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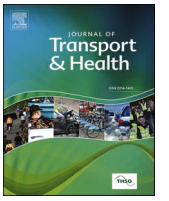

Systemic inequalities in road safety outcomes across high income countries and lessons from intervention approaches

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ABSTRACT

Background: Road safety inequality refers to the systematic and avoidable differences in road safety exposures and health outcomes among various demographic groups, influenced by social, economic, environmental, and structural factors.
Method: A narrative review approach was employed, integrating a systems perspective to examine the interplay of social, economic and environmental factors. Literature searches were conducted across academic databases and grey literature, over the last 15 years yielding 42 sources after applying exclusion criteria. The review was guided by research questions focusing on demographic and geographic disparities, the underlying risk factors, and the effectiveness of interventions.
Results: Findings highlight that most studies concentrate on risk factors rather than interventions. Key risk factors, especially for the young as pedestrians and cyclists, included living in hazardous built environments with high traffic levels and being more exposed to antisocial and illegal driving behaviour. For interventions the evidence suggests the need for multifaceted interventions supported by multi-agency efforts. Effective communication, community engagement, and recognition of broader systemic issues were critical for intervention success.
Conclusions: The review underscores the importance of integrating road safety within wider social and environmental strategies to maximize co-benefits. System-wide interventions targeting young pedestrians and cyclists, are recommended. Future research should address gaps in understanding the multifaceted nature of road safety inequalities and develop comprehensive, scalable interventions.

1. Introduction

Road safety inequality refers to the disparities in road safety risks and health outcomes experienced by different groups based on age, sex and socioeconomic status (SES). The concept of inequality in road safety outcomes refers to the strong socioeconomic gradient in road casualties where people living in the most deprived areas or in the lowest social classes are more likely to be killed or seriously injured as road users compared to those in the highest social class or living in the most affluent areas. These disparities are typically systemic and preventable, arising from a range of social, economic, environmental, and structural influences or wider determinants

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(Dahlgren and Whitehead, 1991). A wider determinants approach to road safety involves addressing the broader social, economic, and environmental factors that influence road safety outcomes. Instead of focusing solely on individual behaviour or road engineering, this approach considers how wider determinants—such as poverty, education, housing, employment, urban planning, and health inequalities—affect people's exposure to road hazards and their ability to stay safe.

For example, people living in deprived areas may face more dangerous traffic conditions due to poorly maintained infrastructure, higher pedestrian and cyclist risks, and limited access to safety resources. A wider determinants approach would involve tackling these underlying issues through cross-sector collaboration (involving transport, health, education, and social services) to improve overall living conditions and reduce road safety risks for pedestrians and cyclists. This strategy emphasises prevention by addressing the root causes of road safety inequality, not just the symptoms.

The aim of the narrative review was to identify key themes, concepts, and trends in the international literature from high income countries related to identifying risk factors and intervention approaches to address inequalities in road safety. The limitations of these studies are discussed and future approaches identified. This review is novel in filling a gap in the literature by providing a strategic analysis of the link between deprivation and road safety casualties on the topic of inequalities related to road safety outcomes.

2. Method

Literature on academic databases (e.g. Web of Science, JSTOR, Scopus, Science Direct etc) over the last 15 years was searched (2008- until October 2024). Grey literature such as government reports was also searched via internet searches and Google Scholar. Exclusion criteria included if the research was from editorials or think pieces.

Searches were carried out used the following terms "Road safety" AND "Injur*" AND "inequal*" in any field of journal articles which returned 206 results. Searches were repeated substituting "inequal*" for "depriv*" which returned 227 results. Additional searches were carried out using "Road safety" AND "casual*" AND "inequal*" which returned 33 results. Finally, data was searched using "Road safety" AND "casual*" AND "depriv*" which returned 36 results. After screening using exclusion criteria and removing duplicates the final number of journal articles included was 36. Further searches of government research projects/databases were carried out which returned six studies. The final sample of literature therefore included 42 sources.

Mendeley software was used as the repository for data collection. The researchers (who are experienced reviewers) worked independently but collaboratively to organise the data thematically (usually under risk factors or interventions) and to note key details such as country of origin, study type and key findings which were then described narratively and summarised in a table.

3. Findings

3.1. Risk factors

3.1.1. Young road users

It is well established in the literature that deprivation has an impact on road safety. The UK government is possibly unique in monitoring road casualties by deprivation annually. Over the last 10 years in England, the number of killed and seriously injured (KSI) casualties has increased in the most deprived decile, whereas in the least deprived decile rates have decreased. This deprivation-injury relationship is particularly prevalent among young pedestrians and cyclists (Smith et al., 2022; Transport for London).

In the UK, a report by the National Child Mortality Database (Williams et al., 2023) found children (birth −17 years-old) in the most deprived neighbourhoods had a death rate twice that of those in the least deprived areas. Younger children appear to be particularly vulnerable. Using English emergency department data, Hughes et al. (2014) found road traffic injuries (RTIs) were found to increase with increasing deprivation for children between birth and 14 years-old between April 2010 and March 2011. The most deprived were almost at three times greater risk compared with the least deprived (Adjusted Odds Ratio (AOR) 2.77, $p < 0.001$).

Towner et al. (2011) investigated the connection between reported road traffic injuries and exposure to risk in the road environment, along with various individual, family, and environmental risk factors in adolescents aged 13–14 years from the UK's Avon Longitudinal Study of Parents and Children (ALSPAC). ALSPAC, was a cohort study in the UK, initiated in 1991, it provided extensive data on children's health, development, and environment over 18 years. A representative sample of 6090 children aged 13–14 participated in this road safety study. The study aimed to contribute to the debate on whether there are fewer inequalities in injury outcomes during youth compared to younger childhood and adulthood.

They found that 5.5% reported a non-fatal road collision in the last year, with 71% being passengers in motorised vehicles, 18% cyclists, and 11% pedestrians. About 30% of the children involved in a collision were injured, 18% of these sought medical attention, and 3% of these stayed overnight in hospital.

There was no indication of variations in any of the socioeconomic indicators for children who experienced collisions as passengers. However, there was some indication that children from more deprived backgrounds were more prevalent among cyclists and pedestrians. Towner et al. argued that their findings offered support for the 'equalisation in youth' hypothesis regarding road traffic collisions in 13–14-year-olds. This hypothesis suggests that social disparities in health are more pronounced at a young age when parental and home influences are most substantial, but these differences decrease during the 11 to 16-year period, only to widen again in later years.

A similar picture of inequality and road injury risk is seen in other high-income countries. Brubacher et al. (2016) investigated crash outcomes using police data for British Columbia, Canada for 2003 to 2012. They found that lower socio-economic status was associated with more crashes involving pedestrians, injury and fatal collisions, and speed related fatal collisions. Another study from Canada

analysed hospital data and revealed a high road injury rate of young males from socially deprived rural areas. However, little information is given about potential risk factors other than age and sex (Dummer et al., 2010).

Hosking et al. (2013) analysed hospital in-patient and mortality data for people injured on the roads in Aukland, New Zealand. Travel modes were coded using ICD-10 external cause codes and day cases were excluded to ensure that only the most severe injuries were counted. Injury rates for children living in the most deprived decile (unadjusted for ethnicity or gender) were three times higher than children living in the least deprived decile. After controlling for the effects of ethnicity and gender, a one decile increase in deprivation was associated with a 9% increase in injury risk in children (0–14 years) and an 11% increase in adults (25–64 years), but only a 3% increase in injury risk in older adults (65+ years).

3.1.2. Ethnicity

Ethnicity is linked to the relationship between deprivation and road injury. Shaori et al. (2022) found incidents of child pedestrian collisions were centred around schools in Greater London situated in regions with a higher percentage of the population belonging to Black, Asian, and minority ethnic groups.

Steinbach et al.'s (2010) study using London data revealed children who were 'Black' had a 50% higher pedestrian injury rate than children who were 'White'. While injury rates for children who were 'White' and 'Asian' increased with area deprivation, no such link was found for children who were 'Black', who faced higher risks in all areas. In 2014, they explored exposure during the morning school commute and found 'Black' children still had higher injury rates, especially in less-deprived areas, partly due to different travel patterns like more bus use and longer distances. However, exposure levels alone did not explain the higher rates. In 2016, they examined the "group density" effect, finding children who were 'Black' had lower injury risks in areas with higher 'Black' populations. There was weak evidence of this effect for children who were 'Asian'. The protective effect of being in less-deprived areas was weaker for children who were 'Black' and 'Asian'. The authors suggested that higher group density might reduce travel times and exposure to injury by providing better access to culturally appropriate services and support networks.

3.1.3. Exposure to road traffic hazards

People from deprived backgrounds are often more exposed to environmental risk because they are more likely to be pedestrians therefore it is essential to take differing levels of exposure (in terms of amount of time and/or distanced travelled) into account.

In the UK, Downey et al. (2019) explored KSIs at signalised intersections, priority-controlled junctions, or roundabouts which accounted for half of pedestrian casualties (2005–2015). They combined data from the STATS19 casualty database, the UK National Travel Survey, and the UK National Census. The study examined contributory factors, exposure in terms of miles walked or driven, and the age, gender, and resident deprivation index of involved road users.

At signalised junctions, pedestrian casualty rates per billion miles walked were over 2.9 times higher for those in the most deprived quintile compared to the least deprived quintile. For car and van drivers, the pedestrian crash rate was 4.7 times higher in the most deprived quintile compared to the least deprived quintile. At priority-controlled junctions pedestrian crash rates per billion miles walked were 2.0 times higher and for car and van drivers involved in pedestrian crashes the rates were 5.0 times higher in the most deprived quintile compared to the least deprived quintile. At roundabouts, pedestrian crash rates per billion miles walked were 1.2 times higher and for car and van drivers involved in pedestrian crashes the rates were 3.2 times higher in the most deprived quintile compared to the least deprived quintile.

O'Toole and Christie (2018) compared child KSIs in road traffic collisions (RTCs) among 4–10 and 11–15 year-olds. Findings revealed a nearly threefold increase in the risk for pedestrian injuries in deprived areas across childhood, even after accounting for exposure. The study further showed a social inequality gradient emerging in later childhood for cycling and car occupant casualties. However, considering the average miles cycled per year, the risk of cycling injury was significantly higher for 4–10 year-olds than for 11–15 year-olds. They argued that limited exposure to cycling among younger children may contribute to their poorer understanding of safe cycling practices, possibly leading to an increased risk of injuries. For car occupants, the risk was greater for older children in the most deprived areas, especially when exposure was considered. The study highlighted the need to consider different age categories and transport modes in understanding road traffic injury risks by deprivation.

Aldred (2018) used National Travel Survey (NTS) data to explore a broader range of crashes, specifically those including single bike incidents and pedestrian falls, as well as disability. The study covered 2007 to 2012 for all Great Britain, but England only for 2013 to 2015. It examined road injuries to individuals over 16 years-of-age by mode and mode per hour and mode per mile. A total of 147,185 participants were included in the study.

For incidents involving pedestrians and vehicles, the lowest income group (less than £25,000) had an adjusted risk of involvement in crashes of 2.36 times (95% Confidence Interval (CI) 1.71 to 3.26) the highest income group. For pedestrians with disabilities, the odds ratio increased to around four times after adjustment. For pedestrian falls, those on the lowest income had a 43% higher risk of falling, but this was not a significant increase (Odds Ratio (OR) 1.43, 95% CI 0.95 to 2.17). Generally, more walking was associated with a higher risk of injury, but the exposure data were limited by the fact that a high proportion of people do not report walking in the past week. The NTS was also reported to under count falls.

In Rhone, France, Licaj et al. (2011) compared how type of residence municipality (deprived or not), affected daily travel behaviours and injury rates for young people aged 10–24. The analysis examined different transport modes and considering the distances travelled for each mode. In deprived municipalities, motorcycle users had a higher risk of injury, particularly per kilometre travelled. Car passengers, despite lower car usage in deprived areas, exhibited a significant excess risk per kilometre travelled, especially among young females. The study hypothesised that risky behaviours, like not wearing helmets or seat belts, and the age of vehicles might contribute to the excess risk in deprived areas. The study concluded that car and two-wheeler journeys posed greater risks for young

individuals in deprived municipalities. However, travel data was not available for weekends or during school holidays which might limit the conclusions made from this study.

3.1.4. Neighbourhood characteristics

One of the most widely researched risk factors for road injury is neighbourhood characteristics. Steinbach et al. (2013) studied the distance between home and place of crash according to deprivation and ethnicity. For the period 2000 to 2009, across the whole of the UK, they analysed straight line distances between the crash and centroid of the postcode of residence. For all travel modes the most deprived are injured closer to home.

In the US, McDaniel et al. (2018) explored the spatial and temporal correlation between socioeconomic factors and pedal cyclist fatalities, considering state-level covariates such as bicycling prevalence, safety measures, and total population estimates. They found an association between cycling injuries, lower SES, and rural riding among adolescents. The study revealed a notable increase in rates in Oklahoma (a very rural state), mirroring the state's rise in poverty levels. Their study suggests that low SES, indicated by state poverty rates and education levels, predicts pedal cyclist fatalities, irrespective of population size characteristics.

Rajabali et al. (2019) investigated the correlation between injury hospitalisation rates and socioeconomic factors in Canada. Motor vehicle occupants' injuries had significant associations with neighbourhood income, employment, and education levels. Pedestrians showed associations with neighbourhood income and education levels, with rates decreasing by 11.2% for every 1% increase in education. For cyclists there were no significant associations. They argued that living in deprived areas may expose individuals to various hazards, like unsafe speeding, dense traffic, poor infrastructure, and limited safe play areas. Moreover, they argued that low vehicle ownership and increased pedestrian activity in impoverished neighbourhoods elevate the risk of pedestrian injuries.

3.1.5. Built environment

Dumbaugh et al. (2022) investigated the impact of the built environment on road safety in Orange County, Florida, focusing on lower- and higher-income block groups. The study classified census block groups based on median household income and analysed various factors such as population, ethnicity, traffic, and urban arterial miles in relation to crash data from 2014 to 2016. Lower-income communities experienced three times more total, injurious, and fatal crashes per mile of urban arterial compared to wealthier areas. While lower-income areas had fewer arterial miles than wealthier communities, they had double the average daily traffic, indicating potential non-resident traffic. Pedestrian crashes increased by 15% for each additional mile of arterial thoroughfare in lower-income areas.

The presence of pavement buffers (defined as a parking lane, a planting strip with objects such as trees spaced less than 60 feet apart, or a guardrail) reduced casualty risk in lower-income areas but increased it in affluent areas. The authors explained this by referring to previous research that has shown that walking in lower-income households serves utilitarian purposes, leading to an increase in pedestrian crashes in hazardous environments. Conversely, affluent households undertake recreational walks, allowing them to avoid unsafe areas.

Schwartz et al. (2022) investigated social disparities in child pedestrian collisions in Toronto, Canada, and their relation to the built environment. Despite considering various built environment features, the link between social factors (material deprivation and recent immigrant populations) and collisions remained. A proposed conceptual model suggested complex causal pathways involving individual features, exposure to traffic environments, and walking conditions, particularly in deprived areas where walking behaviours may be unsupervised. The study acknowledged limitations, including lack of detailed data and the cross-sectional design, cautioning against viewing associations as causal risk factors.

Children appear to be particularly vulnerable to inequalities in the built environment. Vidal Tortosa et al. (2012) used casualty and travel data from the UK and observed higher levels of deprivation were associated with elevated risks of slight, serious, and fatal cycling injuries. Inequalities were more pronounced in children, with rates three times higher in the most deprived areas compared to the least deprived ones. Explanations given included more hazardous environments for children in deprived areas and limited opportunities for safe cycling experiences.

Green et al. (2011) employed injury collision prediction models to examine the impact of various socio-economic, demographic, and environmental risk factors associated with deprivation on child pedestrian casualties in Leeds and Bradford, England. The models revealed several significant relationships, such as child pedestrian flows on A roads (major roads), the correlation between junction density and casualty numbers, and the influence of play spaces and domestic garden areas on injury collisions. Additionally, crime, socio-economic factors, ethnicity, proximity to schools, access to services, free school meals, and home working were identified as significant factors affecting child pedestrian injury collisions.

In Canada, Schuurman et al. (2020) employed a mixed-methods approach to identify the built-environment factors contributing to pedestrian casualties. Ten hotspots were identified using data from the Nova Scotia Trauma Registry, and each underwent environmental scans during both summer and winter. Socioeconomic deprivation in the surrounding areas was also assessed. The environmental scans and socioeconomic data were then combined with local knowledge and expertise to provide a more detailed qualitative understanding of the factors contributing to hotspots. They identified risk factors included roads with four wide lanes over hills and blind bends, low-to middle-income housing on one side of the road and a roadside attraction on the other, along with a lack of crosswalks, medians, or traffic-calming measures. Nearly half of the pedestrian casualties were between 11 and 30 years old.

3.1.6. Traffic volume

There is mixed evidence regarding the role of traffic volume. Morency et al. (2012) investigated whether socioeconomic disparities in pedestrian and cyclist injury rates within an urban area can be attributed to varying traffic volume and road geometry in Montreal,

Canada. They conducted a comprehensive observational study spanning five years, involving all individuals injured at intersections (n = 17,498). The findings indicated that residents in poorer neighbourhoods faced higher exposure to traffic and given the same traffic volume, an increased risk of injury due to more major roads and 4-legged intersections. However, a significant portion of the elevated rate of crashes in the poorest urban areas was due to higher population density, walking, cycling, and public transit usage in the poorest neighbourhoods. They argued that the considerable attenuation of socioeconomic gradients when considering traffic volume and road geometry as mediating variables underscores their role along the causal pathway from neighbourhood socioeconomic position to crashes.

Another Canadian study (Alphonsus et al., 2018) explored the correlation between area-level deprivation and the occurrence of injury in traffic collisions and interactions between area-level deprivation and pre-event environmental factors such as light conditions, road repairs, and traffic volume, aligning with the hypothesis that area-level deprivation is associated with community material resources. Data for analysis encompassed collisions and various covariates (time of day, vehicle type, road repair status, road surface condition, speed limit, season, traffic volume, road type) from 2000 to 2010 in Saskatoon, Saskatchewan, obtained from the Saskatchewan Traffic Accident Information System (TAIS). Weather data were sourced from Environment Canada, and area-level deprivation information at the Census Dissemination Area level was procured from the Institute National de Sante Publique du Québec (INSPQ).

The study suggested an increased risk of collisions resulting in injury in the most deprived areas of Saskatoon, consistent across all times of day and traffic volumes, but specifically when road conditions were compromised such as faded markings or potholes. Approximately 11% of the variation in collision severity across areas was attributed to neighbourhood deprivation, but there was no clear dose-response relationship. They argued that further research is needed to clarify interactions between area-level socioeconomic status and road characteristics.

3.1.7. Illegal and antisocial driving behaviours

There is an increasing body of evidence relating to the association between deprivation, illegal and antisocial road behaviour and road casualties in high income countries. Graham and Stephens (2008) explored the relationship between child pedestrian casualties and different components of the English multiple deprivation score and found a consistent positive influence with the crime deprivation score, indicating that areas with higher crime rates also tend to have elevated child pedestrian casualties, including KSIs.

Clarke et al. (2008) analysed a total of 893 cases involving fatal vehicle occupants (1994–2005) sourced from 10 UK police forces. An Index of Multiple Deprivation (IMD) score, based on the primary fatality's address postcode, was assigned to each case, and these scores were categorised into IMD quintiles. In low IMD quintiles, drivers and passengers in fatal crashes were more likely to be without seat belts, under the influence of alcohol, unlicensed, uninsured, and involved in multiple-fatality collisions. Examining driver and passenger fatalities by age showed that all quintiles had high proportions of younger drivers/passengers, especially in the 16–19 age range. Clarke et al. concluded that campaigns and enforcement efforts need to address speeding, driver intoxication, seat-belt use, and unlicensed/uninsured driving and should consider a focused approach in communities within IMD quintiles 1–2. They argued for targeted efforts to address general driver attitudes towards risks, as evidenced by links between seat-belt non-compliance and speeding or intoxication.

Fleury et al. (2010) aimed to assess road risks among residents of disadvantaged or 'sensitive urban neighbourhoods' (ZUS), characterised by dilapidated housing estates, compared to other control urban areas in Lille (France). The findings indicated no excess risk in ZUS areas, compared to control areas, for the 0–19 years age group. However, living in a ZUS was associated with increased risk for both male and female residents, particularly for males. In terms of explanation the authors speculated that criminal behaviour may be linked to poor road safety, noting that police crash reports revealed a prevalence of hit-and-run offenses and refusal to respond to police summonses-accounting for 15% of the collision reports. They also suggested that differences in mobility across areas may contribute to variations in exposure to risk. ZUS residents, for instance, exhibited less car travel, with a higher proportion of walking, potentially explaining the elevated overall traffic collision risk. The study emphasized the need to integrate urban and road safety policies into broader social approaches, particularly within public health policies focused on risk prevention.

Hanna et al. (2012) explored how contextual deprivation and low population density influenced the likelihood of crashes involving young (under 19 years old) unlicensed drivers from January 2000 to December 2006 in the US. Census and material deprivation data were analysed concerning different urbanicity levels and fatal crashes. The study focused on crashes with four-wheeled vehicles, the primary mode of transportation for young people, causing most road fatalities. A total of 3059 unlicensed driver crashes met the inclusion criteria. Material deprivation, not urbanicity, was positively linked to fatal crashes at the county level. They argued that lower-income families' youth often operate older, less crashworthy vehicles, employ risky driving practices, and have limited supervised driving practice time. County-level material deprivation in the US may affect unlicensed driving fatalities due to accessibility and availability of driver licensing and training. They argued that uniformly applied policies might disadvantage socioeconomically marginalised youth, impacting timely license acquisition. They also argued that in urban areas, the unlicensed driving experience involved recreational driving, alcohol-impaired driving, stolen vehicles, younger drivers, and police chases. Recognising fundamental differences in unlicensed driving and urbanicity helps understand area exposures contributing to unlicensed driver fatal crashes.

3.1.8. Parents perceptions of road safety

Christie et al. (2010) aimed to explore and understand the opportunities and barriers for cycling in disadvantaged areas from a holistic perspective exploring the role of individual, social and environmental factors. A questionnaire was completed by 4286 children aged 9–14 from 37 schools; 51% were boys; 38.8% were aged 9–10, 48.5% aged 11–12 and 12.7% aged 13–14. Eight focus groups engaged a total of 67 parent participants, 90% being mothers.

The survey showed that most children owned a bike but only 2% cycled to school, and only 40% of all students had received cycle proficiency training. Parents' accounts revealed apprehensions regarding road safety in their neighbourhoods. Some participants were aware of collisions in the vicinity. Concerns included perceptions of excessive speeding by drivers, and there were sentiments that young individuals, both as drivers and motorbike riders, exhibited antisocial behaviour on the roads. The authors concluded that considering the elevated levels of antisocial driving in disadvantaged areas effective police enforcement becomes essential for enhancing the safety of neighbourhoods for children, whether they are cycling or walking.

Cloutier (2010) investigated parental attitudes towards child pedestrian road safety near primary schools in diverse urban settings in Montreal, Canada. The study involved 193 parents from six schools varying in deprivation levels and pedestrian injury risks. Results indicated low parental knowledge of child pedestrian risks, with road traffic collisions a primary concern. Parental fears varied across schools and varied by deprivation levels. Despite lower-than-expected response rates and a more educated sample, the study suggested that less privileged parents may underestimate child pedestrian risks. The study suggests leveraging parental concerns for local actions, developing tools to enhance parental understanding, and targeting interventions in schools. The authors advocated for reevaluating the role of cars in cities and promoting pedestrian-friendly urban planning.

However, in the UK Lowe et al. (2011) found residents in disadvantaged areas had a good understanding of road safety risks, but faced issues like dangerous parking, speeding, low seat-belt use, and limited child restraint use, worsened by poor enforcement. They argued that effective road safety requires partnerships with strategic planning, data sharing, leadership, and clear goals.

The study recommended more direct community involvement and a bottom-up approach to improve intervention effectiveness. It stressed addressing environmental and planning issues and noted that educational initiatives alone may not significantly reduce casualties.

3.2. Intervention approaches

3.2.1. The need for system level interventions to address risk factors

Mannocci et al. (2019) sought to comprehensively review the literature (largely reviews and meta-analyses published 2000–2017) regarding the socio-demographic risk factors associated with adolescents involved in road collisions. They argued that there were limited reviews on injury prevention strategies underscoring the lack of reliable evidence supporting the effectiveness of pedestrian education in preventing injuries in childhood. Mannocci et al. argued that specific injury prevention strategies are needed based on educational level, income, and social status, as these factors contribute significantly to inequalities and varying efficacy levels of road safety interventions for adolescents globally.

Similarly, Laflamme et al. (2010) reviewed the relationship between socioeconomic inequality and children's unintentional injuries in Sweden, explaining their findings using the "fundamental causes" theory. This theory suggests that affluent individuals have advantages in protecting themselves and their children, while deprivation increases exposure to hazards and limits protection. They emphasized the importance of understanding these mechanisms for policy development and suggested aligning safety strategies with initiatives to alleviate deprivation.

They noted that social welfare policies improving mobility, living conditions, and equity in care can reduce exposure differences. For example, the UK has steep social gradients in child pedestrian injuries, while Sweden, with safety-for-all measures, has negligible gradients. Potential interventions include legislation, passive safety measures, community-based programmes, home safety education, and attractive recreational spaces. Ensuring these interventions are effective across socioeconomic groups is crucial for reducing injury inequalities.

3.2.2. Multifaceted, multiagency approaches

In 2002, the UK Department for Transport launched the Neighbourhood Road Safety Initiative (NRSI) with funds for fifteen Local Authorities in England to reduce road casualties in disadvantaged areas. The initiative combined engineering, education, enforcement, and health promotion, emphasizing community collaboration and stakeholder involvement. Interventions included secure play spaces, cycle training, a summer programme on antisocial vehicle use, road safety theatre, and child car seats for disadvantaged families.

The evaluation, using quantitative and qualitative methods, found a 9% casualty reduction, though pre-existing trends complicated impact isolation. Improvements were notable for both children as pedestrians and car occupants (1–15 years) and young adults (16–24 years) as car occupants. Stakeholders such as the Department of Transport, health professionals, local agencies, and community leaders were crucial for sustained impact, though challenges included inadequate training and unclear roles.

The evaluation highlighted the need for a holistic, community-engaged approach with sustained efforts, targeted interventions, and ongoing professional development. Further evaluation led to a guide for practitioners, emphasizing the links between disadvantage and road casualties, and the importance of targeting diverse at-risk populations (Christie et al., 2011).

3.2.3. Child pedestrian training

Kerbcraft was a UK child pedestrian training scheme for 5 to 7-year-olds in deprived areas, teaching safe crossing, junction behaviour, and crossing between parked cars through practical roadside training. A randomised control trial (Whelan et al., 2008) showed significant improvements in all skills for trained children. After the intervention, 28% of trained children demonstrated safe behaviour, rising to 44% at a later post-test, compared to 20% and 29% for control children. Trained children improved in checking parked cars and navigating junctions, with no gender differences in performance or training impact.

Schools supported the programme, with 43% of head teachers noting improved parent-school relationships. Active volunteers felt valued and reported social benefits. The programme's success depended on the coordinator's ability to build relationships, motivate,

and be flexible. Cooperation from schools, innovative training, and scheduling that avoided conflicts with the National Curriculum also contributed to the programme's effectiveness.

3.2.4. Parent education

O'Toole and Christie (2019) explored the effectiveness (outcome and process) of parent road safety education for in-car, pedestrian and cyclist safety, to highlight gaps in literature and further research. The evidence suggested that road safety education for parents with low socioeconomic status had a positive impact on parent and child behaviour. Bike safety and/or helmet wearing projects increased helmet use, but general use widened inequalities due to greater effect among the least deprived (high SES) in some areas, while targeted programmes increased use in the most deprived. It found that organisations working with the most deprived can support improvements in helmet use, safety/booster seat use (for younger children). Parents were found to be motivated by concrete injury prevention messages. Process evaluation, covering how to recruit and engage parents, needs more research and there is even less research considering parents of "at risk" groups.

3.2.5. Speed management

Steinbach et al. (2010) argued that reducing speed limits reduces crashes and injuries and could narrow deprivation-based inequalities. They studied London crashes and casualties from 1986 to 2006 and found decreases across all quintiles, with the least deprived areas seeing the greatest reductions. However, the most deprived areas saw no overall change in casualties. They concluded that 20mph speed limits prevented widening deprivation-based inequalities in road casualties and suggested addressing crash risks on major routes not suitable for speed limit reductions. The study's limitations include its focus on crash location rather than residence, the potential influence of other interventions like speed cameras, and under-reporting associated with STATS19 (official road casualty data reported by the police). They also couldn't account for changes in exposure, noting that pedestrians might walk more in 20mph areas, potentially increasing injury risk.

In their narrative review of the role of cycling infrastructure for reducing cycling injuries, Mulvaney et al. (2015) suggest that implementing interventions such as 20 mph speed restrictions in urban areas can effectively decrease cyclist collisions or redesigning busy or complex segments of cycle routes may also be advantageous in reducing collision risks for cyclists. They found that robust conclusions regarding the impact of cycling infrastructure on cycling collisions in terms of severity of injury, sex, age, and social deprivation level of the casualty cannot be drawn due to a lack of evidence.

3.2.6. The need for community engagement

Christie et al. (2012) conducted a qualitative study in a London borough with the Somali community to build trust, understand challenges, and provide road safety advice using social marketing principles. They emphasized that a road safety service promoting equality requires detailed casualty data and community engagement. Despite the perceived weakness of qualitative evaluations, they suggested routine injury data should include ethnicity to assess intervention impact.

Kimberlee (2008) described the Streets Ahead on Safety project in Birmingham, targeting high child pedestrian injury rates in a deprived, predominantly Black, Asian, and Minority Ethnic community. The project involved school staff, parents, engineers, and 405 children from four primary schools, using activity days and interactive quizzes to enhance road safety and environmental awareness. An environmental audit of a school route was also conducted. While final outcomes weren't reported, qualitative feedback indicated improved road safety knowledge, awareness, self-confidence, and sense of responsibility.

3.2.7. Young drivers

Tapp et al. (2013) based their work on the evidence that young driver crash risk is highest for young men from the most deprived areas. A three-stage project, it reviewed the literature and case studies to inform primary qualitative research before a pre-trial design to introduce components to the trial cohort before producing a final design. The rationale for this approach was that the multiplying effect of deprivation is likely to add underlying complexity to the development of young people that influences crash risk, e.g. effects of disruptive behaviours, emotional disturbance, poor anger management, increased short termism, living for the moment, increased recklessness and thrill seeking.

The study aimed for 50 participants, of whom 42 were recruited, 32 engaged and 23 completed; free karting sessions were offered as an incentive. Those who were recruited had left education early, had family breakdown and involvement with the criminal justice system; most had been involved in road crashes previously.

The qualitative research showed that driving fast was a status symbol among the group. They were also found to have limited ability to plan and manage their time, making delivering education very difficult. The behaviour change initiative that combined vehicle driving data, advanced driver coaching and engagement ideas significantly improved driving skill and reduced aggressive driving. Further, the project had much wider health benefits than were initially intended, but the cohort was too small for the findings to be regarded as generalisable. The youth worker leading the project was felt to be critical to its success. However, it was more successful than traditional education.

3.2.8. Legislation to reduce legal blood alcohol limits

Haghpanahan et al. (2019) evaluated the impact of lowering legal blood alcohol limits for drivers in Scotland from 80 mg (mg) alcohol/100milletres (ml) blood to 50 mg per 100 ml. They aimed to see if this change affected road traffic crashes (RTCs) and if it influenced deprivation-based variations in crash rates, as alcohol consumption is higher in deprived areas. The study, covering two years before and after implementation, found no change in RTCs per week in Scotland and no difference compared to England and

Wales. The analysis included all RTCs, not just those related to alcohol, and may have undercounted unreported RTCs. The authors concluded that the lack of effect might be due to insufficient ongoing information, education, and enforcement, such as random breath testing.

These studies are summarised in Table 1.

4. Discussion

Most studies on road safety and inequalities focus on risk factors rather than interventions. The exceptions are a few reports funded by UK government which show considerable promise in terms of multifaceted approaches. In summary, the key themes that emerge in terms of the modifiable risk factors which influence the relationship between inequality and road safety outcomes are shown in Fig. 1 below:

In summary, this model indicates that young people who live in deprived areas compared to more affluent areas experience more road risks because they are dependent on walking and the built environments are more hazardous, with more antisocial driving, and some parts of the community may be less aware of these risks. Further these areas may have less provision for safe play, so the streets provide this function. As car occupants there is evidence that some drivers are more reckless and less law-abiding creating hazards for themselves and others and low uptake of safety belt wearing means they could experience more injuries and deaths in the event of a collision.

There are several limitations of previous studies. Few countries regularly monitor road casualties by deprivation and there is a need for more routine data to be collected and analysed on a regular basis. However, whilst describing the relationship between deprivation and road casualties by combining routinely collected data sources is useful to delineate target areas and groups, it does not really explain what the causal mechanisms are. We may know more about how people living in deprived areas are more exposed to environmental hazards but not the range of behaviours carried out by the person that was injured or by the collision partner i.e. the behaviours of the vehicle drivers and pedestrians. For example, if the child casualty was young, we would want to know: were they supervised, were they playing in the street or going to school, did they have any educational special needs or disabilities and was the driver speeding or impaired?

Similarly, other than a few studies (e.g. Christie et al., 2010; Lowe et al., 2011) commissioned by the UK government, people who live in deprived areas are rarely engaged with to explore their views on the road risks they face on a daily basis. The research is dominated by quantitative expositions of the relationship between road casualties and area-based deprivation and therefore our knowledge remains relatively superficial. Qualitative research is needed to drill down and understand the lived experience of deprived communities to understand the context, barriers and facilitators of safe mobility in these environmentally hazardous areas. This type of approach would go a long way to providing a needs assessment and informing intervention approaches (Yardley et al., 2020). Indeed, there is a growing discourse in health spheres advocating the role of participatory, co-research especially among young people echoing the trope 'nothing about us, without us' (McDonagh and Bateman, 2012). Social marketing approaches to understand road safety behaviours and the context in which they occur are needed (Smith, 2006).

In the UK other academic disciplines such as public health insist that research covers patient involvement and engagement in setting the research agenda. From a public health perspective, a large gap in our understanding is the individual and lifestyle factors, which are at the centre of the social determinants of health conceptual model (Dahlgren and Whitehead, 1991). These behaviours need to be understood in a holistic way, and in the context of wider community and environmental factors.

Related to the understanding of individual behaviours, is the lack of a systems approach to understanding the roles of different stakeholders or 'actors in the system' in mitigating risks. Stakeholders working in public health, transport planning, policing, education and emergency services all have a role to play. However, there is a dearth of research on their perspectives and capacity to deliver road safety interventions in a targeted way working with communities.

The lack of studies on the evaluation of intervention approaches in the peer reviewed literature is a concern. The question that needs to be asked to is why? Is it because governments do not measure road casualties by deprivation and therefore do not know if there is a problem in which they need to intervene? Progress on this could be made by developing logic maps especially addressing the wider determinants and informed by contextual understanding of road safety behaviours in deprived areas (Michie et al., 2011; Hills, 2010). For example, the link between unlicensed and uninsured driving and road crashes might be better understood by talking to young people, more precisely young men, in deprived areas about how they learn to drive, what role models they have and what are the barriers to licensing and insurance. For example, a wider determinants approach might be to explore the barriers to licensing such as the cost of insurance. For young men in the UK new driver insurance is around £3000 (nearly 4000 US dollars) which is arguably prohibitive potentially forcing people to drive outside of the legal system.

Structural inequalities in society can create areas of material deprivation where a constellation risks factor coalesce and create poor road safety outcomes. These inequalities in road safety are prevalent and persistent but policy makers can help ameliorate the risks through targeted stewardship and investment of resources. The following are implications for policy and practice to address inequalities in road safety outcomes.

1. Intervention approaches need to be population-based to produce effects at scale and not focus on changing the behaviour of a few high-risk individuals. Interventions should be proportionate (or targeted) and universal. This also avoids marginalisation of specific groups.

Table 1
Summary of literature reviewed.

Author and year	Country	Target population	Main findings in relation to deprivation	Observational or intervention or review
Aldred (2018)	UK	Pedestrians	- Lowest-income group had 2.36 times higher crash risk compared to the highest-income group.	Observational
Alphonsus et al. (2018)	Canada	All	- Increased risk of injury collisions in the most deprived areas, especially when road conditions were compromised. – 11% of variation in collision severity attributed to neighbourhood deprivation, but no clear dose-response relationship observed.	Observational
Brubacher et al. (2016)	Canada	All	- Lower socioeconomic status linked with higher rates of pedestrian collisions, injury collisions, and speed-related fatal collisions. - Those from deprived areas at greater risk for various types of road injuries.	Observational
Christie et al. (2010)	UK	Parents of children	- Parents in deprived areas concerned over road safety, including speeding and antisocial behaviour by young drivers and motorbike riders.	Observational
Christie et al. (2011)	UK	Children	- Significant casualty reduction in deprived areas, with notable improvements for children and young adults as pedestrians and car occupants.	Intervention
Christie et al. (2012)	UK	Child pedestrians (Somali community)	- Promoting road safety equality requires detailed casualty data and community engagement.	Observational
Clarke et al. (2008)	UK	Young drivers	- Fatal crashes in lower IMD quintiles were associated with risky behaviours such as seat-belt non-compliance, driving under the influence, and unlicensed/uninsured driving. - Younger drivers/passengers, aged 16–19, were disproportionately represented across all IMD quintiles. - Suggested targeted campaigns addressing these risk factors with a focus on high-risk communities in deprived areas.	Observational
Cloutier (2010)	Canada	Parents of children (5–14 years)	- Low parental awareness of child pedestrian risks, with road traffic collisions being a significant concern, and variations in parental fears across schools based on deprivation.	Observational
Department for Transport (2023)	UK	All	- Over the last 10 years casualties increased in the most deprived decile, though decreased in the least deprived decile rates have decreased -particularly among young pedestrians and cyclists.	Observational
Downey et al. (2019)	UK	Pedestrians	- Pedestrian casualty rates significantly higher in the most deprived quintile, especially at signalised junctions and for car and van drivers. - Deprivation was associated with greater exposure to risk at different junction types.	Observational
Dumbaugh et al. (2022)	USA	All	Lower-income communities, experienced three times injury crashes per mile of urban arterial road compared to wealthier areas and had double the average daily traffic despite having fewer arterial miles, indicating potential non-resident traffic. - Pedestrian crashes increased with amount arterial roads in lower-income areas. - Pavement buffers reduced casualty risk in lower-income areas but increased it in affluent areas.	Observational
Dummer et al. (2010)	Canada	Males 12-24	- High road injury rate among young males	Observational
Fleury et al. (2010)	France	All	- Found no excess risk in deprived urban areas for the 0–19-year-olds, but a higher risk for male and females, particularly males. - Police reports indicated a prevalence of hit-and-run offenses and refusal to respond to police summonses, contributing to collision risks.	Observational
Graham and Stephens (2008)	UK	Child pedestrians	- Found a positive correlation between high crime deprivation scores and child pedestrian casualties	Observational
Green et al. (2011)	UK	Child pedestrians	- Factors associated with injury risk in deprived areas were child pedestrian flows on arterial roads, high junction density, access to play spaces/gardens, crime levels, proximity to schools, access to services, free school meals, and home working.	Observational
Haghpanahan et al. (2019)	UK	All	- No change in crashes related to alcohol in deprived areas	Intervention
Hanna et al. (2012)	USA	Young drivers	-Material deprivation associated with fatal crashes. - Lower-income youth often used older, less crashworthy vehicles and limited supervised driving time, contributing to higher fatal crash rates.	Observational
Hosking et al. (2013)	New Zealand	All	- A one decile increase in deprivation was associated with a 9% increase in injury risk in children (0–14 years) and an 11% increase in adults (25–64 years), but only a 3% increase in injury risk in older adults (65+ years).	Observational

(*continued on next page*)

Table 1 (*continued*)

Author and year	Country	Target population	Main findings in relation to deprivation	Observational or intervention or review
Hughes et al. (2014)	UK	Children	- The most deprived children at almost three times the risk.	Observational
Kimberlee (2008)	UK	Young People	- Qualitative feedback indicated improved self-confidence, responsibility, and road safety knowledge.	Intervention
Laflamme et al. (2010)	International	Children	- Affluent individuals have more protective advantages, while deprivation increases exposure to hazards.	Review
Licaj et al. (2011)	France	Children	- Risk of injury highest for motorcyclists and car passengers in deprived areas.	Observational
Lowe et al. (2011)	UK	All	- Residents in disadvantaged areas had a good understanding of risks but faced challenges such as dangerous parking, speeding, low seat-belt use, and poor child restraint practices, exacerbated by weak enforcement.	Observational
Mannocci et al. (2019)	International	Male adolescents	- Injury prevention strategies need to be tailored to education level, income, and social status - Lack of reliable evidence supporting pedestrian education in preventing childhood injuries.	Review
McDaniel et al. (2018)	USA	Cyclists	- Cycling injury rates increased with rising poverty levels.	Observational
Morency et al. (2012)	Canada	All	-Residents of poorer neighbourhoods faced higher exposure to traffic and an increased injury risk, particularly on t major roads and at complex intersections.	Observational
Mulvaney et al. (2015)	International	Cyclists	– 20 mph speed limits and redesigning busy routes could decrease collisions - lack of evidence on the effects of cycling infrastructure on injury severity across different demographics.	Review
O'Toole and Christie (2019)	UK	Parents	- Safety initiatives targeting low socioeconomic status parents positively influenced parent and child behaviour, especially in helmet and car seat use. - General programmes tended to widen inequalities, but targeted efforts increased safety among the most deprived.	Review
O'Toole and Christie (2018)	UK	Children 4-15	- Highlighted a social inequality gradient, with older children in deprived areas more likely to experience cycling and car occupant casualties.	Observational
Rajabali et al. (2019)	Canada	All	- Motor vehicle occupant injuries were significantly associated with neighbourhood income, employment, and education levels. - Pedestrian injuries decreased as education levels increased, but no significant associations were found for cyclists.	Observational
Schuurman et al. (2020)	Canada	Pedestrians	- Casualty scenarios included four wide lanes over hills and blind bends, low - to middle-income housing with mixed land use, a lack of crosswalks, medians, or traffic-calming measures.	Observational
Schwartz et al. (2022)	Canada	Children1-17	- Social factors (material deprivation and immigrant populations) remained linked to collisions even when considering built environment features.	Observational
Shoari et al. (2022)	UK	Children	- Ethnicity and deprivation were linked, with collisions more common in disadvantaged neighbourhoods.	Observational
Steinbach et al. (2010)	UK	Child pedestrians	– 20 mph speed limits prevented widening deprivation-based inequalities but did not reduce casualties in the most deprived areas.	Intervention
Steinbach et al. (2016)	UK	Child pedestrians	- Black children faced lower injury risks in areas with higher Black populations, possibly due to better access to culturally appropriate services.	Observational
Steinbach et al. (2013)	UK	All	- For all travel modes the most deprived are injured closer to home.	Observational
Steinbach et al. (2014)	UK	Child pedestrians	- Black children had higher injury rates during school commutes, even in less-deprived areas, partly due to different travel patterns.	Observational
Tapp et al. (2013)	UK	Young drivers	- Participants, who had often left education early and faced family breakdowns, engaged in high-risk driving behaviours such as speeding for status. - Some benefits though the small cohort limited generalizability.	Intervention
Towner et al. (2011)	UK	Children 13-14	- Children from more deprived backgrounds were more prevalent among cyclist and pedestrian casualties.	Observational
Vidal Tortosa et al. (2021)	UK	Cyclists	- Deprivation was associated with elevated risks of slight, serious, and fatal cycling injuries, particularly for children. - Children in the most deprived areas faced cycling injury rates three times higher than those in the least deprived areas.	Observational
Whelan et al. (2008)	UK	Children 5-7	- Significant improvements in children's road-crossing behaviours. - Trained children demonstrated safe behaviour, increasing in later post-tests, compared to lower results for the control group.	Intervention

(*continued on next page*)

Table 1 (*continued*)

Author and year	Country	Target population	Main findings in relation to deprivation	Observational or intervention or review
Williams et al. (2023)	UK	Children	- Children in the most deprived neighbourhoods had twice the death rate compared to those in the least deprived areas. - Younger children were particularly vulnerable to fatal incidents.	Observational

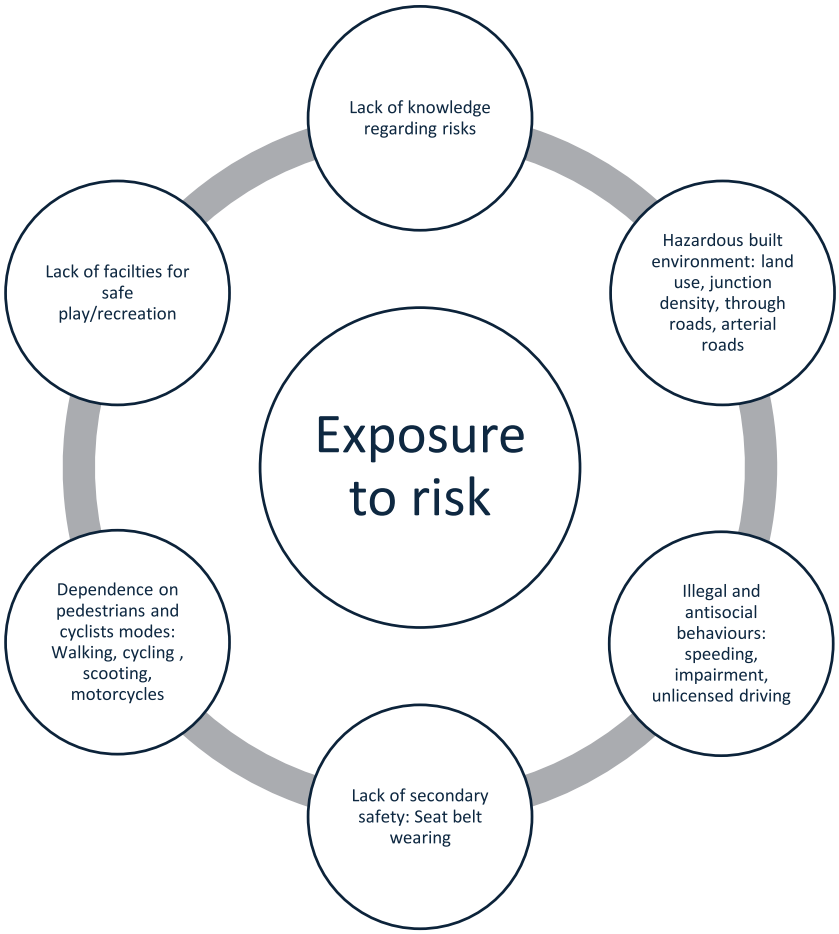

Fig. 1. Modifiable risk factors which characterise the relationship between exposure to risk and road safety outcomes in deprived areas.

2. Intervention approaches need to understand the barriers and facilitators for adopting safe behaviours from a wider determinant's perspective. For example, children may play in the street because they live in overcrowded housing and there is no safe place to play (Christie, 1995).
3. The focus needs to be on behaviour change with multifaceted, multi-agency support involving engineering, education, and enforcement. The evidence suggests that having a dedicated partnership officer facilitates partnership work between multiple agencies.
4. There needs to be deep consideration of the communications around any planned changes to the local environment which affect the speed and volume of traffic. The stewardship and management of the system needs joint ownership by both local authorities and the communities they serve.
5. There is a need to recognise that wider systemic issues affect road safety outcomes and that not all solutions will be traditional road safety interventions. For example, road safety may need to be addressed by the creation of safe places to play to reduce children's exposure to road traffic. This also has implications for the types of delivery partners that need to be engaged with. In the case of safe plays areas, partners may be children's services within councils.
6. There is a need to see road safety as part of system and make the case for the co-benefits of road danger reduction such as creating more liveable neighbourhoods which support health and wellbeing and more sustainable environments - sustainable safety in the Netherlands is an example of this (Wegman and Aarts, 2006). In addition, proposed interventions need to be cost effective.

7. It is strongly recommended that interventions focus on system wide interventions which reduce the harms for young people especially as pedestrians and cyclists (aged 0–16) and car occupants (aged 0–29).
8. Finally, it is recommended that governments need data to measure and monitor the relationship between deprivation and road casualties to ensure that resources are targeted proportionately.

Moreover, despite much of this review being informed by research from the UK and Canada many of the recommendations apply to high income countries especially those with old urban developments and where census data can enable identification of area-based deprivation.

4.1. Strengths and limitations

A strength of this review is that it focuses on a people who live in deprived areas that experience greater risks than more affluent areas and identifies intervention approaches to address modifiable risk factors. The review showed that there were relatively few countries that addressed inequalities related to road casualties and fewer still that conducted intervention studies. The review was conducted among high income countries to represent a relatively homogenous group, but it is recognised that this excludes those in low-income countries who have the greatest burden of road traffic injuries among their poorest communities. In searching grey literature UK government documents were easy to source and this may reflect a bias in the approach. In addition, grey literature is by definition not peer reviewed.

CRediT authorship contribution statement

Nicola Christie: Writing – review & editing, Writing – original draft, Methodology, Funding acquisition, Formal analysis, Conceptualization. **Sarah Jones:** Writing – original draft, Methodology, Funding acquisition, Formal analysis, Conceptualization. **Sarah E. O'Toole:** Writing – review & editing, Writing – original draft.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

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