Preadolescent Temperament and Risky Behavior: Bicycling Across Traffic-Filled Intersections in a Virtual Environment

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Objective This investigation used a bicycling simulator to examine how preadolescent temperament is related to risky behavior. Methods Children aged 10 and 12 years (N = 109) rode a bicycle through a virtual environment where they crossed intersections with continuous cross traffic. Mothers filled out the Early Adolescent Temperament Questionnaire-Revised. Results Older children and male participants timed their entry into the intersection more precisely than did younger children and female participants, as did 10-year-old children higher in inhibitory control and 10-year-old boys higher in aggression. However, only 10-year-old children higher in inhibitory control had more time to spare when they cleared the intersection. For 10-year-old boys higher in aggression, cutting in more closely behind the lead vehicle was accompanied by less stopping at intersections, less waiting before crossing, and choosing smaller gaps to cross. Conclusions The Discussion section focuses on inhibitory control as a protective factor and aggression as a risk factor for car–bicycle collisions.

Key words bicycling; prevention; road crossing; temperament; unintentional injuries.

Bicycle crashes are among the most common causes of severe injuries in childhood. Nationally, nearly 400,000 children are treated at emergency rooms in the United States each year for bicycle-related injuries (Mehan, Gardner, Smith, & McKenzie, 2009). Even when injury rates are adjusted for current amount of bike riding (both time and distance), children in late childhood and early adolescence are most at risk for bicycling injuries (Thompson, Thompson, & Rivara, 1990). A significant number of these injuries are due to collisions with motor vehicles. In 2010, for example, there were 11,000 such bicycling injuries in children between the ages of 5 and 15 years, and approximately one third of all bicyclist fatalities involving collisions with motor vehicles occurred at intersections (National Highway Traffic Safety Administration, 2012). As others have noted, prevention of serious bicycling injuries cannot be accomplished through helmet use alone, but must also include efforts to prevent collisions between bicycles and motor vehicles (Rivara, Thompson, & Thompson, 1997). A critical first step in developing such programs is understanding why such collisions occur. Here, we examine how age, gender, and temperament might contribute to risky road-crossing behavior using an immersive and interactive bicycling simulator.

Age Differences in Children’s Road-Crossing Skills

Successful road crossing involves first selecting a gap that is large enough for safe crossing and then crossing through the gap without colliding with any vehicles. To determine whether a gap between two vehicles affords crossing, riders must judge the temporal size of the gap in relation to the time it will take them to cross the road. Once riders identify a gap that affords safe crossing, they must coordinate self and object movement to cross the intersection safely. Specifically, children must time their entry into the intersection so as to avoid colliding with the lead vehicle in the
gap while maintaining an acceptable safety margin with the rear vehicle in the gap. To maximize time relative to the trailing car in the gap (i.e., time to spare), the rider should cut in closely behind the lead car while crossing as quickly as possible. Importantly, given the dynamic nature of traffic, gap decisions and crossing movements must be tightly linked. That is, selecting a gap that affords crossing can lead to poor outcomes if the rider delays too long before moving, and precisely coordinating movement can also lead to poor outcomes if the rider selects a gap that is too small to afford safe crossing.

Recent work on road crossing has focused on age differences in how child and adult cyclists cross a single lane of traffic in an immersive and interactive virtual environment (Plumert, Kearney, & Cremer, 2004; Plumert, Kearney, Cremer, Recker, & Strutt, 2011). Children aged 10 and 12 years and adults rode an instrumented bicycle through an immersive virtual environment consisting of a residential street with multiple intersections. Participants faced continuous cross traffic coming from the left side, with randomly ordered temporal gaps between cars (some crossable, some uncrossable). A robust finding from this work is that 10- and 12-year-old children and adults chose the same size gaps for crossing, but children ended up with less time to spare when they cleared the path of the approaching car. Further analyses revealed that children delayed initiation of crossing relative to adults, which resulted in less time to spare when clearing the path of the approaching car.

These findings are consistent with previous work indicating that child pedestrians also delay initiation of road crossing relative to adults (Barton & Schwebel, 2007; Lee, Young, & McLaughlin, 1984; Pitcairn & Edlmann, 2000; Schwebel, Gaines, & Severson, 2008; te Velde, van der Kamp, Barela, & Savelbergh, 2005). This delay appears at least in part due to difficulties with coordinating self and object movement (Chihak et al., 2010; te Velde et al., 2005). For example, Chihak et al. (2010) found that 10- and 12-year-old cyclists had less time to spare than adult cyclists when intercepting a single moving gap on the run in an immersive and interactive virtual environment. Together, these findings indicate that the ability to coordinate self and object movement is undergoing change into late childhood and early adolescence (Plumert, Kearney, & Cremer, 2007).

Gender Differences in Road-Crossing Behavior

Another factor that may play an important role in child cyclists’ road-crossing behavior is gender. Boys engage in more risky behavior than girls, and are much more likely to be injured than girls (Baker, O’Neill, & Karpf, 1992). In 2010, for example, boys between the ages of 5 and 15 years accounted for the majority of cyclists killed (79%) or injured (73%) in crashes involving motor vehicles (National Highway Traffic Safety Administration, 2012). Moreover, although boys appear to know as much as girls about what safe behavior entails (Mori & Peterson, 1995), boys approach hazardous situations more quickly and fearlessly (Morrongiello & Rennie, 1998; Peterson, Brazeal, Oliver, & Bull, 1997).

Although little is known about gender differences in child cyclists’ road crossing, Barton and Schwebel (2007) have examined gender differences in 5- to 8-year-old pedestrians’ road-crossing behavior. They used a road-crossing task developed by Lee et al. (1984) in which children crossed a “pretend road” set up parallel to an actual road. Children watched the cars on the actual road and crossed when they believed that they could safely reach the other side of the pretend road (i.e., before the oncoming vehicle crossed their line of travel on the real road). They found that girls waited longer to cross and attended more to the traffic than did boys. Boys missed fewer opportunities to cross and engaged in more “anticipations” (i.e., entering the near lane of traffic before the far lane was completely open) than did girls. This pattern of findings suggests that boys engaged in both more skilled and risky behavior than did girls.

Child Temperament and Risky Behavior

Temperament is frequently implicated as a major contributor to childhood injury risk. Temperament is defined as a set of individual differences expressed as generally stable behavioral tendencies throughout infancy and childhood, and into adulthood, reflecting both reactivity to external stimuli as well as internal self-regulation (Rothbart, 1989). Conceptually, temperament helps to shape the child’s experience within the physical and social environment. That is, temperamental characteristics such as activity level, approach tendencies, and impulsivity may lead children to seek out some situations and avoid others. For example, highly active and approach-oriented children may seek out new and unfamiliar situations (Schwebel, 2004). Novel situations may lead to injuries because such situations force children to react to potentially unforeseen dangerous problems.

Numerous cross-sectional studies support the idea that impulsive and undercontrolled children are at risk for both minor and major unintentional injuries (e.g., Jaquess &
Finney, 1994; Plumert & Schwebel, 1997; Schwebel, 2004). For example, Schwebel (2004) found that children high in impulsivity and low in effortful control had more injuries requiring medical attention. Similar findings have been reported linking temperament with more minor everyday injuries (Plumert & Schwebel, 1997). Several longitudinal studies have also found a link between temperament and unintentional injuries (Bijur, Golding, Haslum, & Kurzon, 1988; Pulkkinen, 1995; Schwebel & Plumert, 1999). For example, Pulkkinen (1995) found that among males, peer- and teacher-rated aggression at ages 8 and 14 years predicted injury history at age 27 years. Similarly, Schwebel and Plumert (1999) found that children who were impulsive and undercontrolled at age 4 years had a history of injuries requiring medical attention at age 6 years. Thus, early manifestations of impulsivity, aggression, and high activity level are predictive of later injury risk, particularly for males.

Together, these studies indicate that children lower on inhibitory control and higher on aggression are at greater risk for injury, presumably because these children engage in risky behaviors. However, with the exception of findings from Schwebel et al., studies examining the link between temperamental characteristics and injury risk have used self- or parent-reported measures of risky behaviors or unintentional injuries, but have not directly examined how temperamental characteristics are related to observed risky behaviors, particularly in older children and adolescents. To better understand how risky behaviors might mediate the link between temperamental characteristics and unintentional injuries, more information is needed about how temperamental characteristics are related to observed risky behaviors.

The Present Investigation

The goal of the present investigation was to examine how temperamental characteristics (i.e., inhibitory control and aggression) and gender differences are related to road-crossing behavior in 10- and 12-year-old children. We focused on 10- and 12-year-old children because those in this age range are at high risk for car–bicycle collisions (National Highway Traffic Safety Administration, 2012). To measure children’s actual road-crossing behavior without putting them at risk for injury, 10- and 12-year-old children crossed several intersections while riding an immersive interactive bicycling simulator through a virtual environment. While children were riding the bicycle, mothers filled out a child temperament questionnaire. Based on previous research, we hypothesized that children rated by parents as lower in inhibitory control (i.e., undercontrolled or impulsive) and higher in aggression would exhibit more risky bicycling behaviors. Namely, we expected them to stop and wait less at intersections, cross smaller gaps, and have less time to spare. We also hypothesized that boys might exhibit more skilled road-crossing behavior than girls. Specifically, we expected that boys would cut in more closely behind the lead vehicle when entering the intersection, resulting in more time to spare relative to the trailing vehicle when they cleared the intersection. We also explored whether the relationship between temperament and bicycling behavior was moderated by age or gender.

Method

Participants

One hundred nine 10- and 12-year-old children participated. There were 26 male and 26 female 10-year-old subjects (M = 10 years 10 months; range = 10–11 years 1 month) and 31 male and 26 female 12-year-old subjects (M = 12 years 9 months; range = 12–13 years 1 month). The bicycling performance data (but not temperament data) from twelve 10-year-olds and twelve 12-year-olds were part of a previous study (Plumert et al., 2011). All children were recruited from the same child research participant database maintained by the Psychology Department at the University of Iowa. Parents received a letter describing the study followed by a telephone call inviting children to participate. Ninety-two percent of the children were Caucasian, 2% were Hispanic/Latino, 2% were multiracial, 1% were African American or Black, and 2% chose not to answer. Seventy-one percent of mothers had a 4-year-college education or beyond. The study was approved by the Institutional Review Board at the University of Iowa. Children received $10 for participating in the study.

Apparatus and Materials

The study was conducted using a high fidelity real-time bicycling simulator. An actual bicycle mounted on a stationary frame was positioned in the middle of three 10-feet-wide × 8-feet-high screens placed at right angles relative to one another, forming a three-walled room. The pedals, handlebars, and right hand brake on the bicycle were all functional. Three Electrohome DLY 1280 projectors were used to rear project high-resolution textured graphics onto the screens (1,280 × 1,024 pixels on each screen), providing participants with 270 degrees of nonstereoscopic immersive visual imagery. The viewpoint of the scene was adjusted for each participant’s eye height. Four speakers and a subwoofer provided spatialized sound.
of car engine noise. Participants rode through a virtual town on a 2.25-km-long two-lane residential roadway with stop signs at the intersections. There were 15 cross streets that intersected the primary roadway at 150-m intervals. There were no stoplights or stop signs at the intersections for the cross traffic. All roadways were 12 m wide and at a level grade.

Design and Procedure

Parents and children first provided their written consent (or assent) to participate in the study. The experiment began with a 3- to 5-min warm-up period designed to familiarize them with the characteristics of the bicycle and the virtual environment. Children rode the bicycle through three intersections without cross traffic. Children were instructed to stay in the right lane and to stop at each intersection. After the warm-up session, children participated in an ∼15-min test session in which they crossed the 12 remaining intersections. There was no traffic on the street with the participant, but there was continuous cross traffic at each of the intersections. The cross traffic was restricted to the lane closest to the child and always approached from the child’s left side. Children crossed a set of four high-density intersections with many tight gaps sandwiched between sets of four control intersections in which children encountered randomly ordered gaps ranging from easily crossable to uncrossable (see Plumert et al., 2011 for a detailed description of the scenario). Children were instructed to stop at all intersections and to cross each intersection without getting hit by a car.

Parent-Reported Measures

Mothers completed the parent form of the Early Adolescent Temperament Questionnaire-Revised (EATQ-R; Ellis & Rothbart, 2001), a measure of child temperament for ages 9–16 years. The EATQ-R is a 62-item instrument that asks parents to rate items on a 5-point Likert scale, ranging from almost always untrue of their child to almost always true of their child. The EATQ-R yields eight temperamental dimensions and two behavioral dimensions. For the current study, two dimensions were selected for inclusion based on their relation to the hypotheses: Inhibitory Control and Aggression. Previous research suggests good internal reliability (Cronbach’s $\alpha$ ranges from .66 to .86; Ellis & Rothbart, 2001). Cronbach’s $\alpha$ for the Aggression scale in our sample was .77. Because of a low Cronbach’s $\alpha$ for the Inhibitory Control scale, we removed one of the items, resulting in a 4-item scale with a Cronbach’s $\alpha$ of .51 (see Muris & Meesters, 2009 for similar findings with the self-report form).

Coding and Measures

Coders viewed computer-generated two-dimensional replays of the paths of the rider and cross traffic through the simulated environment, along with the clock times corresponding to the positions of the rider and cross traffic. Coders visually coded whether the rider came to a complete stop, defined as staying below a speed of 0.10 m/s for 2 s or more at an intersection. Coders also visually coded the time when the rider started moving, defined as the point at which the rider consistently stayed above a speed of 0.10 m/s when accelerating to cross the intersection. Exact percent agreement for coming to a complete stop was 100%, and the Pearson correlation for the time when the rider started to move was $r = .998 \ (N = 16)$.

Two bicyclist behaviors were automatically recorded by the computer software for each intersection: (1) the time when the rider entered the roadway, defined as the time that the front tire crossed the edge of the intersection; (2) the time when the rider cleared the path of the approaching car, defined as the time when the rear wheel of the bike cleared the path of the approaching car. The coordinates of both the rider and the leading and trailing cars in the gap were also recorded for each of these time points. The computer software also recorded the number of gaps that passed while the rider was waiting to cross.

This information was used to calculate the following variables (averaged across intersections) for our analyses: (1) stopping, defined as whether the rider came to a complete stop at the intersection; (2) waiting, defined as the number of gaps children saw between the time they arrived at the intersection and the time they started to cross; (3) gap size, defined as the temporal size of the gap children crossed; (4) timing of entry, defined as the time between the rider and the lead car when the rider entered the intersection; and (5) time to spare, defined as the time between the rider and the tail car when the rider cleared the tail car. Stopping and waiting at intersections for a crossable temporal gap between cars (i.e., gap size) are all considered safe bicycling behaviors. Thus, higher values on these variables reflect better road-crossing behavior. For timing of entry, it is safer to enter the intersection closely behind the lead car, as this leaves more space between the child and the tail car in the gap; thus, lower scores indicate more precise timing of entry. For time to spare, safe bicycling behavior entails exiting the roadway with as much time as possible between the child and the oncoming car; thus, higher scores indicate more time to spare between the child and the oncoming car.
Results

Zero-Order Correlations Between Temperament and Bicycling Behavior

A priori power analysis indicated that a sample size of 109 would be sufficient to detect medium and large effect sizes in our planned analyses (power = .80, α = .05). Descriptive data and zero-order correlations for the two temperament variables and the five bicycling performance variables are presented separately for 10- and 12-year-old subjects in Table I. Within each age-group, correlations were computed separately for boys and girls.

There was a significant negative correlation between aggression and inhibitory control for 10-year-old girls, \( r = -0.67, \ p < .001 \), but not for 10-year-old boys, \( r = -0.01, \ p = .689 \). For 10-year-old girls, neither aggression nor inhibitory control was significantly correlated with any of the bicycling performance measures. For 10-year-old boys, however, aggression was significantly related to several dimensions of risky bicycling behavior. Higher levels of parent-reported aggression were related to less stopping at intersections, \( r = -0.45, \ p < .05 \); less waiting before crossing, \( r = -0.58, \ p < .01 \); choosing smaller gaps to cross, \( r = -0.47, \ p < .05 \); and cutting in closer behind the lead car, \( r = -0.52, \ p < .01 \). However, the relationship between aggression and time to spare was not significant, \( r = 0.23, \ p = .27 \).

The negative correlation between aggression and inhibitory control approached significance for 12-year-old girls, \( r = -0.38, \ p = .056 \), and was significant for 12-year-old boys, \( r = -0.43, \ p < .05 \). For 12-year-old girls, aggression was negatively correlated with timing of entry, \( r = -0.42, \ p < .05 \). For 12-year-old boys, neither aggression nor inhibitory control was significantly correlated with any of the bicycling variables.

Relations Between Child Temperament and Bicycling Behavior

We conducted a series of hierarchical regression analyses to examine whether individual differences in aggression and inhibitory control predicted children’s bicycling behavior, and whether these relationships were moderated by age and gender (Table II). For all regressions, age, gender, aggression, and inhibitory control were entered in the first model; the two-way interactions between the moderators (i.e., age and gender) and temperament were entered in the second model; and the three-way interactions between age, gender, and temperament were entered in the third model.

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Table I. Bivariate Correlations of Child Temperament and Bicycling Performance

<table>
<thead>
<tr>
<th>Variable</th>
<th>Males</th>
<th>Females</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
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<tbody>
<tr>
<td>10-year-old children</td>
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<tr>
<td>Child temperament*</td>
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</tr>
<tr>
<td>1. Aggression</td>
<td>2.24 (0.71)</td>
<td>2.35 (0.79)</td>
<td>-0.67***</td>
<td>0.09</td>
<td>-0.02</td>
<td>-0.09</td>
<td>-0.24</td>
<td>0.24</td>
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</tr>
<tr>
<td>2. Inhibitory control</td>
<td>3.69 (0.44)</td>
<td>3.64 (0.64)</td>
<td>-0.01</td>
<td>-0.12</td>
<td>0.13</td>
<td>0.16</td>
<td>-0.09</td>
<td>0.10</td>
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<tr>
<td>Bicycling performance measures</td>
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<tr>
<td>3. Stopping</td>
<td>0.61 (0.23)</td>
<td>0.68 (0.26)</td>
<td>-0.45*</td>
<td>0.09</td>
<td>0.79***</td>
<td>0.81***</td>
<td>0.22</td>
<td>0.28</td>
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<tr>
<td>4. Waiting</td>
<td>6.54 (2.14)</td>
<td>7.66 (3.73)</td>
<td>-0.58**</td>
<td>-0.05</td>
<td>0.67***</td>
<td>0.75***</td>
<td>0.05</td>
<td>0.30</td>
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<tr>
<td>5. Gap size</td>
<td>4.01 (0.29)</td>
<td>4.04 (0.38)</td>
<td>-0.47*</td>
<td>0.07</td>
<td>0.51**</td>
<td>0.74***</td>
<td>0.25</td>
<td>0.38</td>
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<tr>
<td>6. Timing of entry</td>
<td>1.11 (0.42)</td>
<td>1.49 (0.57)</td>
<td>-0.52**</td>
<td>-0.20</td>
<td>0.40**</td>
<td>0.38</td>
<td>0.21</td>
<td>-0.71***</td>
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<tr>
<td>7. Time to spare</td>
<td>1.59 (0.48)</td>
<td>1.13 (0.59)</td>
<td>0.23</td>
<td>0.25</td>
<td>-0.03</td>
<td>0.05</td>
<td>0.34</td>
<td>-0.79***</td>
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<td>12-year-old children</td>
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<td>Child temperament*</td>
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<tr>
<td>1. Aggression</td>
<td>2.20 (0.58)</td>
<td>2.05 (0.54)</td>
<td>-0.38</td>
<td>-0.04</td>
<td>0.00</td>
<td>-0.07</td>
<td>-0.42*</td>
<td>0.22</td>
<td></td>
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<tr>
<td>2. Inhibitory control</td>
<td>3.54 (0.71)</td>
<td>3.72 (0.52)</td>
<td>-0.43*</td>
<td>-0.27</td>
<td>-0.17</td>
<td>-0.12</td>
<td>0.27</td>
<td>-0.19</td>
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<tr>
<td>Bicycling performance measures</td>
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<tr>
<td>3. Stopping</td>
<td>0.66 (0.21)</td>
<td>0.56 (0.31)</td>
<td>-0.07</td>
<td>-0.11</td>
<td>0.58**</td>
<td>0.78***</td>
<td>0.17</td>
<td>0.34</td>
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<tr>
<td>4. Waiting</td>
<td>6.92 (2.43)</td>
<td>6.66 (3.36)</td>
<td>-0.09</td>
<td>-0.08</td>
<td>0.48**</td>
<td>0.71***</td>
<td>-0.06</td>
<td>0.41*</td>
<td></td>
</tr>
<tr>
<td>5. Gap size</td>
<td>4.05 (0.27)</td>
<td>3.98 (0.34)</td>
<td>-0.18</td>
<td>-0.14</td>
<td>0.49**</td>
<td>0.73***</td>
<td>0.27</td>
<td>0.35</td>
<td></td>
</tr>
<tr>
<td>6. Timing of entry</td>
<td>0.99 (0.44)</td>
<td>1.31 (0.45)</td>
<td>-0.07</td>
<td>0.10</td>
<td>0.53**</td>
<td>0.47**</td>
<td>0.64***</td>
<td>-0.71***</td>
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</tr>
<tr>
<td>7. Time to spare</td>
<td>1.66 (0.36)</td>
<td>1.24 (0.43)</td>
<td>-0.24</td>
<td>-0.03</td>
<td>-0.26</td>
<td>-0.07</td>
<td>0.13</td>
<td>-0.46**</td>
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</tbody>
</table>

Note. Intercorrelations for male participants (n = 26, 31) are presented below each diagonal, and intercorrelations for female participants (n = 26, 26) are presented above each diagonal.

*Temperament measure is a parent-report measure.
*p < .05. **p < .01. ***p < .001.
gender, and temperament were entered in a third model. There were no significant three-way interaction effects in any of the analyses; thus, only the first two models are reported here.

The first regression testing whether age, gender, and temperament predicted the proportion of intersections at which children stopped was not significant, $F(8, 100) = 1.08, p = .382$. Likewise, the second regression testing whether the variables predicted how long children waited before crossing the intersection was not significant, $F(8, 100) = 0.84, p = .570$. The third regression tested whether age, gender, and temperament predicted the size of the gaps that children chose to cross. There was a significant main effect of aggression on mean gap size ($\beta = -0.23, b = -0.11, SE = 0.05, p = .036$), with children rated higher in aggression choosing smaller gaps to cross. However, the full model was not significant, $F(8, 100) = 1.03, p = .420$.

The fourth regression tested whether age, gender, and temperament predicted how children timed their entry into the intersection with respect to the lead car in the gap. The first model was significant, $F(4, 104) = 7.86, p < .001$, with significant effects of age ($\beta = -0.19, b = -0.10, SE = 0.04, p = .032$), gender ($\beta = -0.36, b = -0.18, SE = 0.04, p < .001$), and aggression ($\beta = -0.31, b = -0.24, SE = 0.07, p = .001$). Twelve-year-old children cut in more closely behind the lead vehicle than did 10-year-old children (i.e., timed their movement more precisely). Likewise, boys cut in more closely behind the lead vehicle, as did children with higher levels of aggression.

The full model for timing of entry that included the interaction terms was also significant, $F(8, 100) = 4.68, p < .001$, and the main effects for age, gender, and aggression remained significant. The interaction between age and inhibitory control was statistically significant ($\beta = 0.23, b = 0.20, SE = 0.09, p = .028$). As shown in Figure 1, the $b$ for the 10-year-olds was significantly different from zero, $t(102) = -2.53, p = .013$, whereas the $b$ for the 12-year-olds was not statistically different from zero, $t(102) = 0.50, p = .626$. Therefore, 10-year-old children with higher inhibitory control cut in more closely behind the lead car than those with lower inhibitory control. Twelve-year-old children with lower and higher inhibitory control did not differ in their timing of entry into the roadway.

The fifth regression analysis tested whether age, gender, and temperament predicted how much time participants had to spare when they cleared the path of the trailing car in the gap. The first model was significant, $F(4, 104) = 7.16, p < .001$, with a significant effect of gender ($\beta = 0.44, b = 0.22, SE = 0.05, p < .001$), indicating that boys had more time to spare than girls.

### Table II. Summary of Hierarchical Regression Analyses for Variables Predicting Stopping, Waiting, Gap Size, Timing of Entry, and Time to Spare for All Participants

<table>
<thead>
<tr>
<th>Variable</th>
<th>Stopping $\beta$</th>
<th>Waiting $\beta$</th>
<th>Gap size $\beta$</th>
<th>Timing of entry $\beta$</th>
<th>Time to spare $\beta$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Step 1</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Age</td>
<td>$-0.10$</td>
<td>$-0.07$</td>
<td>$-0.05$</td>
<td>$-0.19^*$</td>
<td>$0.11$</td>
</tr>
<tr>
<td>Gender</td>
<td>$0.02$</td>
<td>$-0.07$</td>
<td>$0.03$</td>
<td>$-0.36^{***}$</td>
<td>$0.43^{***}$</td>
</tr>
<tr>
<td>Aggression</td>
<td>$-0.17$</td>
<td>$-0.17$</td>
<td>$-0.23^*$</td>
<td>$-0.31^{**}$</td>
<td>$0.17^*$</td>
</tr>
<tr>
<td>Inhibitory control</td>
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<td>$-0.11$</td>
<td>$-0.11$</td>
<td>$-0.11$</td>
<td>$0.10$</td>
</tr>
<tr>
<td>$R^2$</td>
<td>0.05</td>
<td>0.03</td>
<td>0.04</td>
<td>0.23^{***}</td>
<td>0.22^{***}</td>
</tr>
<tr>
<td>$F$</td>
<td>1.22</td>
<td>0.83</td>
<td>1.18</td>
<td>7.86^{***}</td>
<td>7.16^{***}</td>
</tr>
<tr>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age</td>
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<td>$-0.05$</td>
<td>$-0.03$</td>
<td>$-0.20^*$</td>
<td>$0.13$</td>
</tr>
<tr>
<td>Gender</td>
<td>$0.01$</td>
<td>$-0.09$</td>
<td>$0.02$</td>
<td>$-0.35^{***}$</td>
<td>$0.43^{***}$</td>
</tr>
<tr>
<td>Aggression</td>
<td>$-0.17$</td>
<td>$-0.13$</td>
<td>$-0.20^+$</td>
<td>$-0.32^{**}$</td>
<td>$0.15$</td>
</tr>
<tr>
<td>Inhibitory control</td>
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<td>$-0.04$</td>
<td>$-0.04$</td>
<td>$-0.17^+$</td>
<td>$0.17^+$</td>
</tr>
<tr>
<td>Age $\times$ aggression</td>
<td>$0.01$</td>
<td>$0.04$</td>
<td>$-0.01$</td>
<td>$0.11$</td>
<td>$-0.19^+$</td>
</tr>
<tr>
<td>Gender $\times$ aggression</td>
<td>$0.12$</td>
<td>$0.17$</td>
<td>$0.16$</td>
<td>$0.23^*$</td>
<td>$-0.26^*$</td>
</tr>
<tr>
<td>Gender $\times$ inhibitory control</td>
<td>$0.11$</td>
<td>$-0.03$</td>
<td>$-0.03$</td>
<td>$0.01$</td>
<td>$-0.02$</td>
</tr>
<tr>
<td>$\Delta R^2$</td>
<td>$0.04$</td>
<td>$0.03$</td>
<td>$0.03$</td>
<td>$0.04$</td>
<td>$0.07^+$</td>
</tr>
<tr>
<td>$F$</td>
<td>1.08</td>
<td>0.84</td>
<td>1.03</td>
<td>4.68^{***}</td>
<td>4.98^{***}</td>
</tr>
</tbody>
</table>

*p < .10  **p < .05  ***p < .01  ****p < .001.
The full model for time left to spare that included the interaction terms was also significant, $F(8, 100) = 4.98$, $p < .001$, and the main effect of gender remained significant. Furthermore, the interaction between age and inhibitory control was statistically significant ($b = -.25$, $SE = 0.09$, $p = .014$). As shown in Figure 2, the $b$ for the 10-year-olds was significantly different from zero, $t(102) = 2.76$, $p = .024$, whereas the $b$ for the 12-year-olds was not different from zero, $t(102) = -.65$, $p = .519$. Ten-year-old children with higher inhibitory control had more time to spare between themselves and the approaching car than did those with lower inhibitory control, whereas 12-year-old children with lower and higher inhibitory control did not differ.

The goal of this investigation was to examine how age, gender, and temperament were related to child cyclists’ road-crossing behavior. As in other work, we found that older children timed their entry into the intersection more precisely (i.e., cut in more closely behind the lead car in the gap) than did younger children. Likewise, male participants timed their entry into the intersection more precisely than did female participants, and also had more time to spare when they cleared the intersection. We also found significant links between temperamental characteristics and bicycling behavior. Interestingly, 10-year-old children higher in inhibitory control timed their movement more precisely when they entered the intersection and had more time to spare when they cleared the intersection than did their counterparts lower in inhibitory control. Ten-year-old boys higher in aggression also cut in more closely behind the lead vehicle, but they did not have more time to spare than their counterparts lower in aggression. Moreover, this behavior was accompanied by less stopping at intersections, less waiting before crossing, and choosing smaller gaps to cross.

The finding that older children cut in more closely behind the lead car than did younger children is consistent with other work showing developmental changes between the ages of 10 and 14 years in the ability to synchronize self and object movement (Chihak et al., 2010; Grechkin, Chihak, Cremer, Kearney, & Plumert, 2012; Plumert et al., 2011). Ten-year-old children in particular are less likely than older children and adults to precisely time their entry into the intersection, often resulting in a smaller margin of safety with the tail car. Ten-year-old children also show greater change across intersections in their time to spare than do 12-year-old children or adults (Plumert et al., 2011). Ten-year-old children in particular are less likely than older children and adults to precisely time their entry into the intersection, often resulting in a smaller margin of safety with the tail car. Ten-year-old children also show greater change across intersections in their time to spare than do 12-year-old children or adults (Plumert et al., 2011). In the current study, most of the individual differences in the temperament–bicycling behavior relationship were observed in 10-year-old children, suggesting that 10-year-olds may be at a transitional age with respect to their performance in our road-crossing task.

The finding that girls cut in less closely behind the lead car and had less time to spare relative to the tail car than did boys indicates that gender also plays a role in road-crossing behavior. Like the younger children, girls appeared to hesitate in initiating movement. Why might this be the case? One possibility is that preadolescent boys have more experience with tasks that require precise timing of movement such as sports activities or video games, which are related to perceptual-motor performance (Tirre &
Another possibility is that when confronted with a fun but risky situation, boys may be less likely to perceive themselves to be vulnerable to injury than girls (Morrongiello & Dawber, 2004). Furthermore, girls are more likely to experience lower confidence, less exhilaration, and more fear than boys when exposed to a potential risky situation (Peterson et al., 1997). In our task, girls may have erred by making sure the lead car was completely passed before initiating movement. Given that there was no difference in the size of gaps that boys and girls chose to cross, hesitation of initiation of movement into the roadway with respect to the lead car necessarily meant that girls ended up with less time to spare relative to the tail car.

Of particular interest in this investigation was the relationship between temperamental characteristics and road-crossing behavior. Unexpectedly, we found that 10-year-old children higher in inhibitory control cut in more closely behind the lead vehicle when they entered the intersection and also had more time to spare relative to the tail vehicle when they cleared the intersection. Thus, it appears that 10-year-old children characterized by higher levels of internal self-regulation exhibited more mature road-crossing skill in our task. In fact, 10-year-old children higher in inhibitory control looked exactly like the 12-year-olds with respect to timing of entry and time to spare. The ability to tightly synchronize self and object movement may be related to inhibitory control because it requires a high degree of concentration and control. These findings suggest that higher inhibitory control may be a protective factor for car–bicycle collisions. Specifically, younger children higher in inhibitory control appear to engage in the kind of mature road-crossing behavior that increases their margin of safety, while at the same time avoiding gaps that are too small for safe crossing.

We also found that children higher in aggression chose smaller gaps and cut in more closely behind the lead vehicle when they entered the intersection. However, unlike the 10-year-olds higher in inhibitory control, they did not have significantly more time to spare when they cleared the intersection. The relationship between aggression and bicycling behavior was most pronounced in the 10-year-old boys (although the three-way interaction between aggression, age, and gender was not significant in the regression analyses). Although 10-year-old boys higher in aggression timed their entry into the intersection more precisely than those lower in aggression, this behavior was also accompanied by a constellation of risky bicycling behaviors (i.e., less stopping at intersections, less waiting before crossing, and choosing smaller gaps to cross). Moreover, more precise timing of entry did not produce gains in time to spare, as they were also taking smaller gaps. Thus, although the 10-year-olds higher in inhibitory control and the 10-year-olds boys higher in aggression both exhibited precise timing of entry into the intersection, the differences in their gap choices resulted in more risky road-crossing behavior for the 10-year-old boys higher in aggression.

The finding that children rated higher in aggression, notably the 10-year-old boys, exhibited more risky bicycling behavior is consistent with other studies showing

![Figure 2. Two-way interaction between inhibitory control and age to predict time to spare when exiting the intersection (higher values represent better performance).](http://jpepsy.oxfordjournals.org/)...
that children who are aggressive and noncompliant have more unintentional injuries (Brehaut, Miller, Raina, & McGrail, 2002). Likewise, children with oppositional defiant disorder and conduct disorder (who are typically characterized by higher levels of aggressive behavior) are at elevated risk for injury (Davidson, 1987; Schwebel, Speltz, Jones, & Bardina, 2002; Schwebel, Tavares, Lucas, Bowling, & Hodgens, 2007). According to Schwebel and Gaines (2007), children who exhibit oppositionality may be particularly at risk for injury because they typically do not heed advice from adults when told to stop performing a potentially dangerous activity. Moreover, aggressive children may experience high levels of excitement when confronted with potentially dangerous activities, leading to even less behavioral inhibition (Steinberg, 2007). Ten-year-old boys higher in aggression may have found riding the bicycling simulator a particularly stimulating activity, as it involves real-world danger without negative consequences. A high level of excitement may have led to more reckless riding in the virtual environment. However, further research is needed to determine whether such children also engage in reckless riding in the real environment.

There are several limitations to this study. First, the sample was largely composed of Caucasian children from highly educated families. Moreover, because we did not retain information about response rates to our recruitment attempts, we do not know whether some families were more likely to participate than others. More work is needed to determine whether these results generalize to other groups of children, particularly children who come from lower income and minority families. Second, the internal consistency of the EATQ-R Inhibitory Control scale was low in our sample ($\alpha = .51$). Therefore, although the relationships between inhibitory control and movement timing in the younger age-group are intriguing, these results should be interpreted with caution. (Because of the relatively low Cronbach’s $\alpha$ for our inhibitory control subscale, we re-ran regression analyses using two alternate scales: the EATQ-R effortful control scale [which includes all of the inhibitory control, attention, and activation control items] and the EATQ-R “Component 9” scale, a similar scale proposed by Muris and Meesters [2009] that includes all activation control items and some of the attention and inhibitory control items. The Cronbach’s $\alpha$s for the two scales were .87 and .83, respectively. Neither scale was associated with measures of bicycling behavior. It is important to note that inhibitory control and effortful control are intended as overlapping constructs, yet they are considered somewhat distinct [Rothbart & Bates, 2006].) Finally, the three-way interaction between age, gender, and temperament was not significant in the regression analyses.

A larger sample size would be needed to detect this three-way interaction, as the effect size of the interaction was small. Thus, although the correlations between parent-rated aggression and risky road-crossing were strong for 10-year-old boys, future research with larger sample sizes will be needed to determine whether this pattern is unique to this particular group of children.

One additional consideration is how the temperament variables for boys and girls in our study relate to the patterns of temperament in the extant literature. In particular, a meta-analysis of gender differences in temperament (Else-Quest, Hyde, Goldsmith, & Van Hulle, 2006) found that there is a moderate gender effect for inhibitory control, with females scoring higher than males. In the current study, there were no gender differences in inhibitory control for 10-year-old boys and girls, but by 12 years of age, the expected pattern begins to emerge, with girls have relatively higher levels of inhibitory control. Else-Quest et al. (2006) did not examine aggression in the meta-analysis, but they found negligible gender differences in anger and frustration. In the current study, the 10-year-old girls had slightly higher levels of aggression than boys, with the pattern reversing by 12 years of age, at which time boys evidenced higher levels of aggression. In another recent study examining preadolescent gender differences in 10-year-old children using the EATQ-R, De Boo & Spiering (2010) found no gender differences in effortful control or aggressive mood. This pattern of results for 10-year-old children is similar to that reported for the 10-year-olds in the current study.

What implications do these results have for preventing car–bicycle collisions? An important component in developing intervention strategies for reducing bicycling injuries is determining who and what to target for intervention. Although there are numerous ways to focus intervention efforts, determining which segments of the population are most at risk for a particular type of injury appears to be a useful approach to targeting intervention efforts (Rivara & Aitken, 1998). Our findings indicate that 10-year-old children, and especially 10-year-old boys higher in aggression, may engage in the kinds of risky behaviors that put them at greatest risk for bicycle crashes. These children may especially benefit from bicycle training programs that provide feedback on gap choices and movement timing. For example, a bicycling simulator could be used to safely and systematically train children on choosing safe gaps for crossing and on initiating movement at the right time. Such training may help children learn to more tightly link decisions and actions when crossing roads with traffic.
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Conflicts of interest: None declared.

References


