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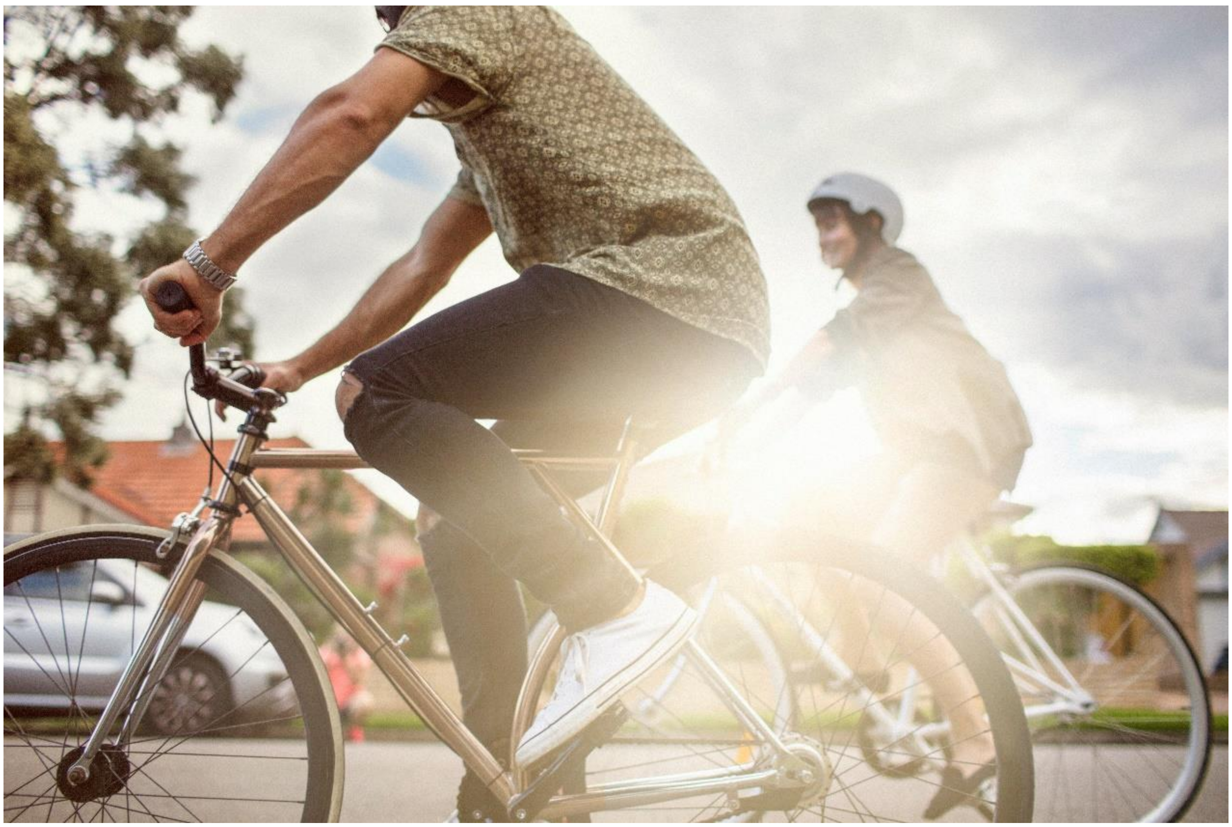
EVIDENCE BRIEF

Effectiveness of Engineering Interventions on Road Safety



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Key Messages

- Ontario has a high burden of injury due to motor vehicle collisions; improvements to existing built environment infrastructure could help decrease this burden.
- Understanding the effectiveness of engineering interventions, one of the 'Three E's' of injury prevention (enforcement, education, and engineering) is an important part of informing infrastructure development and re-development for road safety.
- Engineering interventions are effective in reducing motor vehicle collisions and making the roads safer for vulnerable populations.
- Several engineering interventions (built environment interventions) such as red-light cameras, dynamic speed feedback signs, roundabouts, and cycling infrastructure decrease motor vehicle collision rates.

Issue and Research Question

Injuries due to motor vehicle collisions (MVCs) are of significant public health concern in Ontario. The rate of collisions in the province has increased over time from 586.7 per 100,000 population in 2012 to 600.8 per 100,000 population in 2019, despite efforts across sectors in Ontario to reduce the burden. Lower rates of MVCs were observed in 2020 and 2021; however, these rates are likely artificial decreases due to the reduction in MV traffic and volume observed during the COVID-19 pandemic.[1]

Interventions to prevent injuries are classified according to the "Three E's of Injury Prevention": Education, Enforcement and Engineering.[2] This framework can be used to classify interventions when developing programs of public health to promote road safety, as well as to support a multi-faceted approach to preventing collision-related injuries. This evidence brief completes the third in the Three E's series examining the existing review-level evidence on road safety interventions;[3,4] the effectiveness of Education and Enforcement interventions have been published previously. This brief will examine Engineering interventions, including changes to the built environment and road infrastructure on collisions and collision pathway outcomes.

Methods

A literature review was conducted to identify and synthesize the existing evidence on engineering-based road safety interventions across any population and geographic region. Systematic searches were conducted in October of 2022 to identify all relevant articles. Public Health Ontario Library Services conducted the search in MEDLINE, Embase, PsycINFO, Global Health, CINAHL, SocINDEX, and Cochrane Database for Systematic Reviews using relevant vocabulary and subject headings. All database results were integrated, and duplicates were removed. The search strategy is available upon request. English-language peer-reviewed articles were eligible for inclusion if they examined the effect of an engineering-based road safety intervention and were published between 2018 and 2022. Papers were excluded if they did not have a MVC or collision pathway outcome (e.g., speed, volume), did not have reproducible search methods, were not review-level articles, or did not include evaluation of an engineering intervention. One reviewer screened all titles and abstracts, and a second reviewer screened a random selection of titles and abstracts. Full-text versions of all articles for inclusion were reviewed independently by two reviewers. One reviewer then performed data extraction for the included articles and categorized the content according to intervention type. A random selection of articles was chosen by the second reviewer to identify any discrepancies in data extraction. The Health Evidence Quality Assessment Tool for Review Articles was used to conduct a quality appraisal for each included review.[5] Two reviewers appraised each paper individually and any discrepancies were discussed to reach consensus.

Main Findings

The literature search identified 931 articles, from which 21 met the inclusion criteria. Five were systematic reviews, four were meta-analyses, four were Cochrane reviews, three were both systematic reviews and meta-analyses, two were literature reviews, two were literature reviews and meta-analyses, and one was an environmental scan and scoping literature review.

The quality appraisal found that nine of the articles were determined to be of strong quality, nine were moderate, and three were scored weak and excluded from this evidence brief.

Red Light Cameras

Two studies examined the effect of implementing red light cameras (RLC) at intersections. Cohn et al. conducted a systematic review and meta-analysis that examined the effect of RLCs on various collision outcomes. This included total crashes, injury crashes, property damage only (PDO) crashes, specific types of crashes (e.g., rear-end, right angle crashes), as well as red light violations. This review included studies from the US, Canada, Australia, and Singapore[6]. Authors reported statistically significant reductions in certain crash types including total injury crashes (pooled estimate of effect= 0.80, 95%CI: 0.68, 0.95), total right-angle crashes (0.76, 95%CI: 0.65-0.90), and right angle injury crashes (0.71, 95%CI: 0.58, 0.86). No statistically significant reductions were observed for total PDO crashes, total turning (same roadway) crashes or total crashes on red light running.[6] Mixed results were reported for rear-end crashes, with some studies in this review reporting increases of 9-20%, and others reporting a 12.4% reduction. The pooled estimate for rear end injury crashes demonstrated a non-significant decrease of 1%, (95%CI: -20%, 24%). The authors concluded that while RLCs may reduce red light violations, they may also increase rear end crashes.[6]

Aeron-Thomas et al. conducted a Cochrane review that also looked at the effectiveness of RLCs and aimed to quantify their impact on the incidence and severity of MVCs and red-light violations.[7] This review specifically examined the extent to which included studies adjusted for regression to the mean (RTM) and “spillover effects” such as awareness campaigns and warning signs that accompanied the RLC interventions. These additional interventions were hypothesized to impact driver behaviour beyond the RLC treatment sites. In studies where RTM and spillover effects were adjusted for, RLCs were found to be effective in reducing total fatal MVCs by 29% (0.71, 95%CI: 0.55, 0.93); estimates from studies that only partially adjusted for RTM reported similar reductions (0.87, 95%CI: 0.77, 0.98). Non-statistically significant results were reported for total fatal crashes in the one study that did not adjust for RTM, as well as right angle fatal crashes, total crashes, and red-light violations.[7]

Roundabouts

A meta-analysis was conducted to examine the effect of converting intersections into roundabouts on collisions and injuries.[8] This review included studies that were conducted in Great Britain, Denmark, Sweden, Norway, Australia, Netherlands, Switzerland, Germany, the United States, and Belgium.[8] The results were analyzed using meta-regression and found that intersections that were converted into roundabouts demonstrated a 72% reduction in fatal collisions (95% CI: -85%, -49%), and a 44% reduction in injuries (95% CI: -52%, -35%).[7] Another study found roundabouts decreased fatal crashes by 62%, fatalities by 87%, severe injuries by 58%, and minor injuries by 59%.[15]

One review assessed the effect of roundabouts specifically on cyclist safety and collisions and looked at operational and design characteristics, the presence and type of bicycle facilities, and road user behaviours at the roundabout.[9] This review included studies from Australia, New Zealand, and North America.[9] Authors reported that crashes involving cyclists increased approximately 100% when roundabouts were installed at lower-speed intersections (40-50km/hr) but decreased by 40% when installed at higher-speed intersections (60km/hr).[9] This suggests that roundabouts are more effective at reducing cyclist-related collisions at higher-speed intersections but may be detrimental at lower-speed intersections. Additionally, more severe cyclist crashes were seen at multi-lane roundabouts compared to single-lane roundabouts, and larger roundabouts with central islands were shown to be safer for cyclists.[9] Finally, roundabouts that replaced intersections with traffic signals demonstrated greater increases in injury crashes among cyclists compared to those that replaced non-signalized intersections.[9]

This review also looked at the presence and type of bicycle facilities at roundabouts.[9] For cycle lanes, on-road lanes performed worse and were associated with a greater number of crashes (100% or more) compared to separated cycle lanes or infrastructure with no bicycle facilities at all.[9] Marked cycle lanes within the roundabout increased cyclist crashes by 33% compared to no cycle lanes, but separated lanes reduced crashes by 84%.[9] Finally, when looking at driver and cyclist behaviours, it was found that many cyclists would avoid roundabouts that did not have cycle-specific lanes, and even with cycle lanes, many cyclists chose alternative routes within the roundabout.[9] It was concluded; therefore, that roundabouts do not improve safety for cyclists as much as for drivers, and may actually increase cycle crashes. This was particularly true for roundabouts with on-road cycle lanes or no cycle facilities. The types of roundabouts that seem to be safer for cyclists are those with lower motor vehicle volumes and speeds, one lane, those that are physically separated, and are smaller in size with larger/higher central islands.[9]

Roads with Reversible Lanes

One systematic review and meta-analysis examined the effectiveness of roads with reversible lanes (i.e., lanes where traffic direction changes based on the time of day). The paper by Manuel et al. estimated reversible lane safety by examining collisions by collision type; applying both fixed effects (FE) and random effects (RE) meta-analysis to assess the outcomes.[10] Overall, there was a 31-33% increase in collisions (All estimates [FE: 1.29; 1.26, 1.32], [RE: 1.31; 1.21, 1.42]) associated with installation of reversible lanes, and these results were similar across collision types.[10] The only exception was off-peak (i.e., non-rush hour times of the day) collisions where the effect was not significant as reported in the RE model.[10] It was concluded that a significant increase in collisions was associated with the installation of reversible lanes overall; observed by both the fixed and random effects models.[10] This was particularly true for injury collisions, PDO collisions, and collisions in peak travel periods.[10]

Cycling Infrastructure

A systematic review by Mulvaney et al. assessed different types of cycling infrastructure, including cycle lanes, advanced stop lines, use of colour markings, cycle tracks, cycle paths, management of the road network, speed management, cycle routes and networks, and roundabout design.[11] They were not able to gather sufficient evidence to produce conclusive results for advanced stop lines, use of colour markings, cycle tracks, and cycle paths.[11] Additionally, there were no reported decreases in the number of collisions for cycle lanes, cycle lanes through signalized and priority junctions, or cycle routes and networks.[11]

Dynamic Speed Feedback Signs

A meta-analysis conducted by Flynn et al. examined the effectiveness of dynamic speed feedback signs (DSFS) that indicate the speed of an approaching vehicle for five different site types: school zones, work zones, transition zones, straight sections and curves, both for use by heavy and light duty vehicles.[12] The objective of this paper was to look at the overall effect of DSFS on speed. Authors found that vehicle speeds were reduced following DSFS installation, and this effect was most prominent downstream of the DSFS installation site.[12]

Area-Wide Traffic Calming Schemes

The systematic review by Bunn et al. assessed the effects of area-wide traffic calming for preventing traffic-related crashes, injuries, and deaths. This review included studies sites from Germany, the United Kingdom, Australia, the Netherlands, Denmark, Japan, and Spain.[13] Outcome measures included the number of collisions resulting in death or injury, pedestrian-MVCs and other collisions.[13] The pooled rate ratio (RR) demonstrated a non-statistically significant reduction in road user deaths (RR=0.70; 95% CI: 0.23, 2.68); however, review authors note that this estimate did not account for the potential heterogeneity between studies.[13] The pooled RR for areas with traffic calming measures compared to control areas, combining both fatal and non-fatal injuries, was 0.85 (95% CI: 0.75, 0.96); for road traffic crashes it was 0.89 (95% CI: 0.76, 1.0), and for pedestrian-MVCs it was 1.01 (95% CI: 0.88, 1.16);

heterogeneity was not accounted for in these estimates.[13] Overall, it was concluded that area-wide traffic calming schemes have the potential to reduce road traffic deaths and injuries; however, the review noted some limitations. This included small sample sizes (e.g., the number of collision injuries and deaths are relatively low) as well as the interpretability of the effect estimates due to the heterogeneity across included studies.[13] Authors concluded that further research that incorporates these limitations into evaluation of this BE intervention is required to determine its efficacy.

Two studies included in the review by Mulvaney et al. examined collision rates following the installation of 20-mph zones.[11] One reported a statistically significant decrease in cyclist casualties by 32.9%, and the other found reductions in all cyclist causalities of 16.9% (95% CI: 4.8%, 29%).[11] Additionally, roads in areas adjacent to the 20-mph zones saw a non-significant 4.6% reduction (95% CI: -2.5%, 11.7%) in all cyclist causalities.[11] Another study assessed the effects of speed cameras and other interventions such as vertical and horizontal deflections, carriageway narrowing, and speed activated signs as traffic calming measures. Speed camera installation saw a non-significant decrease in cyclist collisions and a 34% significant decrease in cyclist collisions (95% CI: -56%, -7%) at sites where other engineering schemes were also installed.[11]

Three studies in the review by Pollack et al. reported reductions in pedestrian-MVCs associated with measures to slow vehicles, including a 22% reduction after speed hump installation, with a greater decline among children compared to adults (43%, 20%, respectively).[14]

Pedestrian Safety Infrastructure

Pollack et al. conducted a systematic review to evaluate changes to the BE that support walking as well as to examine the impacts the BE has on pedestrian injury.[15] The interventions included pedestrian countdown signals (PCS), pedestrian crossings (including rectangular rapid flashing beacon, pedestrian refuge island, and advanced yield or stop markings and signs), parallelogram-shaped pavement markings, and school crossing guards at pedestrian crossings.[14]

Pedestrian countdown signals demonstrated mixed results on pedestrian-MVCs, with one study demonstrating a 70% decrease in crashes, another study supporting a 13% non-statistically significant decrease, and a third study reporting a 26% increase in the rate of pedestrian-MVCs after installation of the signal.[14] Three studies reported safety improvements associated with pedestrian crossings, but the results were mixed overall.[14] Pedestrian crossing treatments at non-signalized intersections were associated with greater reductions in pedestrian-MVCs compared to untreated sites, and parallelogram shaped pavement markings significantly reduced the frequency and severity of crashes at pedestrian crosswalks.[14] Another study in the review found that pedestrian-MVC rates remained unchanged at school crossing guard locations after implementation, and that most pedestrian-MVCs involving children, occur outside of school travel times.[14]

Left-Turn Countermeasures

A review by Samuel et al. evaluated the effectiveness of countermeasures to reduce the risk of left turn crashes.[15] Two studies included in the review examined protected left turns. One demonstrated a 77% reduction in left turn crashes and a 56% reduction in total crashes, and the other found that the average left-turn crash rate per year (per approach) was 0.20, compared to 0.50 when the protected left turn was redesigned to a permissive left turn. Positive effects were also observed in evaluating signals with flashing yellow arrows, with one study demonstrating a statistically significant decrease in left turn crashes by up to 40% and a 35% reduction in injury crashes.[15]

Looking at changes to intersection geometry, a recently designed and effective left-turn countermeasure is a diverging diamond interchange (DDI), which were reported to decrease total crash frequencies by 48%, and fatal and injury crashes at ramps by 34%.[15] Another study in this review found strong evidence of angle-crash reductions of 67% with DDI implementation.[15] Another intersection geometry-based countermeasure are left turn bay extensions, which were shown to reduce collisions by 57%, rear-end collisions by 63%, and sideswipe collisions by 58%.[15]

Discussion and Conclusions

The aim of this evidence brief was to summarize the existing scientific evidence on the effectiveness of engineering interventions on reducing collisions and increasing road safety. Various reviews and meta-analyses were included that reviewed several engineering interventions; however, some studies lacked a positive effect of the interventions on collisions or collision pathway outcomes. Further, some studies failed to draw conclusions due to lack of evidence of effectiveness. The interventions assessed included red light cameras, roads with reversible lanes, roundabouts, left turn countermeasures, pedestrian safety infrastructure, cycling infrastructure, area-wide traffic calming schemes, and dynamic speed feedback signs. The majority of interventions were associated with reductions in collisions. There were three interventions; however, that were associated with increased risk of negative outcomes; two specifically for cyclists. This included roundabouts implemented at lower speed intersections and multi-lane roundabouts for cyclists[8] as well as reversible lanes that were associated with an increased risk of collisions.[9]

Some interventions demonstrated mixed results, such as PCS, where two studies reported a decrease in pedestrian MVCs, and one reported a 26% increase.[14] This highlights the importance of high quality, locally relevant data to inform the implementation of road safety interventions, particularly to ensure the safety of vulnerable road users such as cyclists and pedestrians. Further, interventions should be evaluated in the context in which they are implemented to ensure they are appropriate for the end user. For example, if PCS are implemented in senior safety zones or school zones, longer crossing times may be necessary to facilitate safe crossing of the intersection. Municipalities should evaluate all BE interventions during and after implementation to support adaptation to local needs.

Specifications and Limitations of Evidence

The purpose of an evidence brief is to investigate a research question in a timely manner to help inform decision making. The evidence brief presents key findings, based on a systematic search of the best available evidence near the time of publication, as well as systematic screening and extraction of the data from that evidence. It does not report the same level of detail as a full systematic review. Every attempt has been made to incorporate the highest level of evidence on the topic. There may be relevant individual studies that are not included; however, it is important to consider at the time of use of this brief whether individual studies would alter the conclusions drawn from the document.

Implications for Practice

This evidence brief aimed to inform road safety planning and guide future research priorities. It is imperative that road safety interventions are evidence-based to ensure effectiveness and efficient use of resources; however, the literature on engineering interventions must first be of sufficient quality and consistency to inform practice. Further, when effective interventions are fitted or retro-fitted to the environment, they must be evaluated in the context in which they are implemented. Any necessary adaptations must be made given the results of the evaluation in order to ensure fidelity. For example, if pedestrian countdown signals are added to existing signalized intersections, particularly those are that implemented in school or senior safety zones, the timing of the signal must suit the road user to ensure safe crossing times.

The results reported in this evidence brief were extracted from articles that were screened and determined to be of moderate or strong quality. This enables practitioners to inform public health programs for road safety with evidence on effective engineering interventions to reduce the number and severity of MVCs. The impact of MVCs on individuals and families can be reduced if effective interventions, supported by scientific evidence, are applied across Ontario.

Additional Resources

Effectiveness of Education, Training Programs and Awareness Campaigns on Road Safety

Effectiveness of Enforcement Strategies on Road Safety Outcomes

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