervention studies," and "safety measures."

2.2. Study Selection and Eligibility. After removing duplicate records, Khabiri and Jahangiry independently screened the titles and abstracts of the studies and disagreements resolved by consensus. Full text of the articles was retrieved and assessed for eligibility for inclusion in the review. Inclusion criteria were as follows: the interventions targeted pedestrians, published articles, and articles in English. Exclusion criteria were Review studies, letters to the editor, and abstracts presented at conferences (see Appendix).

2.3. Types of Interventions. All the interventions used for pedestrians to increase their visibility were considered for the review. All studies designed in randomized controlled trials, noncontrolled interventions, and before and after interventions were considered as intervention criteria. All types of nighttime and daytime visibility interventions on pedestrians were reviewed.

2.4. Data Extraction. The general characteristics of the studies were extracted by the two authors (Khabiri and Jahangiry) and include the following: author, year, country, study design, sample size, age of participants, measurements, findings, type of intervention, and duration of the intervention. Quality assessment was not included in this information due to the variety of study types and the numerous approaches to quality measurement.

3. Results

3.1. Studies' Characteristics. Our systematic search identified 13,472 records, of which 5749 duplicated articles were removed, and 7723 records were initially screened on the basis of title and abstract. After full reading of 804 articles, 14 articles were considered eligible to be included in the review (see Figure 1). The general characteristics of the studies are presented in Table 1. Fourteen studies with 2190 participants were included in the review. One study was from Korea [20], two from France [21, 23], four from the United States [3, 14, 22, 27], one from Qatar [24], one from Canada [25], two from Australia [26, 29], and one from Germany [17].

3.2. Characteristics of the Interventions for Pedestrian Visibility Based on the Nature of the Strategies for Enhancing Pedestrian Visibility. The strategies for enhancing pedestrian visibility were categorized according to the nature of the intervention strategies, components, and benefits. The categorizations highlight a diverse range of strategies employed to enhance pedestrian visibility, including technological solutions, wearables, nonverbal communication, detection-based warnings, and educational interventions. Each strategy addresses specific aspects of pedestrian safety and contributes to the overall goal of preventing accidents and improving road safety (see Table 2).

3.2.1. Smart Glasses–Based Personnel Proximity Warning System [20].

Strategy: Utilizing smart glasses with Bluetooth beacons attached to heavy equipment to provide real-time proximity warnings to workers [20].

Components: Bluetooth beacons, smart glasses.

Benefits: Hands-free operation, potential for additional functionalities.

This article described an intervention involving smart glasses as part of a system utilizing Bluetooth beacons attached to heavy equipment or vehicles to transmit signals to the smart glasses worn by workers. The proximity of the equipment or vehicle was determined by the signal strength, and a visual alert was displayed to the wearer when they were in close proximity to heavy equipment or vehicles. The use of smart glasses allowed the workers to keep their hands-free while they received alerts, which could enhance work efficiency. The system also offered the potential for supporting various other functions through application development. The results showed that there was a detection distance of at least 10 m regardless of the direction in which the worker was looking. The alert was successful in all 40 trials at distances of 10 m or more [20]. The smart glasses–based personnel proximity warning system shows promise for improving safety on construction and mining sites [20].

3.2.2. Vibrotactile Wristband for Older Pedestrians to Assist Them in Making Safer Street-Crossing Decisions [21].

Strategy: Wearable device to assist in making safer street-crossing decisions.

Components: Vibrotactile wristband.

Benefits: Significant decrease in collision risks, well received by users.

The article described an intervention using a vibrotactile wristband to assist older pedestrians in making safer street-crossing decisions [21]. The purpose of the intervention was to assess the effectiveness of the wristband in reducing collision risks and improving pedestrian behavior. The study involved three groups of participants: younger senior participants (60–69 years), older senior participants (70–80 years), and younger adults (20–45 years). The participants performed a street-crossing task in a simulated two-way traffic environment both while wearing and not wearing the vibrotactile wristband. The wristband delivered warning messages to the participants. The results of the study showed that wearing the wristband led to a significant decrease in the percentage of decisions that resulted in collisions with approaching cars. The benefits of the wristband were particularly noticeable among women in the older senior group, who had fewer collisions in the far lane and when vehicles approached rapidly. However, it should be noted that collisions still occurred, and correspondence between participants' responses and the wristband's advice was only around 51.6% on average. The practical application of this haptic device is that it can partially compensate for age-related gap-acceptance difficulties and reduce street-crossing risks for all users. The findings of the study could benefit the design of devices allowing communication between vehicles, infrastructure, and pedestrians [21].

3.2.3. A Driver's Behavior in Response to a Smiling Pedestrian [23].

Strategy: Nonverbal communication (smiling) for a positive impact on driver behavior.

Components: Pedestrian's facial expression [23].

Benefits: Increased number of drivers stopping, slower driving speeds.

Findings regarding the effect of a pedestrian's smile on drivers' behavior were presented and the positive impact of smiling on driving behavior, such as the increase in the number of drivers who stopped and drove slower, were discussed [23]. The researchers conducted several experiments to evaluate how seeing a smile influences a driver's decision to stop and their driving speed. In the first part of the study, male and female research assistants were

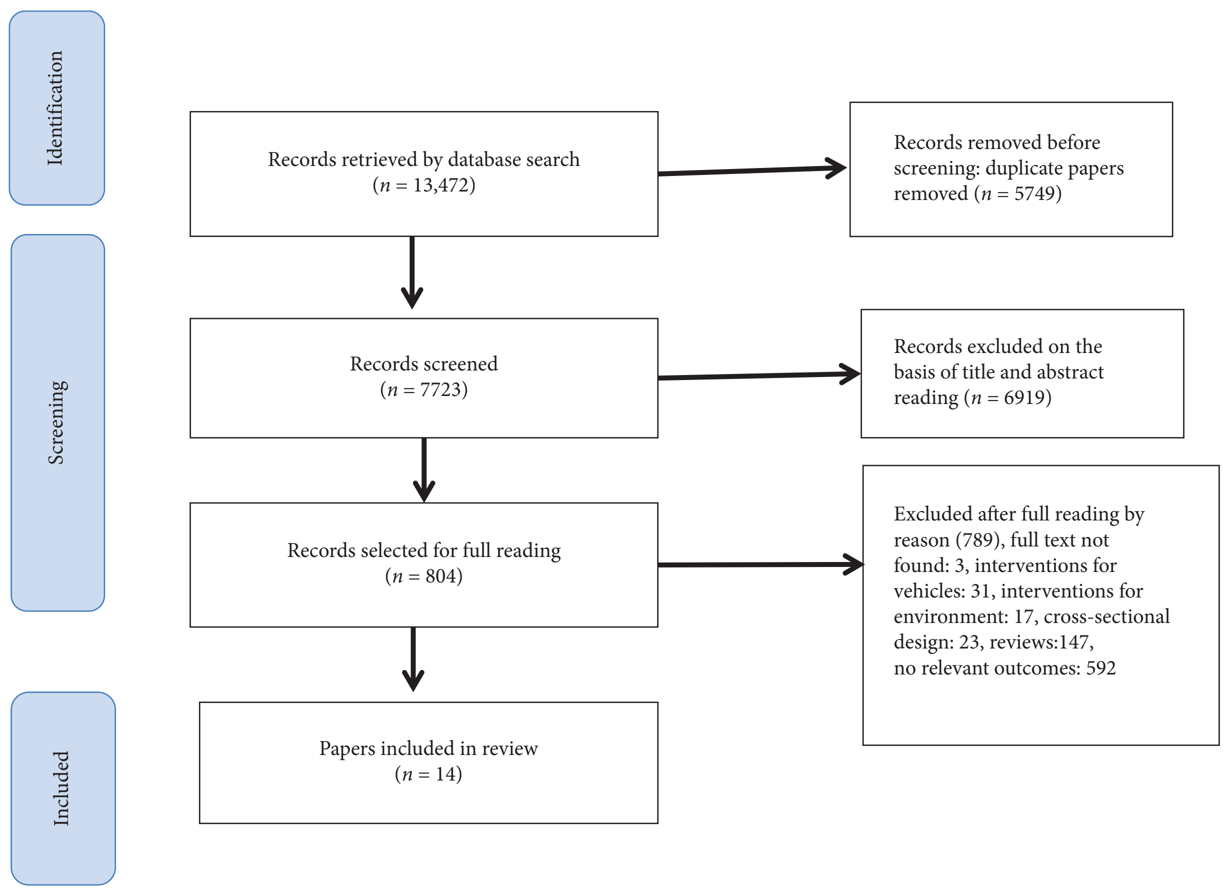

Figure 1: Study selection process.

positioned at various pedestrian crossings and were instructed to either smile or not smile at oncoming drivers. The results showed that when the research assistants smiled, there was an increase in the number of drivers who stopped at the pedestrian crossings. The same effect was observed when a pedestrian attempted to cross outside of the designated pedestrian crossing. Furthermore, the study found that after witnessing a pedestrian smile, motorists tended to drive slower, indicating that a smile can induce a positive mood in a motorist and lead to more careful driving behavior [23].

3.2.4. Detection-Based Warning Strategies for Pedestrian Visibility [24].

Strategy: Implementing detection-based warning systems.

Components: LED lights and variable message signs (VMSs).

Benefits: Increased yielding rates and reduced vehicle–pedestrian conflicts.

The effects of detection-based warning strategies on pedestrian visibility and vehicle yielding behavior at uncontrolled midblock crosswalks were assessed in Qatar [24]. The authors conducted a driving simulation experiment at Qatar University involving 67 volunteers with a valid Qatari driving license. In the experiment, an untreated condition (Control) was compared with three treatment conditions: an advanced VMS, and LED lights. Each condition was tested with a yield/stop controlled, marked crosswalk in the presence and absence of a pedestrian. Several analyses were performed to evaluate pedestrian visibility and driving behavior, including vehicle–pedestrian interactions, driving speed, acceleration/deceleration variations, and lateral position. The results of the study demonstrated that both the LED and VMS conditions were effective in increasing yielding rates by up to 98.4% and in significantly reducing vehicle–pedestrian conflicts. These treatments also motivated drivers to reduce their speed in advance [24].

3.2.5. In-Ground Flashing LED Lights for Distracted Pedestrians [26].

Strategy: In-ground flashing lights to attract distracted pedestrians' attention.

Components: In-ground flashing LED lights.

Benefits: Effective in capturing distracted pedestrians' attention.

The researchers conducted a controlled laboratory study with 24 participants to assess distracted pedestrians' detection of flashing LED lights by using eye gaze movements recorded by an eye tracker and behavioral responses

Table 1: Summary of studies.

First author	Year	Country	Study design	Sample size	Age of participants
Baek and Choi [20]	2020	South Korea	Developing a wearable personnel proximity warning system	—	—
Cœugnet, Dommes, and Panëels [21]	2017	France	Assessing the effectiveness of a vibrotactile device and studying older pedestrians' behavior when wearing a wristband designed to help them make safer street-crossing decisions	57	60–80 years
Fitzpatrick and Park [22]	2021	USA	Evaluating pedestrian crossing treatments including pedestrian hybrid beacon (PHB), rectangular rapid flashing beacon (RRFB), or LED-embedded crossing warning sign (LED-Em)	—	—
Guéguen, Eyssartier, and Meineri [23]	2016	France	A smile influences an oncoming driver's behavior	1600 drivers (889 men and 711 women)	20–70 years
Hussain et al. [24]	2021	Qatar	Two treatment groups and one control group design	67 pedestrian	19–58 years
Huybers, Van Houten, and Malenfant [25]	2004	Canada	A series of experiments	—	—
Larue et al. [26]	2020	Australia	A controlled laboratory study ($N = 24$)	—	30.4
Lehsing et al. [17]	2019	Germany	Wore safety goggles with diffusing filters	24	31
Mulvaney et al. [13]	2006	UK	Cluster randomized controlled trial	377 children	7–9 years
Sayer and Buonarosa [14]	2008	USA	Stimulated field study	17 drivers	69.8
Sayer and Mefford [3]	2004	USA	Stimulated field study	—	—
Schwebel et al. [27]	2021	USA	Intervention program	385	—
Tyrrell, Patton, and Brooks [28]	2004	Czech republic	A mixed-methods design	48	19 years
Wood et al. [29]	2015	Australia	Improving pedestrian conspicuity with clothing	24	24.9 years

Table 2: Summary of key findings and health promotion strategies in interventions.

First author	Measurements	Findings	Type of intervention	Duration
Baek and Choi [20]	Proximity determined by the signal strength through Bluetooth	A visual alert was displayed to the smart glasses wearer when in proximity. Mental, temporal, and physical stress was the lowest when using the system	Smart glasses–based personnel proximity warning system	—
Cœugnet, Dommes, and Panëels [21]	A vibrotactile wristband	The percentage of decisions that led to collisions with approaching cars decreased significantly when participants wore the wristband	Comparison of older pedestrian behavior with and without a vibrotactile wristband delivering warning messages	—
Fitzpatrick and Park [22]	Driver yielding, the individual driver response to the crossing pedestrian	The PHB was found to be highly effective during the nighttime and the daytime	Statistical evaluations were used on the staged pedestrian data in pedestrian hybrid beacon (PHB), rectangular rapid flashing beacon (RRFB), or LED-embedded crossing warning sign (LED-Em).	—
Guéguen, Eyssartier, and Meineri [23]	Pedestrian smiles and drivers' stop	A smile increased the number of drivers who stopped. The same effect was observed when the pedestrian tried to cross outside the pedestrian crossing	Asking pedestrians to smile at oncoming drivers when crossing	—
Hussain et al. [24]	Drivers' alertness and yielding behavior	The results showed that both the LED and VMS conditions were helpful in increasing yielding rates up to 98.4% and in reducing vehicle–pedestrian conflicts significantly	Eight marked crosswalks were designed for both targeted situations (i.e., PA situation and PP situation). In the PA situation, the crosswalks were designed without any pedestrian, while in the PP situation, a pedestrian was approaching the crosswalk at a constant speed of approximately 5 km/h	—
Huybers, Van Houten, and Malenfant [25]	The effects of a symbolic "yield here to pedestrians" sign and advance yield pavement markings on pedestrian/motor vehicle conflicts, motorists' yielding behavior, and the distance motorists' yield in advance of crosswalks	In Experiment 1, the sign, when used alone, reduced pedestrian–motor vehicle conflicts and increased motorist yielding distance. Advance yield pavement markings, when used alone, were as effective in reducing pedestrian–motor vehicle conflicts and increasing yielding distance	A symbolic "yield here to pedestrians" sign and advance yield pavement markings on pedestrian–motor vehicle conflicts, motorists' yielding behavior, and the distance motorists' yielded in advance of crosswalks	—
Larue et al. [26]	Eye gaze movements via an eye tracker and behavioral responses via response times assessed the detection of flashing LED lights	Distracted participants were able to detect the activation of the floor and wall-mounted LED lights with over 90% accuracy	Illuminated in-ground LED lights embedded in pathways	—
Lehsing et al. [17]	Simulated vision impairment	At crossings with interactive pedestrians, the behavior adaptation between the driver and the pedestrian took longer and was less correlated in contrast to the situations with noninteractive pedestrians	Mild vision loss in interactions between drivers and human-controlled, interactive pedestrians	—
Mulvaney et al. [13]	Wearing of reflective or fluorescent items	Providing free visibility aids and an educational booklet on road safety significantly increased the use of visibility aids	A reflective and fluorescent slap wrap (an item that can be worn around an arm or trouser leg and is readily removable) and a reflective durable sticker, in addition to educational material on the importance of being seen in the dark	8 weeks

Table 2: Continued.

First author	Measurements	Findings	Type of intervention	Duration
Sayer and Buonarosa [14]	Characteristics of high-visibility safety garments that make them effective for daytime use	Detection distances between fluorescent yellow-green and fluorescent red-orange garments were not significantly different, nor were there any significant two-way interactions involving garment color. Pedestrians were detected at longer distances in lower complexity scenes. Arm motion significantly increased detection distances for pedestrians wearing a Class 2 vest but had little added benefit to detection distances for pedestrians wearing a Class 2 jacket	Effects of garment color (fluorescent yellow-green or fluorescent red-orange), the amount of background material (vest or jacket), pedestrian arm motion (moving or stationary), scene complexity (low or medium), and driver age (younger or older) on the conspicuity of personal safety garments	—
Sayer and Mefford [3]	Detect pedestrians	The configuration of the retroreflective trim, trim color, placement in the work zone, and driver age significantly affected pedestrian conspicuity. The intensity and the amount of retroreflective trim did not	Using instrumented vehicles on a closed track, participants drove through simulated work zones attempting to detect pedestrians located in the work zones with retroreflective personal safety garments	—
Schwebel et al. [27]	Crossings during	In a model stratified by phone/warning type and baseline distraction rates, Android phone users who received a warning that blocked the full screen and had a high baseline distraction rate (≥ 75% distracted crossings) had 64% decreased odds of distraction during the alert phase (OR 0.36, 95% CI 0.25–0.51) and 52% decreased odds of distraction during the postintervention phase (OR 0.48, 95% CI 0.25–0.94)	Mobile phone application alerts distracted pedestrians directly.	3 weeks
Tyrrell [28]	Describe pedestrian–driver encounters, communication, and decision strategies at marked but unsignalized crossings in urban areas and how the parties involved experience and handle these encounters	Participants failed to appreciate the benefits of reflective clothing and of high-beam illumination	Visibility was influenced by educational interventions, clothing reflectance, and the headlamp beam setting	—
Wood et al. [29]	Pedestrian recognition distances were recorded for each blur and pedestrian clothing combination while participants drove an instrumented vehicle around a closed road course	Recognition distances for pedestrians were significantly reduced	Pedestrians had one of three clothing conditions: everyday clothing, a retroreflective vest, and retroreflective tape positioned on the extremities in a configuration that conveyed biological motion	—

measured by response times. The LED lights were positioned on the floor and on the wall to compare their effectiveness in attracting attention. The results of the study showed that distracted participants were able to detect the activation of both floor and wall-mounted LED lights with over 90% accuracy. The distraction tasks, both visual and auditory, increased reaction times. However, even when distracted, participants showed improved performance with floor LED lights located closer to them, resulting in shorter reaction times [26].

3.2.6. Simulated Mild Vision Loss for Driver–Pedestrian Interactions [17].

Strategy: Simulating vision impairment to study driver–pedestrian interactions.

Components: Diffusing filters for visual acuity reduction.

Benefits: Minimal adverse effects on safety, time series analysis for behavior adaptation [17].

The study focused on interactions between drivers and pedestrians at pedestrian crossings with the aim of evaluating the effects of simulated mild vision loss on these interactions. The study highlighted the importance of visual cues and gaze in driver–pedestrian interactions, but it did not explicitly address pedestrian visibility as a separate variable. The study did indirectly consider visibility by simulating mild vision impairment in the drivers. The results indicated that simulated vision impairment affected the time it took for drivers to fixate on pedestrians, suggesting a potential impact on visibility [17].

3.2.7. Retroreflectors and Visibility Aids for Pedestrians [13, 30].

Strategy: Using retroreflective materials and providing free visibility aids.

Components: Retroreflectors on clothing, reflective slap wrap, and reflective sticker.

Benefits: Increased use of visibility aids among children and improved pedestrian conspicuity in work zones.

This was an intervention study aimed at investigating the potential effects of retroreflector positioning on motorists' recognition of pedestrians at night when they wore a vertically attached retroreflective stripe on both shoulders, one going around the body at mid-torso, and wrists and ankles with six retroreflective [30]. Each pedestrian wore a black sweat suit with black socks and shoes. The results showed that each retroreflector configuration yielded significantly longer recognition distances than the no-retroreflector configuration. More importantly, the retroreflective markings attached to the limbs led to significantly longer (about 60%–80%) recognition distances compared to the retroreflective markings attached to the torso [30]. The effectiveness of providing free visibility aids to increase visibility among primary school children was assessed in a randomized controlled trial [13]. Children in the intervention group received two visibility aids, a reflective and fluorescent slap wrap and a durable reflective sticker, along with educational material on the importance of being seen in the dark. Observers visited schools at baseline as well as 1 and 8 weeks after the visibility aids were distributed to monitor their use. The children provided with free visibility aids were significantly more likely to use any visibility aid at 1 week (adjusted OR 59.5, 95% CI 18.5–19.0) and 8 weeks (adjusted OR 5.9, 95% CI 3.4–10.4) after distribution compared to children in the control group.

3.2.8. High-Visibility Garments and Factors Influencing to Be Visible [3, 14]. The study recognized the problem of occupational fatalities occurring when pedestrians are struck by vehicles in work zones, particularly when the vehicles are not associated with the work being performed [3]. The researchers conducted a field study using instrumented vehicles on a closed track to evaluate the effects of various attributes of retroreflective trim on pedestrian conspicuity at night.

Drivers participated in the study by driving two passes on a 31-km route and indicating when they detected pedestrians wearing fluorescent garments [14]. The locations of the vehicle and the pedestrians were recorded to measure the detection distances. The results of the study indicated no significant differences in detection distances when fluorescent yellow-green versus fluorescent red-orange garments were worn. Garment color did not have any significant two-way interactions. Arm motion had a significant impact on detection distances for pedestrians wearing a Class 2 vest but had little additional benefit for pedestrians wearing a Class 2 jacket [14].

3.2.9. Pedestrian Visibility Educational Interventions

Strategy: Educational programs to address pedestrians' overestimation of their visibility.

Components: Lectures, demonstrations, and reflective clothing.

Benefits: Reduction in overestimation of visibility, potential for safer behavior.

The study comprised two experiments involving participants estimating their own nighttime visibility while walking toward a stationary car until they believed they were just discernible [31]. In Experiment 1, 48 university students were divided into four groups: lecture, demo, combo (lecture + demo), and control. The lecture group received a guest lecture on applied visual physiology; the demo group watched a demonstration on nighttime pedestrian visibility; the combo group received both the lecture and the demonstration; and the control group received no intervention. The results of Experiment 1 showed that participants who had heard the lecture several weeks earlier (lecture group) provided visibility estimates that were 10% shorter than the control group, indicating a slight improvement. In Experiment 2, nine students taking driver education were tested using a more focused and graphic-intensive lecture. The participants in this experiment gave visibility estimates that were 56% shorter than the control group, suggesting a more substantial improvement [31]. The study found that overall, participants failed to recognize the benefits of wearing reflective clothing and using high-beam illumination to enhance their visibility at night. However, the educational interventions had a positive impact on reducing pedestrians' overestimates of their own nighttime visibility [31].

The researchers recognized that pedestrians' overconfidence in their visibility could lead to dangerous behaviors and increased the risk of accidents. Therefore, they sought to explore potential approaches to increase pedestrian safety at night.

The study highlighted the importance of public education campaigns in increasing pedestrian safety and addressing the issue of inconspicuous pedestrians at night. It emphasized the need to inform pedestrians about their limited visibility and promote the use of reflective clothing to enhance pedestrian visibility to drivers [31].

4. Discussion

The systematic search and review process uncovered 13,472 records, of which 14 articles were eligible for inclusion to provide a comprehensive overview of strategies for pedestrian visibility. The studies covered diverse geographical locations, including South Korea, France, the United States, Qatar, Canada, Australia, and Germany, reflecting a global perspective on pedestrian safety [17–24, 27].

The strategies for enhancing pedestrian visibility were categorized into various interventions, each addressing specific aspects of safety. Regarding technological solutions, the smart glasses–based personnel proximity warning system utilized Bluetooth beacons to deliver real-time proximity warnings to workers [17]. Wearable devices, like the vibrotactile wristband for older pedestrians, were introduced to facilitate safer street-crossing decisions, demonstrating a significant decrease in collision risks [18]. Furthermore, nonverbal communication, specifically a pedestrian's smile, was investigated for its positive impact on drivers' behavior, resulting in an increase in drivers stopping and slower driving speeds [19].

Detection-based warning strategies were explored with LED lights and VMS, leading to improved yielding rates and a reduction in vehicle–pedestrian conflicts [23]. In-ground flashing LED lights targeted distracted pedestrians, effectively capturing their attention and potentially enhancing overall safety [24]. Simulated mild vision loss in driver–pedestrian interactions demonstrated minimal adverse effects on safety, emphasizing the adaptability of behavior in such scenarios [14]. Research indicates that environmental factors significantly contribute to pedestrian accidents at intersections. For instance, Lee and Abdel-Aty's study highlights [32] that darkness is a key factor leading to such incidents. This finding aligns with research by Siddiqui, Chu, and Guttenplan [33], which reveals that the likelihood of pedestrian accidents increases by 42% in foggy conditions, assuming other variables remain constant. These studies underscore the importance of adequate lighting at intersections, especially during low-visibility conditions like darkness and fog. Improved lighting can enhance visibility for both drivers and pedestrians, potentially reducing the risk of accidents. Therefore, investing in enhanced street lighting and visibility measures at intersections could be a critical strategy for improving pedestrian safety in adverse weather conditions.

Regarding strategies focused on specific demographics, free retroreflectors and visibility aids were offered to primary schoolchildren, and their use significantly increased for up to 8 weeks during winter [10]. In another study, retroreflective trim on personal safety garments in work zones significantly improved pedestrian conspicuity, emphasizing the importance of garment design attributes [2]. Factors influencing pedestrian visibility including garment color and background material were studied to enhance the understanding of high-visibility safety garment effectiveness [11]. In a study, Owens et al. concluded that nighttime pedestrian detection was significantly enhanced by reflective limb joint cues compared to upper body cues, and this benefit was greater for middle-aged and older drivers [34].

Educational interventions targeting pedestrians' overestimation of their visibility demonstrated positive outcomes [25]. This highlights the potential of educational programs, including lectures, demonstrations, and reflective clothing, in fostering safer pedestrian behavior [29]. The researchers suggested that implementing research-based public education campaigns could help to increase pedestrian safety by addressing these overestimates and promoting the use of reflective materials. Providing information and raising awareness of the limitations of pedestrian visibility can encourage safer behavior and enhance pedestrian safety in low-light conditions [29].

While traffic advertisements alone can yield positive effects on road safety behaviors, their effectiveness is significantly amplified when combined with other preventive measures such as legislation or road safety education [35]. This aligns with the existing literature that emphasizes the necessity of a multifaceted approach to enhance the impact of communication campaigns. For instance, Zhang et al. [36] evaluated the effectiveness of the USF Bull Walk and Bike Campaign, a university-based pedestrian safety training program. Their study reported an increase in driver surrender behavior from 6.6% to 12.8% following the campaign, demonstrating that educational initiatives can lead to measurable improvements in safety behavior among road users. This suggests that integrating educational elements into traffic campaigns can foster a more significant shift in public attitudes and behaviors.

Furthermore, Hoye and Laureshyn investigated the "SeeMe" campaign in Norway, which aimed to influence both pedestrian and driver behaviors [37]. Their results indicated a 14% increase in the yielding behavior of drivers at pedestrian crossings. This finding underscores the potential of well-designed communication campaigns to create immediate behavioral changes in road users, particularly when they are part of broader educational efforts. These studies collectively suggest that incorporating road safety education into communication campaigns not only enhances their effectiveness but also addresses the underlying behavioral patterns that contribute to traffic incidents.

Systems have been designed to provide real-time alerts to workers, allow for hands-free operation, and have the potential for further development and functionality [20]. The practical application of haptic devices is that they can partially compensate for age-related gap-acceptance difficulties and reduce street-crossing risks for all users [38]. The design of devices allowing communication between vehicles, infrastructure, and pedestrians could benefit from these findings [21]. There are challenges in this field that must be addressed. One significant issue is the acceptance rate, as the effectiveness of bilateral systems relies on widespread buy-in from drivers and pedestrians. If only a small percentage participates, the system's efficiency diminishes. Additionally, high latency in data transmission can delay alerts, potentially resulting in accidents. To mitigate these delays, ongoing improvement in communication technologies is essential. It is also important to recognize that not all pedestrians may have access to compatible devices, which could limit the effectiveness of app-based warning systems [39].

Furthermore, a smile from a pedestrian can contribute to increased safety by encouraging motorists to stop more readily and drive more cautiously. The study regarding pedestrians' smiling also highlights the importance of appropriate nonverbal signals from pedestrians to drivers in enhancing safety. The article mentions the high number of pedestrian fatalities in road accidents, particularly at pedestrian crossings, and the need for drivers to give priority to pedestrians in accordance with traffic regulations. The study suggests that the absence of road markings and visibility issues may contribute to drivers' failure to stop for pedestrians in France [23]. Although several engineering countermeasures (such as traffic signs, traffic sign control, pavement markings, and road geometry) can be used to increase safety through implementation, pedestrian and driver behavior play a critical role in crash risk [40–42].

LED lights and VMS may be effective solutions to improve safety at yield/stop-controlled crosswalks. Although the study focused on the impact of detection-based warning strategies on vehicle yielding behavior, it indirectly addressed pedestrian visibility. The implementation of LED lights and VMS increased drivers' awareness of the presence of pedestrians, leading to improved yielding behavior. However, the study did not involve specifically analyzing the visibility of pedestrians under different conditions or lighting conditions. To assess pedestrian visibility, additional research specifically targeting visibility factors, such as lighting conditions, weather conditions, and pedestrian clothing, could be conducted. This would provide a more thorough understanding of how visibility influences driver behavior and pedestrian safety at uncontrolled midblock crosswalks [24].

The use of LED lights embedded in pathways, particularly in-ground LED lights, is likely to be effective in capturing the attention of distracted pedestrians. However, the study acknowledges the need for further research in real-world conditions to confirm these findings and assess the actual effects on pedestrian behavior [26].

Research suggests that campaigns that involve providing free visibility aids to primary school children should be encouraged. The findings highlight the importance of promoting visibility and road safety measures to reduce child pedestrian and cyclist injuries [13].

Numerous countries have taken some pedestrian safety measures including safe speed restrictions on pedestrian, speed management infrastructure, and safer facilities for pedestrians on intersections, for example, road narrowing, speed hogs, and speed limit 20 km per hour for residential streets in Switzerland and speed tables approached the pedestrian crossing in Senegal [43]. Speed management infrastructure, such as speed hits; pedestrian crossings that create 20 times the chances of drivers' surrender to pedestrians [44]; and well-designed long standings are the best system (and most sustainable).

Interventions for increasing pedestrian visibility on roads have evolved over time and have been implemented in various forms. As there is no single solution to this complex issue, a combination of strategies is needed to ensure that pedestrians are safe and visible on roads.

One limitation of this review is that the quality assessment of the included studies was not incorporated into the extracted information. This omission arose from the diverse range of study types and the varying approaches to quality measurement utilized across the studies reviewed. In addition, the exclusion of the increase in pedestrian visibility at intersections from the analysis is primarily due to the variability in reported outcomes across the interventions studied. While enhancing pedestrian visibility is critical, the results of these interventions were not consistent enough to be pooled for the results in the meta-analysis. Each study employed different methodologies and metrics for measuring visibility, which limited our ability to draw a cohesive conclusion. In addition, we were unable to measure bias within the scope of this review, which may affect the overall interpretation of the findings. In our study, we specifically focus on the secondary network, which includes residential areas and zones with high pedestrian activity, characterized by lower vehicle speeds and volumes. The design principles and traffic flow management strategies in this network are distinct from those of the primary network, where higher speeds and greater vehicle density often necessitate spatial or temporal separation between pedestrians and vehicles. Additionally, detecting intervention zones in the studies reviewed was challenging, as many included studies did not provide clear or consistent definitions of these zones. This limitation affected our ability to analyze the effectiveness of interventions comprehensively.

5. Conclusion

The diverse range of strategies explored in the reviewed studies underscores the multidimensional approach required to enhance pedestrian visibility and safety. It highlights the need for effective interventions to improve detection and recognition of pedestrians by drivers, which is crucial for reducing accidents. From advanced technological solutions to targeted interventions for specific age groups, each strategy contributes to the overarching goal of reducing accidents and improving road safety. The findings suggest that a combination of technological advancements, wearables, nonverbal communication, detection-based warnings, and educational interventions can contribute to a safer pedestrian environment. However, further research is needed to assess the long-term effectiveness and real-world applicability of these strategies.

Appendix A: Reasearch Strategy for Inteventions for Increasing Pedestrian Visibility

Search: ((“intervention s” [All Fields] OR “interventions” [All Fields] OR “interventive” [All Fields] OR “methods” [MeSH Terms] OR “methods” [All Fields] OR “intervention” [All Fields] OR “interventional” [All Fields] OR (“program” [All Fields] OR “program s” [All Fields] OR “programe” [All Fields] OR “programed” [All Fields] OR “programes” [All Fields] OR “programing” [All Fields] OR “programmability” [All Fields] OR “programmable” [All Fields] OR “programmably” [All Fields] OR “programme” [All Fields] OR “programme s” [All Fields] OR “programmed” [All Fields] OR “programmer” [All Fields] OR “programmer s” [All Fields] OR “programmers” [All Fields] OR “programmes” [All Fields] OR “programming” [All Fields] OR “programmings” [All Fields] OR “programs” [All Fields]) OR (“clinical trials as topic” [MeSH Terms] OR (“clinical” [All Fields] AND “trials” [All Fields] AND “topic” [All Fields]) OR “clinical trials as topic” [All Fields] OR “trial” [All Fields] OR “trial s” [All Fields] OR “trialed” [All Fields] OR “trialing” [All Fields] OR “trials” [All Fields])) AND (“observability” [All Fields] OR “observable” [All Fields] OR “observables” [All Fields] OR “observation” [MeSH Terms] OR “observation” [All Fields] OR “observe” [All Fields] OR “observed” [All Fields] OR “observer” [All Fields] OR “observer s” [All Fields] OR “observers” [All Fields] OR “observes” [All Fields] OR “observing” [All Fields] OR “watchful waiting” [MeSH Terms] OR (“watchful” [All Fields] AND “waiting” [All Fields]) OR “watchful waiting” [All Fields] OR “observations” [All Fields] OR (“visual” [All Fields] OR “visualisation” [All Fields] OR “visualisations” [All Fields] OR “visualise” [All Fields] OR “visualised” [All Fields] OR “visualises” [All Fields] OR “visualising” [All Fields] OR “visualization” [All Fields] OR “visualizations” [All Fields] OR “visualize” [All Fields] OR “visualized” [All Fields] OR “visualizer” [All Fields] OR “visualizers” [All Fields] OR “visualizes” [All Fields] OR “visualizing” [All Fields] OR “visually” [All Fields] OR “visuals” [All Fields])) AND

Search strategy

(“walked” [All Fields] OR “walking” [MeSH Terms] OR “walking” [All Fields] OR “walks” [All Fields] OR (“pedestrian s” [All Fields] OR “pedestrians” [MeSH Terms] OR “pedestrians” [All Fields] OR “pedestrian” [All Fields])) AND (“warned” [All Fields] OR “warning” [All Fields] OR “warnings” [All Fields] OR “warns” [All Fields] OR “daytime-running” [All Fields] OR “flash*” [All Fields] OR “blink*” [All Fields] OR “color*” [All Fields] OR “yellow*” [All Fields] OR (“sign” [Journal] OR “sign” [All Fields]) OR (“lamp” [Journal] OR “lamp” [All Fields]) OR “contrast*” [All Fields] OR “reflect*” [All Fields] OR (“retro” [All Fields] AND (“reflect” [All Fields] OR “reflectance” [All Fields] OR “reflectances” [All Fields] OR “reflected” [All Fields] OR “reflecting” [All Fields] OR “reflection” [All Fields] OR “reflections” [All Fields] OR “reflective” [All Fields] OR “reflectively” [All Fields] OR “reflectiveness” [All Fields] OR “reflectives” [All Fields] OR “reflectivities” [All Fields] OR “reflectivity” [All Fields] OR “reflects” [All Fields])) OR (“fluoresce” [All Fields] OR “fluoresced” [All Fields] OR “fluorescence” [MeSH Terms] OR “fluorescence” [All Fields] OR “fluorescences” [All Fields] OR “fluorescent” [All Fields] OR “fluorescently” [All Fields] OR “fluorescents” [All Fields] OR “fluoresces” [All Fields] OR “fluorescing” [All Fields])))

Data Availability Statement

The data collection tools and datasets generated and/or analyzed during the current study are available from the corresponding author upon reasonable request.

Ethics Statement

The study received ethical approval from the Ethics Committee of Tabriz University of Medical Sciences (No.: IR.TBZMED.REC.1400.1231). All methods were performed in accordance with the ethical standards. Written informed consent was obtained from all participants.

Consent

Please see the Ethics Statement.

Conflicts of Interest

The authors declare no conflicts of interest.

Author Contributions

L.J. was responsible for the study design. R.K. and L.J. did the screening. R.K., L.J., H.R.B., and H.S.-b. were responsible for data interpretation. R.K., L.J., and H.R.B. conducted the drafting of the manuscript. All authors have read and approved the final manuscript.

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