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Examining how different measurement approaches impact safety outcomes in child pedestrian research: Implications for research and prevention

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A R T I C L E I N F O

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A B S T R A C T

There has been a great deal of research aimed at understanding the causes of child pedestrian injury. Many different methods have been employed with the goal of designing simulations that produce rigorous assessment of children's behaviors without putting children at risk of actual pedestrian injury. Most research has assessed children's pre-crossing decision making and extrapolated crossing outcome measures from estimates of mean walking speed. This study explores the nature and extent of measurement bias that is introduced when average walking speed is used to produce estimates of outcomes versus measuring actual in-road behavior directly. Using a within-subjects design and a fully immersive virtual reality pedestrian simulator, both measures were taken. Comparisons based on regression models revealed the extent of differences in results produced by measurement bias. Results indicated that measurement bias is produced when average walking speed is used such that hits and high risk crossings are overestimated and missed opportunities are underestimated, resulting in an overall overestimate of children's risk for pedestrian injury. The discussion highlights how these two measurement approaches emphasize different underlying processes as determinants of child pedestrian injury risk.

1. Introduction

Pedestrian injury represents a serious threat to the health and wellbeing of children worldwide (World Health Organization, 2013). In Canada, pedestrian injuries are the fourth leading cause of death and a leading cause of injury for children 0–14 years (Public Health Agency of Canada, 2012). In the United States, recent data indicates that 8000 children were injured and 207 were killed as pedestrians or cyclists in 2014 (NHTSA, 2014). Although children under 15 represent only about 20% of the population of the US, one large scale study (n = 5000) revealed that this group accounts for 38% of pedestrian injuries (Peng and Bongard, 1999). In fact, the number of pedestrian injuries affecting 5–10 year-olds is estimated to be more than four times higher than that for adults (Thomson et al., 1996). Thus, children constitute a 'high risk' group for pedestrian injury. In light of this, there has been considerable research interest in identifying factors that contribute to child pedestrian risk to aid in the development of effective interventions.

Although there has been long-standing debate about the relative importance of built environment factors (e.g., road design, vehicle speed) and child behavioral factors (Thomson et al., 1996), it is now generally agreed that both are important determinants of pedestrian risk (Cross and Hall, 2005).

Both road design and vehicle speed are important environmental determinants of pedestrian injury. A large proportion of injuries to children occur at midblock locations (Desapriya et al., 2011) where no traffic controls (e.g., lights, signs, crosswalks) are present (Mayr et al., 2003). Younger children (5–9 years) are especially likely to be injured at midblock locations (DiMaggio and Durkin, 2002) where roads are wide and straight and parking on both sides is allowed. This road design encourages higher speeds and prevents drivers from seeing children from behind parked cars (Schieber and Vegega, 2002).

In addition to environmental factors, how children cross streets also affects their risk of pedestrian injury. Road crossing is a complicated task that implicates attention, perception, and motor abilities. Selectively attending to traffic, accurately perceiving time-to-contact information, and precisely timing motor movements to dynamic perceptual information are all essential skills for crossing streets safely (Thomson et al., 1996). Young children often fail to look both ways before crossing (Thompson et al., 1996). They interpret greater distance between themselves and an oncoming vehicle as indicating greater safety, even when time-to-contact information would suggest otherwise based on a car's speed (Morrongiello et al., 2015a). Importantly, research shows also that young children are less efficient at implementing a crossing compared to older children or adults. Specifically, although children choose the same size gaps between cars as adults to cross into, they hesitate longer before starting (i.e., *start delay),* which decreases

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the available time to cross and increases risk of being hit as they cross (Demetre et al., 1992; Pitcairn and Edlmann, 2000; Plumert et al., 2004). In fact, the implementation of movement based on visual information is emerging as particularly important to understanding young children's risk of injury as pedestrians (Plumert and Kearney, 2014; Plumert et al., 2004; Plumert et al., 2011). When tested in ways that allow greater perceptual-motor coupling, children have been found to perform similarly to adults (Demetre et al., 1992; Lee et al., 1984; Simpson et al., 2003). In addition, naturalistic observations of children's road crossings reveals infrequent hazardous decisions (Routledge et al., 1976). These diverse findings emphasize the importance of perceptual-motor coupling.

Connelly et al. (1998) assessed child judgments of time-to-contact simultaneously with judgments about their ability to cross safely by asking children to indicate, at the roadside, the point at which a vehicle was too close for them to cross safely. They found that when vehicles approached at speeds above 60 km/h, 5–6 and 8–9 year olds made more unsafe judgements than 11–12 year olds. However, when such judgments are coupled with action (e.g., walking across a pretend or virtual road) then younger children have been shown to be more cautious, allowing more safe opportunities to pass before choosing a gap (Demetre et al., 1992; te Velde et al., 2005). Thus, coupling of motor behavior with perception appears to produce more cautious pedestrian behavior in children compared to when they are asked to make crossing judgements devoid of perceptual-motor coupling. Consistent with this notion, recent research has demonstrated that children actually show evasive action *during* a crossing when the car is on a course to hit them (Morrongiello et al., 2015). The pattern of these findings highlights the importance of methodology decisions in studies of children's crossing skills: *different* pedestrian capabilities are likely to be manifested, depending on whether or not children experience complete coupling of perceptual-motor experiences when making crossing decisions.

Historically, research examining the determinants of child pedestrian injury has employed passive methods such as table top simulations (e.g., Thomson, 1997) and video presentation of traffic (e.g., Pitcairn and Edlmann, 2000) or more interactive road-side methods that do not allow control over traffic conditions (e.g., Barton and Schwebel, 2006; Demetre et al., 1992). More recently, virtual reality (VR) has been used so that highly realistic and precisely controlled traffic conditions can be presented while at the same time providing no real risk of injury to children (e.g., McComas et al., 2002; Plumert et al., 2004; Schwebel et al., 2008; Tolmie et al., 2005). One limitation of most VR applications, however, is that the child does not actually cross the street in traffic. Rather, s/he indicates when an initiation would occur and the participant's average walking speed is then used to 'estimate' what the outcome would have been based on assuming a constant walking speed (Byington and Schwebel, 2013; Congiu et al., 2008; Schwebel et al., 2008, 2012b; Thomson et al., 2005). These approaches provide important information about pre-crossing behaviors. However, because the dynamic adjustment of behavior to in-road risk is missed in these studies, they may introduce measurement bias and underestimate children's abilities. This issue was addressed directly in the current study by using a fully-immersive virtual reality system (See Method 2.3.3) in which children crossed in virtual traffic and experienced complete coupling of perceptual-motor information. The same sample of children was used to measure participants' average walking speed (used to 'estimate' safety measures) and actual walking speed (used to compute 'actual' safety measures), so the safety outcomes could then be compared to determine the extent of measurement bias when outcomes are estimated.

The importance of this type of comparative analysis of different methods is reflected in past research. For example, greater child hesitation after choosing a gap to cross into (*start delay*) is frequently considered a risk factor for injury in children because adults seldom do so (Pitcairn and Edlmann, 2000). However, gap choice and hesitation outcomes have been shown to be sensitive to the methodology employed and the impact of start delay on the safety of the crossing has been brought into question. One study, for example, using videos of traffic and crossing behavior, measured by children pressing a button on a keyboard, found significant age differences in gap size choice, with 7 year olds choosing larger gaps than adults and also positive correlations between start delay and gap size, suggesting that children are strategic in gap choice and take into account their own tendency to delay (Pitcairn and Edlmann, 2000). Young and Lee (1987) showed that 5 year olds rejected 45% of gaps of adequate duration to cross (i.e., a *missed opportunity*) compared with only 10% rejection by adults, suggesting that children may not be as skilled at using temporal information but that they adjust for this by having a wider safety margin for gap acceptance. However, a series of three experiments conducted by Demetre et al., (1992) compared the pretend road method with a 'two-step' method (i.e., children stand close to the curb of a real road and take two steps toward it to indicate their intention to cross) and showed that the pretend road method overestimated missed opportunities, but not more critical estimated measures of risk (i.e., child-vehicle collisions or close calls). Risky gap choices, on the other hand, did not vary across methodologies or between children and adults. Most relevant to the current discussion, te Velde et al., (2005) conducted an experiment showing that gap choice is sensitive to the methodology employed. They compared the crossing decisions of children (5–7, 10–12 years) and adults when making these verbally (not crossing) or based on crossing. Traffic was generated in a lab consisting of a moving bicycle on a track and participants were told to look at the bike at different distances and make their decision verbally or walk across the path of the approaching bike. The study employed a within-subjects design to compare conditions and showed that verbal judgments resulted in more unsafe crossing decisions than actually crossing. No age differences were found in gap choice, but younger children tended to show greater start delay than older children and adults. Thus, it is clear that gap selection and start delay are interrelated but the nature of this relationship is not consistent across studies and varies depending on methodology used. The current study sought to extend these findings by comparing the relationship between start delay, gap choice and safety indices using estimated crossing behavior versus actual crossing behavior and to determine to what extent the estimation measurement approach biases results that explain the relationship between pre-crossing decisions and risk outcomes.

It is also important to consider how safety outcomes are operationalized and how differences may influence how impactful measurement bias may be on results. What is considered a near or miss close call seems somewhat arbitrary and varies across researchers. For example, Demetre et al. (1992) defines a "tight fit" as a crossing in which the child would have been hit or narrowly escaped but does not define a narrow escape. Clancy et al. (2006) define a near miss as the participant being within 0.5 s of being hit, whereas Schwebel et al. (2014a,b) combine close calls with hits and define this measure as the proportion of trials that the child came within 0 (hit) to 1 s of being hit. Given that safety outcomes vary across researchers in terms of the degree of risk included it is important to determine how measurement bias resulting from estimating versus measuring directly may interact with the degree of risk inherent in the outcome. If evasive action is the primary mechanism driving the difference between estimates and actual measures then outcomes such as hits should produce a larger difference in the measures than measures that include lower risk crossings such as near misses at 1 s. The current study addressed this hypothesis by comparing High Risk Time Left to Spare (HRTLS) measures that were calculated based on actual position data versus estimates based on average walking speed for 4 levels of risk, including hits and near misses of varying time-frames.