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The Role of Body Mass Index in Child Pedestrian Injury Risk

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Abstract

The goal of the current investigation was to examine obesity as a potential risk factor for childhood pedestrian injury. A racially diverse sample of 7- and 8-year-old children completed a road-crossing task in a semi-immersive virtual environment and two pedestrian route selection tasks. Multiple linear regression analyses revealed that children with a higher Body Mass Index (BMI) waited less before crossing, had a smaller temporal buffer between themselves and oncoming traffic while crossing, and had more collisions with traffic. Girls were more cautious than boys when crossing the virtual roadway. Unlike the results from the virtual road-crossing task, BMI was not associated with risky route selection. Instead, race emerged as the strongest predictor, with African-American children selecting riskier routes for crossing. Together, these findings suggest overweight and obese children may be at increased risk for pedestrian injury. The discussion considers explanations for why obese children may exhibit riskier road-crossing behavior.

Keywords

Obesity; Child Pedestrian Injury; Road Crossing; Injury Risk

1. Introduction

Pedestrian injury ranks as the 9th leading cause of death and 14th leading cause of disability in children aged 6 to 11 years (National Center for Injury Prevention and Control [NCIPC], 2013). Reports estimate that deaths resulting from pedestrian-motor vehicle crashes cost 1.52 million dollars annually in medical care alone for children in this age range (NCIPC, 2013).

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Previous work identifies a number of factors that increase risk for childhood pedestrian injuries. One risk factor is age, with child pedestrians between the ages of 6 and 8 years experiencing 1.5 times more motor vehicle crash-related deaths than pedestrians between the ages of 9 and 11 years (NCIPC, 2013). Another risk factor for pedestrian injuries is gender. Boys experience almost double the number of pedestrian injuries than girls, with nearly 7,000 non-fatal injuries reported among males aged 6 – 11 in 2013 (NCIPC, 2013). Location is yet another risk factor, with mid-block crossings having the highest incidence of pedestrian injury in children aged 5 to 9 years (Agran et al., 1994; DiMaggio & Durkin, 2002).

Another potential risk factor for child pedestrian injuries is obesity. Rates of pediatric obesity have doubled over the past 30 years (Ogden et al., 2014), and childhood obesity is associated with various health risks including high blood pressure, high cholesterol levels, diabetes, and joint problems (Freedman et al., 2007; Taylor et al., 2006). However, the role of obesity in childhood pedestrian injury risk is not well understood.

1.1 Crossing Roads Safely

Crossing roads safely involves two essential components: 1) choosing a gap that affords safe crossing, and 2) successfully timing movement through the gap. A gap affords crossing if the time available for crossing (i.e., the temporal size of the gap) is greater than the time needed to cross through the gap (Lee et al., 1984). Choosing an appropriate gap for crossing requires accurately judging time to arrival (i.e., when the lead and tail vehicles will reach the crossing point), as well as accurately estimating the time needed to cross the road. To successfully time movement through a narrow gap, individuals must cut in closely behind the lead vehicle in the gap while crossing before the tail vehicle reaches the crossing point. Given the dynamic nature of traffic, gap decisions and crossing movements must be tightly coordinated (Plumert & Kearney, 2014). A gap will no longer afford crossing if the child waits too long before moving. Previous work indicates that both child pedestrians and cyclists often delay initiation of crossing, resulting in close calls with approaching traffic (Barton & Schwebel, 2007; O'Neal et al., 2015; Plumert et al., 2004; 2014).

Along with decisions about which gap to cross and when to start moving, children must also decide where to cross the roadway. Like gap affordances, judging route affordances requires that pedestrians evaluate the tradeoff between timely arrival at their destination and safe places to cross roads, while simultaneously considering their own road-crossing skill. Crossing diagonal to the roadway usually results in less time to reach the final destination, but also increases exposure to traffic and the possibility for a collision, whereas crossing perpendicular to the roadway reduces exposure to traffic, thereby decreasing the likelihood of a motor vehicle collision. Compared to children aged 6 – 11 years, adults most often chose to cross roadways using direct, perpendicular routes and marked crosswalks when presented with road-crossing scenarios on a computer screen (Tabibi & Pfeffer, 2003, 2007). Other studies have shown that young children often select routes that maximize exposure to traffic by crossing roads diagonally and not crossing at marked crosswalks (Barton & Schwebel, 2007; Barton et al., 2012).

1.2 Obesity as a Potential Contributor to Pedestrian Injury

Although little is known about the link between BMI and childhood pedestrian injuries, past work has revealed a positive association between obesity and injury in children 9 to 17 years old (Bazlemans et al., 2004). Several studies have identified obesity as a risk factor for injuries to the lower extremities. For example, Kessler and colleagues (2013) examined the association between BMI and all types of fractures, sprains, strains, and dislocations, and found that fractures to the foot, ankle, leg, and knee were associated with higher BMI. Similarly, in a study of children aged 3 to 14 years presenting with a traumatic injury in the emergency department, Pomerantz and associates (2010) found that obese children had more injuries to the lower extremities than non-obese children. Yet another study found that in cases of motor-vehicle collisions, obese older children and adolescents displayed an increased pattern of injuries to the lower extremities (Haricharan et al., 2009; Pollack, Xie et al., 2008).

Obesity also adversely affects children’s walking. A recent study of normal weight, overweight, and obese 5- to 9-year-old children found that compared to normal weight children, overweight and obese children had a larger base of support while walking, poorer explosive leg strength, and decreased balance (Pathare et al., 2013). Others have found that obese children ages 8–13 also show deficits in gait cycle, gait velocity and cadence (Hills & Parker, 1991; McGraw et al., 2000). These traits result in an increase in energy costs (Hills & Parker, 1992) and may create slower walking speeds, which are associated with riskier pedestrian situations (Langlois et al., 1997). Further, childhood obesity has been implicated in abnormal knee loading when walking (Gushue et al., 2005), which could be painful (Chan & Chen, 2009). Together, these findings indicate that obesity contributes to added stress on children’s bodies when engaged in physical activities such as walking. In the context of pedestrian behavior, this added stress is likely to influence the way in which overweight and obese children choose to cross roads. Specifically, they may compromise safety in order to expedite crossing.

Beyond physical aspects of obesity that may influence pedestrian safety, obesity is associated with deficits in executive functioning, including impulsivity and disinhibition (Braet et al., 2007; Cserjesi et al., 2007). Some scholars have speculated that the same executive functioning traits that are associated with attention-deficit hyperactivity disorder (ADHD), such as poor self-regulation and increased reward sensitivity, also affect how children respond to food, leading to weight gain (Davis, 2010; Holtkamp et al, 2004; Puder & Munsch, 2010). Other work has shown that lower levels of aerobic fitness, often comorbid with obesity (Ogden & Carroll, 2010), are associated with children’s poorer performance in school and on measures of cognitive control such as selective attention and response inhibition (see Chaddock et al., 2011 for a review).

These executive function deficits may negatively impact road-crossing performance as well. Stavrinos et al. (2011) found that safe street crossings were less common among children diagnosed with ADHD, who also exhibited executive dysfunction, compared to children not diagnosed with ADHD. In a comparison of how 10- to 14-year-old children with and without ADHD cross roads in a bicycling simulator, Nikolas et al. (2015) found that hyperactive-impulsive symptoms uniquely predicted risky decision-making (i.e., taking smaller gaps when crossing intersections), whereas inattention symptoms uniquely predicted timing deficits (i.e., worse timing of entry and less time to spare). In a similar study, Stevens and colleagues (2012) found that child cyclists lower in inhibitory control had less time to spare upon exiting the lane compared to children higher in inhibitory control. Chaddock and colleagues (2012) found that 8- to 10-year-old children who were low in aerobic fitness had fewer successful crossings on a virtual road while distracted by cell phone use compared to children who measured higher in aerobic fitness. Together, these studies suggest that overweight and obese children may engage in risky road crossing due to deficits in executive functioning such as greater impulsivity, poorer attention, and reduced inhibitory control.

The goal of the present study was to examine associations between 7- and 8-year-old children's Body Mass Index (BMI) and pedestrian safety by measuring road crossing performance and route selection. These ages were chosen because children in this age range are at high risk for pedestrian injury (NCIPC, 2013). As part of a larger study testing the effectiveness of virtual reality as a pedestrian safety training tool (Schwebel et al., 2014), children performed a road-crossing task in a semi-immersive virtual environment and completed two pedestrian route selection tasks, one using vignettes and the other using a tabletop model. We hypothesized that children with higher BMI would perform more poorly on all measures of pedestrian behavior compared to their normal weight peers.

2. Material and Methods

2.1 Participants

Two hundred and forty 7- and 8-year-old children (42% male; average age: *M* = 7.97 years, *SD* = .64) were recruited from community sources in the Birmingham, AL area, of which 206 were included for analysis. The sample was racially diverse, with 55% of parents reporting their children as Caucasian, 41% as African-American, and 4% as other races/ethnicities. Thirty-four children were excluded from analysis for the following reasons: discovered ineligible based on age after consenting and enrollment (*n* = 3), unable to understand and follow the study protocol (*n* = 3), failure to complete the full assessment (*n* = 14), or failure to obtain accurate BMI measurements (*n* = 14).

Body mass index (BMI) was calculated using Centers for Disease Control calculations (CDC, 2014). Using height, weight, gender, and age, each child's BMI percentile (*M* = 70.80%-ile, *SD* = 27.45, BMI range: < 1%-ile – 99.80%-ile) was calculated based on BMI-for-age growth charts for boys and girls. BMI percentiles were similar for males (*M* = 73.41%-ile, *SD* = 26.32, BMI range: 0.80%-ile – 99.80%-ile) and females (*M* = 68.88%-ile, *SD* = 28.20, BMI range: < 1%-ile – 99.70%-ile), but there were differences in BMI percentiles across racial and ethnic groups, with lower BMI percentiles for children classified as Caucasian (*M* = 63.47%-ile, *SD* = 29.19, BMI range: < 1%-ile – 99.30%-ile) and "Other" (*M* = 69.98%-ile, *SD* = 25.72, BMI range: 2.60%-ile – 99.80%-ile), and higher BMI percentiles for children classified as African-American (*M* = 80.66%-ile, *SD* =21.87, BMI range: 9.70%-ile – 98.90%-ile) Because such a small number of children fell into the "Other" race category (n=10) and BMI percentiles for the "Other" category were more similar to those of Caucasians than African-Americans, race was collapsed into two categories for analysis, African-American (41%) and non-African American (59%).

Parents provided written informed consent and children provided informed assent. The study was approved by the institutional review board at the University of Alabama at Birmingham.

2.2 Apparatus and Materials

2.2.1 The virtual reality pedestrian environment—The semi-immersive virtual reality (VR) environment used in this study is detailed in previous papers (e.g., Schwebel et al., 2008). In short, the virtual environment simulates an actual crosswalk near a school in the local area. The crosswalk, located mid-block, crosses two lanes of opposing traffic. Children, outfitted with head tracking gear, stand on a wooden curb and watch traffic displayed on three side-by-side 24-inch wide flat panel monitors. When they feel it is safe to cross, children step down onto a trigger plate, which initiates a race- and gender-matched avatar to cross the simulated roadway. Additionally, stepping down changes the perspective from first to third person, thereby allowing children to see if their crossing choice was safe. Importantly, the avatar walks at the child’s typical walking speed, assessed across multiple trials in a different location prior to the virtual road-crossing task. Following the completion of a crossing, a cartoon character provides feedback about the safety of the crossing.

The virtual environment includes ambient and traffic noise and was validated in a study demonstrating that behavior in the virtual environment matched that of the real world environment, both among children and adults (Schwebel et al., 2008).

2.2.2 Route selection materials—Route selection was assessed in two ways, vignettes and tabletop models of intersections. Four written pedestrian vignettes (Barton & Schwebel, 2007) asked children to make road-crossing choices in order to achieve a pressing goal (e.g., catch a dog that escaped the house, make it home for dinner on time). Using a 2-D illustration, experimenters pointed out the locations where the crossings should begin and end. Children made their selections by pointing out the route of their choosing on the illustrated map.

Tabletop models for route selection (Barton & Schwebel, 2007) represented two road scenarios: the intersection of a four-lane road and two-way road in an urban setting and a T-shaped intersection between a major and minor street in a residential setting. Models were built to scale based on real-life intersections at a 1:36 ratio and marked with appropriate cues such as traffic lights, crosswalks, and road striping, as well as trees, buildings, shrubs, and parked vehicles. Use of tabletop road-crossing models has been validated as being similar to selecting road-crossing routes on real roads (Ampofo-Boateng & Thomson, 1991). A wind-up toy represented the child, and was used to retrieve three flags at set locations in each model.

2.3 Design and Procedure

2.3.1 VR road-crossing task—As part of a larger, randomized controlled trial (Schwebel et al., 2014), children’s baseline road-crossing abilities were assessed over the course of a two-hour laboratory visit. Prior to performing the VR road-crossing task, children’s typical walking speed was assessed by having children walk a distance of 25 feet a total of four times. Children then completed 30 road crossings in the virtual environment. Road-crossing trials were blocked into three levels of difficulty: 25 MPH and light volume (8 vehicles/min); 30 MPH and medium volume (12 vehicles/min); and 35 MPH and high volume (16 vehicles/min), presented in random order across participants. Children completed 8 familiarization trials prior to testing. For each trial, children stepped down onto the pressure plate when they felt it was safe to cross the virtual road.

2.3.2 Route selection tasks

2.3.2.1 Vignettes: After hearing the short vignettes read to them, children made two judgments by pointing out their chosen route on the 2-D illustration: which way they would cross the road in a given scenario and which way they felt was safest to cross. Children were permitted to choose the same route for both responses.

2.3.2.2 Tabletop models: Children stood before each tabletop model and experimenters recorded their route selections by drawing their route on a corresponding map, which was later scored. Children imagined they were crossing the street and manipulated the wind-up toy to walk the same way they would if they were on a real road. The toy was wound and placed at the starting point by the experimenter and the child was instructed to point the toy in the direction they wanted the toy to go. Children were permitted to change the position and direction of the wind-up toy at any time during the task in order to reach the flags in sequential order. Children made six crossings in total, three for each of the two models.

2.4 Coding and Measures

2.4.1 Walking speed—The time it took children to walk the 25 ft. distance was recorded in seconds, averaged across the four trials, and then converted to walking speed in miles per hour (MPH).

2.4.2 Road-crossing performance measures—With the exception of *attention to traffic*, the computer automatically recorded outcome measures for each trial. Unless otherwise noted, each measure was averaged over the 30 trials.

Attention to traffic was automatically calculated via head tracking equipment by tallying the number of looks that children made to the left and the right, divided by the amount of time in minutes children waited before crossing the street.

Waiting time was measured as the time in seconds between the start of traffic and the moment the child stepped off of the curb.

Start delay was measured as the latency in seconds between when the tail end of the lead car in the gap passed the crosswalk and when the child initiated the crossing. Smaller values indicate more tightly timed movement into the gap.

Temporal buffer was measured as the shortest time in seconds between the child's avatar and the front bumper of an approaching vehicle in either the near or far lane. Smaller values indicate more risky crossing behavior.

Collisions were a count of crossings (out of 30) in which the child was hit by a car.

Missed opportunities were tallied when a child chose not to cross a traffic gap that was 1.5 times or greater than the time required for the child to cross the street occurred.

2.4.2 Route selection measures

2.4.2.1 Vignettes: Riskier routes were shorter and took less time to complete, whereas safer routes were longer and more time consuming. Scores for each vignette ranged from 1–3 and varied based on the scenario (higher scores indicated riskier routes). In one story, for example, a 1 was scored for crossing on a crosswalk at a more distant signaled intersection, a 2 for crossing on a crosswalk at a closer but unsignaled intersection, and a 3 for crossing perpendicularly or diagonally mid-block without a crosswalk. In another story, a 1 was scored for crossing on a crosswalk at a signaled intersection, a 2 for crossing perpendicularly and then traveling on the sidewalk to the destination, and a 3 for crossing diagonally across the street to the destination. Scores were averaged across the four vignettes to create two measures: children's preferred routes and children's determination of the safest routes.

2.4.2.2 Table-top models: Choices for each crossing were scored according to risk on a 4-point scale (higher scores indicated riskier routes), with a 1 scored for crossing at a crosswalk with a traffic light, a 2 for crossing at a crosswalk without a traffic light, a 3 for crossing at mid-block at a 90° degree angle, and a 4 for crossing a street or intersection diagonally. The six crossing scores were averaged to produce a single measure of risky route selection for the tabletop models.

3. Results

3.1 Data Analytic Strategy

We first computed third-order partial correlations, controlling for age, gender, and race to examine associations between BMI and measures of pedestrian road crossing and route selection. We then conducted multiple linear regression analyses to determine if BMI percentile predicted performance on all dependent measures in the virtual road-crossing task and the route selection tasks, while also accounting for the contributions of age, gender and race. Multicollinearity and normality assumptions were assessed and met in all regression analyses.

3.2 Descriptive Data and Partial Correlations

Table 1 shows descriptive data and third-order partial correlations between BMI percentiles and the VR road-crossing measures, controlling for age, gender, and race. There was a significant positive correlation between BMI percentile and collisions, $r = .20$, $p = .005$. Additionally, there was a significant negative correlation between BMI percentile and missed opportunities, $r = -.13$, $p = .05$.

Table 2 shows descriptive data and third-order partial correlations between BMI percentiles and route selection measures, controlling for age, gender, and race. BMI percentile was not significantly related to the measures of route selection.

3.3 Road-Crossing Performance

A series of multiple linear regressions was conducted to determine if age, gender, race, and BMI predicted road-crossing performance (Table 3). Before examining whether BMI percentile predicted children's performance in the VR task, we examined whether BMI percentile, age, gender, or race predicted walking speed. The model was not significant, $F(4, 201) = 1.53$, *ns,* nor was BMI percentile or any of the other individual variables a significant predictor.

3.3.1 VR measures

Attention to traffic: The model for looks per minute was significant, $F(4, 201) = 4.61$, $p < .001$, with gender ($p = .001$) and race ($p = .002$) emerging as significant predictors. Boys ($M = 31.03$, $SD = 11.56$) had more looks per minute than girls ($M = 26.70$, $SD = 9.90$), and African-American children ($M = 30.85$, $SD = 10.78$) had more looks per minute than non-African American children ($M = 26.92$, $SD = 10.60$).

Waiting time: The model for waiting time was significant, $F(4, 201) = 5.54$, $p < .001$, with gender ($p < .001$) and BMI percentile ($p = .03$) emerging as significant predictors. Girls ($M = 24.06$ s, $SD = 30.68$) waited longer than boys ($M = 11.22$ s, $SD = 6.23$) before crossing, and a 5% increase in BMI percentile was associated with a .68 s decrease in waiting time.

Start delay: The model for start delay was significant, $F(4, 201) = 4.98$, $p < .001$, with gender ($p < .001$) emerging as a significant predictor. Girls ($M = 1.43$, $SD = .52$) had longer start delays than boys ($M = 1.15$, $SD = .36$).

Temporal buffer: The model for temporal buffer was also significant, $F(4, 201) = 4.87$, $p < .001$, with age ($p < .001$) and gender ($p = .02$) emerging as significant predictors. Older children and boys ($M = 3.30$ s, $SD = .98$) had larger temporal buffers between themselves and the oncoming traffic than younger children and girls ($M = 3.04$ s, $SD = .94$). BMI percentile ($p = .08$) also emerged as a marginally significant predictor. Children with higher BMI percentiles had smaller temporal buffers between themselves and the oncoming traffic than did children with lower BMI percentiles. A 5% increase in BMI percentile was associated with a .02 s decrease in temporal buffer.

Collisions: The model for the number of collisions was also significant, $F(4, 201) = 6.52$, $p < .001$, with age ($p < .001$) and BMI percentile ($p = .005$) as significant predictors. Younger children had more collisions than older children, and each 5% increase in BMI percentile was associated with a .04 increase in mean number of collisions (out of 30) with oncoming traffic.

Missed opportunities: Finally, the model for missed opportunities was significant, $F(4, 201) = 3.62$, $p = .007$. Gender ($p = .01$) emerged as a significant predictor, with girls ($M = 3.09$, $SD = 4.49$) missing more crossing opportunities than boys ($M = 1.55$, $SD = 1.77$). BMI percentile ($p = .05$) also significantly predicted missed opportunities. Children with a lower BMI percentiles missed more crossing opportunities than children with a higher BMI percentile. For each 5% decrease in BMI percentile, children missed an average of .09 opportunities for crossing across the 30 trials.

3.4 Route Selection Measures

As with the VR road-crossing measures, we conducted multiple linear regression analyses to determine if BMI percentile predicted route selection performance with age, gender, and race included in the models (Table 4).

3.4.1 Vignettes—The model for children’s selection of their preferred crossing route was significant, $F(4, 201) = 6.92$, $p < .001$, with race as a significant predictor ($p < .001$). African-American children ($M = 2.23$, $SD = .55$) chose riskier routes than non-African American children ($M = 1.81$, $SD = .58$). The model for children’s selection of the safest route was also significant, $F(4, 201) = 13.15$, $p < .001$, with age ($p = .05$), gender ($p = .05$), and race ($p < .001$) as significant predictors. Younger children, girls ($M = 1.45$, $SD = .48$), and African-American children ($M = 1.62$, $SD = .52$) chose riskier routes than their counterparts (boys: $M = 1.31$, $SD = .44$; non-African American: $M = 1.22$, $SD = .34$).

3.4.2 Table top models—The model for table top route selection was significant, $F(4, 201) = 14.26$, $p < .001$, with age ($p = .02$) and race ($p < .001$) as significant predictors. Younger children and African-American children ($M = 3.40$, $SD = .87$) made riskier route selections than older children and non-African American children ($M = 1.22$, $SD = .34$).

4. Discussion

The goal of the current investigation was to examine associations between 7- and 8-year-olds’ BMI percentiles and their pedestrian behavior via measures of road-crossing performance and route selection. To achieve this goal, we asked children to cross a road in a semi-immersive virtual environment and to plan routes across streets and intersections to reach destinations. Children with a higher BMI percentile were riskier when crossing the virtual road compared to those with a lower BMI percentile. They waited less before crossing, had a smaller temporal buffer between themselves and traffic, and had more collisions with traffic. In addition to links between BMI percentile and road-crossing performance, we found that girls were more cautious than boys when crossing the virtual roadway. Compared to boys, they waited longer before crossing, delayed initiation of movement, and had more missed opportunities for crossing. Contrary to our expectations, BMI percentile was not associated with risky route selection. Rather, race emerged as the strongest predictor of choosing risky routes for road crossing, with African-American children choosing riskier routes than non-African American children. These results underscore childhood obesity as a previously underexplored risk factor for pedestrian injury, particularly in terms of perceiving and acting on traffic gap affordances.

How might obesity contribute to riskier road-crossing performance? One logical hypothesis is that children with higher BMI percentiles might be slower to move into a traffic gap, and may walk more slowly once they enter that gap compared to children with lower BMI percentiles. However, we found that walking speed was not related to BMI percentiles in this large and diverse sample, nor was higher BMI percentiles with longer start delays. Thus, slower walking speed and slower initiation of movement do not seem to explain riskier road-crossing performance in children with higher BMI percentiles.

A second explanation for links between BMI percentiles and pedestrian safety is that the increased physical stress placed on the bodies of overweight and obese children made them more impatient to finish the 30 crossings, hence leading to riskier road-crossing performance. Note that each time children initiated a virtual crossing, they had to step down off the curb onto the pressure plate and then step back up onto the curb to prepare for the next trial. This amount of physical strain, plus the time spent standing during the task, may have been sufficient to cause the higher BMI children to take greater risks so they could finish sooner. In fact, we found that children with higher BMI percentiles had shorter wait times and fewer missed opportunities for crossing, suggesting that they were more impatient to cross. Additionally, increased physical strain and discomfort could lead to less engagement in everyday physical activity. This in turn could influence the amount of road crossing obese and overweight children experience in everyday life, leading to less well-developed road-crossing skills. Further research is needed to determine whether the physical discomforts associated with waiting for a safe gap lead to riskier road crossing in overweight and obese children.

A third explanation is that children with higher BMI percentiles performed more poorly due to executive functioning deficits associated with being overweight or obese. Previous work suggests children low on aerobic fitness perform worse on measures of executive functioning such as selective attention and response inhibition tasks (Chaddock et al., 2012). Children with higher BMI percentiles in the present study did not differ from normal-weight peers on measures of attention to traffic, which suggests that attention was similar among children of all weights. However, our findings that children with a higher BMI percentile waited less before crossing, had a smaller temporal buffer between themselves and traffic (albeit only marginally significant), and had more collisions with traffic could be explained by poorer response inhibition and greater impulsivity often present in subsets of children with higher BMI percentiles. Other work with normal weight children has shown that inhibitory control is associated with road-crossing performance in children (Stevens et al., 2012). Note, however, that the explanations for risky road crossing offered above are not necessarily mutually exclusive. Poor cognitive control could exacerbate impatience due to physical discomfort, and physical discomfort could make it harder for obese children to exert cognitive control over their actions.

One important question these results raise is the extent to which the findings with the virtual road-crossing task generalize to road crossing in the real world. One might expect that similar processes would operate in the real world, with obese children exhibiting more willingness to take unsafe gaps due to problems with physical discomfort or cognitive control. Our finding that a 5% increase in BMI percentile was associated with a .04 increase in collisions across 30 street crossings in virtual traffic translates to an increase of 1.17 collisions with traffic per 100 crossings in children whose BMI is in the 95th percentile rather than the 50th percentile. At the same time, we recommend further epidemiological research to determine the extent to which BMI is related to real-world pedestrian risk taking and injuries. Likewise, further behavioral research, including field-based work, is needed to better understand the processes that may put obese children at risk for pedestrian injuries. For example, observational studies of obese and non-obese children’s behavior at the roadside would be useful to validate the results from the current VR study.

BMI percentile was not associated with risky route selection, possibly because there was little physical strain involved with tracing a route on paper or moving an action figure on a tabletop model. Rather, race emerged as a strong predictor of choosing risky routes for street crossing in both the vignette and tabletop model tasks, with African-American children being more likely to choose routes that increased exposure to traffic. This could be due to the fact that most of the African-American children in this sample lived in lower-income, urban areas. Living in such environments is associated with increased exposure to traffic and less adult supervision (Schwebel & Gaines, 2007). In addition, children living in urban areas may have more experience with crossing roads than children from more suburban neighborhoods, leading to greater willingness to take risks.

Our finding that girls were more cautious than boys when crossing roads is largely consistent with the road-crossing literature (e.g., Barton & Schwebel, 2007; Stevens, Plumert, Cremer, & Kearney, 2013). Girls in the present study waited longer before crossing, had more missed opportunities for crossing, and also entered less closely behind the lead car in the gap than boys. This kind of hesitation suggests that girls were more conservative in their road crossing than boys. Notably, this more conservative approach did not result in safer crossing, as girls had a smaller temporal buffer with traffic in the roadway than boys.

There are limitations to the present research that should be addressed. Although the current virtual environment has been validated (Schwebel et al., 2008), there is a concern of translating these findings to real world behavior. The virtual road crossings begin in first person, but are completed in third person by having an avatar cross the virtual roadway. The avatar walks at a fixed speed, which matches the average walking speed of the subjects, but does not allow for in vivo compensation of crossing speed when necessary. At present, however, it is not clear whether these kinds of adjustments play a critical role in children’s road crossing. Recent work by Morrongiello and colleagues (2015) shows that children often make adjustments when crossing virtual roadways while wearing a Head Mounted Display (HMD). However, recent work by O’Neal et al. (2015) shows that road crossing time rarely varies even between 6-year-old children and adults. Further, obesity may affect children’s pedestrian behavior differently as children age, as the cognitive skills needed to cross roads safely are still under development. Therefore, investigating age differences in the role of obesity in pedestrian safety is needed.

5. Conclusion

Taken together, these results suggest that obesity may compromise child pedestrian safety. As such, these results add to the known negative effects of childhood obesity on physical health and chronic disease. Future research should further address links between obesity and child pedestrian injuries by considering the potential meditational role of factors such as activity level, aerobic fitness, and physical discomfort.

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Highlights

- Children with higher BMI percentiles exhibited riskier road crossing in a virtual environment
- BMI percentile was not associated with risky route selection.
- High BMI percentile may increase pedestrian risk via impatience to cross.
- Children with higher BMI percentiles may be at increased risk of pedestrian injury.

Table 1

Descriptive data and partial correlations between BMI and road-crossing performance measures, controlling for age, gender, and race.

Variable	Mean (SD)	(1)	(2)	(3)	(4)	(5)	(6)
(1) BMI %-ile							
(2) Waiting Time	18.64 (24.47)	−.15					
(3) Attention to Traffic	28.52 (10.82)	−.09	$-.18^{**}$				
(4) Start Delay	1.32 (.48)	−.04	$.25^{**}$	$-.18^{**}$			
(5) Temporal Buffer	3.15 (.97)	$-.12^{*}$	.13	.04	−.20		
(6) Collisions	1.59 (1.16)	$.20^{**}$	$-.20^{**}$	−.10	$.16^{*}$	$-.71^{**}$	
(7) Missed Opportunities	2.44 (3.68)	$-.13^{*}$	$.60^{**}$	−.13	$.24^{**}$	$.43^{**}$	$-.38^{**}$

[*] $p \le .05$,

[**] $p \le .01$

Table 2

Descriptive data and partial correlations between BMI and route selection measures, controlling for age, gender, and race.

Variable	Mean (SD)	(1)	(2)	(3)
(1) BMI %-ile				
(2) Preferred Route	1.98 (.60)	.02		
(3) Safest Route	1.39 (.47)	−.02	.42**	
(4) Table Top	2.83 (1.11)	−.09	.17*	.17*

$^{*}p \le .05$,

$^{**}p \le .01$

Table 3

Multiple linear regression analyses predicting road-crossing performance measures.

	B	S.E.B	β	R^2	F
Walking speed				.03	1.53
Age	−.12	.12	−.07		
Gender	−.24	.16	−.11		
Race	−.14	.17	−.06		
BMI %-ile	.01	.003	.14		
Attention to Traffic				.10	4.61***
Age	.47	1.14	.03		
Gender	4.85	1.49	.22***		
Race	4.86	1.56	.22**		
BMI %-ile	−.03	.09	−.09		
Waiting Time				.09	5.54***
Age	2.67	2.58	.09		
Gender	−12.11	3.35	−.25***		
Race	−1.17	3.56	−.03		
BMI %-ile	−.14	.004	−.13*		
Start Delay				.09	4.98***
Age	−.04	.05	−.06		
Gender	−.28	.07	−.29***		
Race	.04	.07	.04		
BMI %-ile	−.001	.001	−.04		
Temporal Buffer				.10	4.87***
Age	.35	.12	.23***		
Gender	.31	.16	.16*		
Race	.04	.16	.02		
BMI %-ile	−.05	.002	−.12		
Collisions				.11	6.52***

	B	S.E.B	β	R^2	F
Age	−.48	.12	$-.26^{**}$		
Gender	−.17	.16	−.07		
Race	−.01	.16	.004		
BMI %-ile	.01	.002	$.20^{**}$		
Missed Opportunities				.07	3.62^{**}
Age	.43	.39	.08		
Gender	−1.42	.51	$-.19^{**}$		
Race	.11	.54	.01		
BMI %-ile	−.02	.01	$-.14^{*}$		

[*] $p \le .05$

[**] $p \le .01$

[***] $p \le .001$

Note: gender (1, male; 0, female); race (1, African-American; 0, non-African American)

Table 4

Multiple linear regression analyses predicting route selection measures.

	B	S.E.B	β	R^2	F
Vignettes					
Preferred Route				.12	6.92***
Age	−.01	.06	−.01		
Gender	.04	.08	.04		
Race	.42	.09	.34***		
BMI %-ile	.0003	.002	.02		
Safest Route				.21	13.15***
Age	−.09	.05	−.12*		
Gender	−.12	.06	−.13*		
Race	.38	.06	.41***		
BMI %-ile	.004	.001	.02		
Table Top				.22	14.26***
Age	−.26	.11	−.15*		
Gender	.14	.14	.06		
Race	1.02	.15	.46***		
BMI %-ile	−.003	.02	.08		

* $p \leq .05$

** $p \leq .01$

*** $p \leq .001$

Note: gender (1, male; 0, female); race (1, African-American; 0, non-African American)