Developmental Aspects of Children’s Behavior and Safety While Cycling

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Objective To examine children’s competence while cycling, as demonstrated in mistakes in performance and failure to comply with safety rules. Methods Children in three age groups (8, 10, and 12 years) participated in a realistic yet simulated traffic environment. Results The boys’ cycling speed increased steadily with age, while that of the girls increased from 8 to 10 but decreased at age 12. Most children had adequate motor control by age 10, and the youngest compensated for their less developed skills by cycling slowly and braking early at junctions. Serious mistakes, often related to the children’s age and gender, consisted of the children failing to stop at signals or stopping too late, especially at short stopping range. Conclusions There are considerable individual differences in children’s cycling competence that are related to biological factors, such as age and gender, and psychological factors, such as rule compliance and choice of cycling speed.

Key words children; cycling behavior; attention; safety rules; risk taking; traffic environment.
the individual's limited cognitive processing capacity but is also characterized by flexibility and adaptability. More automatic control is found in tasks that have been practiced over longer periods of time. Here, performance tends to be quick and efficient, requiring little cognitive processing, but is also fairly inflexible and less amenable to conscious modification (Schneider & Shiffrin, 1977; Shiffrin & Schneider, 1977). The former mode is likely to be characteristic of the performance of the young, novice cyclist, while the latter mode will be more likely to be characteristic of older children with more cycling experience.

Younger children can also be expected to have difficulty sustaining a state of concentration in many tasks, and to be susceptible to distraction by irrelevant stimuli (Plude, Enns, & Brodeur, 1994; Sandels, 1970). In the young cyclist, this may be seen in a difficulty in attending simultaneously to more than one aspect of a dangerous situation, such as when two cars approach the point at which the child is about to cross the road (Briem & Bengtsson, 2000).

There are various sources of distraction. Listening to music (e.g., through a Walkman) while cycling can, a priori, be expected to distract some children in this complicated task. Previous studies have provided somewhat conflicting evidence, some finding music to improve and others to impair performance on tasks requiring concentration (Beh & Hirst, 1999; Crawford & Strapp, 1994; Daoussis & McKelvie, 1986; Fogelson, 1973; Mayfield & Moss, 1989; Schreiber, 1988; Wolf & Weiner, 1972). Some have shown interaction effects between the presence of music, the difficulty of the task, and the child's age (Higgins & Turnure, 1984). Two effects stand out here, viz., that in some cases music seems to cause cognitive overload, while in others the sound of music stimulates the individual to mobilize extra effort. Either way, music would seem to be a suitable distractor in children's cycling performance.

The way children manage cycling speed is likely to be an important factor in their performance. This applies both to the general choice of speed and the ability to adapt one's chosen speed to prevailing circumstances. While increased speed brings about a reduction in the time available for decisions and maneuvers, some children will cycle faster than their capacity allows and therefore be more exposed to accident risk.

One would expect cycling performance to improve with age and increased cognitive and motor capacity, taken together. Yet the accident statistics do not support this observation (Briem, 2003a; Peterson, Gillies, Cook, & Schick, 1994). This may suggest that older children subject their more developed capacities to greater demands than younger children, by cycling faster and/or under more distracting conditions, thereby increasing their accident risk (Peterson, Oliver, Brazeal, & Bull, 1995; Wilde, 1994).

The present study examines children's cycling behavior, particularly the capacity to react adequately to both variable and systematic changes in attentional requirements. Age- and gender-related differences were hypothesized, both in the children's ability to control the bicycle and in the way situational demands and distraction affect their behavior in critical situations. Thus, older children were expected to have greater confidence in their abilities, to take greater risks, and, as a consequence, to sometimes make serious mistakes. Girls were expected to be more careful than boys, to cycle more slowly, and to make fewer serious mistakes.

**Methods**

**Participants**

A total of 57 children took part in the study, 26 girls and 31 boys, recruited from the second, fourth, and sixth school years (mean ages = 8.7, 10.6, and 13.1 years, respectively) at a primary school in a town in southern Sweden. Participation was voluntary and subject to the approval of the school authorities and teachers and written permission from the parents.

**The Test Site and Materials Used**

The study was conducted at a “traffic playschool,” which is a test track that contains reduced-scale, yet realistic, roads, bicycle lanes, pedestrian lanes, and an abundance of road signs. It is located on the edge of a park near the children's school and is occasionally used for teaching purposes. The layout is shown in Figure 1, and the basic landmarks used in the experiment are marked on the map. The track consists of a simple system of asphalt roads, each divided into two traffic lanes, 2.2 m wide, with a broken line down the middle. Two “rounds,” or laps around the track, were employed: a whole round of the outside of the track (b) and a half round through the middle (c), their total lengths measuring 120 and 90 m, respectively. At the middle of the track, four houses were located around a four-way crossing, and these, along with the trees and bushes, prevented the cyclists from observing the entire track at any one time. Two stationary signaling devices of standard design were installed, one at the railway crossing (triangular sign with...
two red, flashing lights and a sound signal from a bell [(g)], the other at the four-way crossing (standard traffic lights, red-amber-green [(g)]). There was fairly constant traffic noise from nearby streets. The children's behavior was video-recorded from two positions [(h)], diagonally from the front at both crossings (see Figure 1).

Many of the older children brought their own bicycles to the test, while the younger children normally used good, standard bicycles provided at the site, individually adjusted to suit each child. These bicycles all had pedal brakes, while some of the older children had bicycles with hand-operated brakes. All the children cycled the track wearing protective helmets.

Procedure

Before setting off, the children were instructed in groups of two or three to cycle around the track, alternately completing whole rounds (passing the railway crossing) and half rounds (passing the four-way crossing). The children were instructed to behave as if they were in normal traffic, to pay particular attention to the traffic lights, and to stop when the lights changed to red. They were told to cycle at the speed they normally would under comparable circumstances, for instance when cycling to meet a friend. After the instructions, one of the experimenters cycled ahead of the children for two rounds, with signal changes on each round. The instructions were concluded with the children cycling alone twice, with the experimenter looking on.

During the experiment, the children took turns cycling individually, and the children not cycling were not allowed to watch, but sat inside one of the houses. Each child took two turns at cycling (Parts 1 and 2), once with and once without potential distraction in the form of popular music played on a Walkman (using earphones), the children themselves adjusting the volume to a level they found comfortable. In Part 1, the child cycled 11 rounds, alternating half and whole rounds, beginning and ending with a whole round. Signals were changed to red in 4 rounds (R): R5 (whole), R6 (half), R8 (half), and R9 (whole). Then the first child took a 7–10 minute break, sitting inside the house, while the second child cycled his/her rounds in Part 1. The first child returned to take his/her second turn (Part 2), cycling another 11 rounds with four signal changes as before, after which the second child concluded his/her Part 2.

The critical events recorded on video were the children’s reactions when the signal changed to red at the crossings. The two stopping distances before the stop line in front of the signal lights are marked in Figure 1 as e (short) and f (long) (see Independent Measures below). The signal change was activated manually by one of the experimenters when the children’s front bicycle wheel reached the (discreetly) marked stopping distances.
Dependent Measures

Cycling Speed

Time per round (TPR) in seconds was measured with a stopwatch in both Parts 1 and 2 on four whole rounds (R1, R3, R7, and R11) without a signal change, a total of eight times in both parts together: R1 (after starting from a standstill), R3 (before the first signal change), R7 (after two signal changes), and R11 (after four signal changes). The mean speed per round is reported in meters per second (mps) $= 120/TPR$ (1 mps $= 3.57$ km per hour).

Behavior at Signal Changes

The recorded measures of the children's performance were:

- The number of times they failed to brake to a standstill before the stop line when the signal changed. This included (1) the times when the children completely failed to stop at a signal (missed signals); (2) the times when they responded to the signal change but were unable to stop in time, or stopped so late that the cycle partly or completely passed the stop line (overshooting), recorded either as the number of times the children overshot or as a degree of overshooting on a scale from 1 to 3 (1 = more than a quarter but less than half the bicycle, 2 = more than half but less than the whole bicycle, and 3 = the whole bicycle beyond the line); and (3) a combined measure indicating the occurrence of either missed signals or overshooting on a given occasion.

- Their competence when braking at a signal measured by whether they jumped down from the bicycle instead of braking in a more conventional way. This included placing one or both feet on the ground, even while the bicycle was still moving quite fast, then walking, running, or hopping along, holding the bicycle by the handlebars until able to stop.

Independent Measures

Between-subject variables were age group (school years 2, 4, and 6) and gender. Age (8.0–13.7 years) and cycling speed, in mps, were used as correlates in several analyses. Within-subject variables were crossing (railway crossing, four-way crossing), stopping range (long [3.5 m], short [1.5 m]), and distraction (music, no music). Requirement for fast reaction was explicitly varied by activating the signals at either short or long stopping range, and demands were placed on the children's attention capacity by having them listen to music while cycling. The order of levels of all within-subject independent variables was carefully counterbalanced between age groups and genders.

Results

The level of significance was set at $5\%$. Post hoc testing was done for all main factor differences, the Games-Howell ($gh$) for between-subject and Scheffe’s $F$ ($sf$) for within-subject differences. Significant analysis of variance (ANOVA) results are shown in Table I.

Cycling Speed

A child’s cycling speed was estimated as the average of R3, R7, and R11 (a total of six rounds in Parts 1 and 2; overall $M = 3.63$ mps, $SD = 0.58$, range $= 2.50–5.54$). A repeated-measures ANOVA indicated significant main effects of age group, gender, and their interaction (see Table I, Speed; and Figure 2). A breakdown analysis in one-way ANOVAs indicated that the cycling speed increased for boys between Years 2, 4, and 6 ($p_{gh} < .05$ in all three comparisons) and for girls between Years 2 and 4 ($p_{gh} < .05$), but not Year 6. A significant difference between boys and girls was found only in Year 6 ($p_{gh} < .05$).

Missed Signals

Nearly half the children (27) failed to stop at signal changes at least once out of the eight rounds, (see Table II). A one-sample sign test (hypothesized value $= 0$) indicated $p < .01$. No correlation was found between cycling speed and number of missed signals, $r(55) = -.06$, ns.

ANOVA results (Table I, Missed Signals) indicate that the majority of missed signals occurred among the girls, at short stopping range and at the four-way crossing (Figure 3). Direct observation of the video recordings in slow motion revealed that the girls sometimes looked up at the signal light at the four-way crossing from a distance of several meters before it changed to red, then looked down and missed seeing the light change. The children also missed the signal disproportionately often at short range, at the railway crossing, while listening to music.

Overshooting

On average, the children overshot more than twice during eight rounds with signal changes (Table II). While less than one fifth (9) succeeded in coming to a halt on all eight occasions before the bicycle had partly or wholly overshot the stop line (on the scale of 1–3; see
Behavior at Signal Changes above; hypothesized value = 1, \( p < .01 \), more than two fifths of the children (23) failed at least once to stop before the whole bicycle had passed the stop line (gross overshootings = 3, see Behavior at Signal Changes above; hypothesized value = 0, \( p < .01 \)). The degree of overshooting was significantly correlated with cycling speed, \( r(55) = .32, p < .05 \).

ANOVA results (Table 1, Overshooting) indicate that the tendency to overshoot was greatest at short stopping range for the Year 4 girls and the Year 6 boys, with a steady increase in degree of overshooting from age 8 to 12 (\( p_{GH} < .05 \)). Whereas for the girls, overshootings occurred mostly at the four-way crossing, for the boys they occurred at both crossings.

### Missed Signals and Overshooting

As many as 52 out of the 57 participants (91%) either missed a signal or overshot the stop line at least once at the eight signal changes (Table II) (sign test, hypothesized value = 0, \( p < .01 \); hypothesized value = 2, \( p < .05 \)). If we include only serious mistakes (i.e., the child missed the signal or grossly overshot), we see that 41 of the children (72%) committed these mistakes at least one time out of eight (Table II) (sign test, hypothesized value = 0, \( p < .01 \)).

ANOVA results for the absolute occurrence of serious mistakes (Table I, Missed Signals and Overshootings) indicate that such mistakes happen mostly at short stopping range, where they tend to increase with age (\( p_{GH} < .05 \) between Years 2 and 6), and to a much lesser extent at long range, where they decrease with age (\( p_{GH} < .05 \) between Years 2 and 6). This is shown in Figure 4. Also, the girls made more serious mistakes at short range at the four-way crossing than the boys (cf. Figure 3).

### Jumping Down from the Bicycle at Signal Changes

ANOVA results (Table I, Foot-on-Ground Stops) indicate that this inefficient braking method was employed mainly by the younger children (\( p_{GH} < .05 \)) at long stopping range at the railway crossing. Jumping down was also significantly correlated with cycling speed, \( r(55) = -.32, p < .05 \).

### Sequential Effects

#### Speed Throughout the Experiment

Cycling speed was similar in Parts 1 and 2, with means of 3.38, 3.69, 3.66, and 3.59 mps in the four timed rounds. It was
significantly lower in R1 than in R3, R7, and R11 ($p_{SF} < .01$ in all three comparisons) and decreased from R3 to R11 ($p_{SF} < .05$).

**Speed Related to Distraction.** No effects on cycling speed were found, sequential or otherwise, specifically attributable to the incidental music.

**Sequential Effects in Missed Signals and Overshooting.** The children missed the signal less often in Part 2 ($M = .09$) than Part 1 ($M = .16; p_{SF} < .05$), and less often in R9 ($M = .04$) than in R5, R6, and R8 ($Ms = .10, .18, and .18; p_{SF} = .01$). No effects were significantly related to overshooting.

**Discussion**

A basic assumption here is that children’s cycling performance is a joint function of their cognitive and motor capacities and the demands placed on these capacities, and that increased task load leads to a deterioration in performance. Task-load variation was achieved through systematic variation in stopping range and distraction and was further regulated by the children’s own cycling speed. As the children grew older, we found an increase not only in cycling speed, but also in the number of mistakes they made. The majority of mistakes occurred at short stopping range, which required faster reactions.

Contrary to our hypotheses, increasing the presumed cognitive task load even further (i.e., using music as a distractor) did not result in more mistakes due to facilitation or interference. Possible reasons for this are either that music is generally not a distractor for children or that children are able to “tune out” irrelevant and non-demanding stimuli when performing other, more important tasks. The latter explanation receives support in analogous studies of older individuals (Briem & Hedman, 1995).

The children’s cycling mistakes were divided into two main categories: overshootings and missed signals. In the case of overshootings, the child noticed the signal change but did not manage to stop until the bicycle had, partly or wholly, passed the stop line. Speed alone cannot satisfactorily explain all these mistakes. Clearly, the children preferred to stop with the front wheel as close to the line as possible, although generally not across it. This was seen in the video recordings, where

![Figure 3](https://example.com/figure3.png)  
**Figure 3.** Mean number of signals missed by boys and girls, respectively, at short and long stopping ranges, at the railway and four-way crossings. Standard errors are indicated.

![Figure 4](https://example.com/figure4.png)  
**Figure 4.** Mean number of serious mistakes (missed signals and gross overshootings) in relation to stopping range and age group. Standard errors are indicated.

| Table II. The Number (%) of Children Who Made a Specified Number of More or Less Serious Mistakes at the Stop Line on 8 Trials |
|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | M | Odds |
| MS | 30 (53) | 8 (14) | 10 (18) | 8 (14) | 1 (2) | 1.0 | 1.8 |
| OS | 9 (16) | 16 (28) | 15 (26) | 8 (14) | 3 (5) | 4 (7) | 2 (4) | 2.0 | 1.4 |
| GOS | 34 (60) | 18 (33) | 4 (7) | 1 (2) | 0.6 | 1.15 |
| MS + OS | 5 (9) | 9 (16) | 9 (16) | 9 (16) | 13 (23) | 9 (16) | 2 (4) | 1 (2) | 3.0 | 1.3 |
| MS + GOS | 25 (42) | 18 (32) | 10 (18) | 10 (18) | 3 (5) | 1 (2) | 1.5 | 1.6 |

MS = missed signals; OS = overshooting; GOS = gross overshooting.

The last two columns show the mean number of mistakes per child and the odds that a cycling child will make a mistake.
the children, while waiting for the light to change back to green, often moved the bicycle backward behind the stop line after having overshot. Cycling at a fairly high speed, aiming to stop as close to the line as possible, is bound to sometimes result in overshootings. Telling children to cycle at a normal speed and not to race clearly did not have an effect.

More than half of the children completely failed to stop at least once in eight signal changes, thus making a mistake that in real traffic would be associated with high risk of being run over. This included both the times when the children clearly did not see the signal and the times they noticed the signal too late and did not bother to stop. From the video recordings, we saw that the latter sometimes occurred: The children, while cycling past either of the crossings, would occasionally brake, shout out, grimace, or grin sheepishly, but, being beyond the stop line, would carry on cycling.

The children missed signals more often at the four-way crossing, which, unlike the railway crossing, had only a light signal. The significance of the sound signal was corroborated by the fact that the children more frequently missed the signal at short range at the railway crossing when listening to music. It is possible that the children at times relied on the sound of the bell to tell them to stop at the railway crossing, causing them to pay less attention to the light or even disregard it altogether. Obviously, listening to music while cycling may serve to mask other, important auditory events, in a way that compromises the children's safety.

The boys generally made more speed-related mistakes than the girls. The girls, however, missed more signals than the boys, primarily girls in Years 4 and 6 at the four-way crossing. In the video recordings, we see these girls cycling slowly round the track. At the four-way crossing before the light changed, they would sometimes quickly look up, then down again, cycling straight past, apparently without any idea that the light had changed to red, a remarkable lapse of attention. In contrast, the boys, cycling considerably faster, often appeared more vigilant, directing their gaze at the signal as the light changed to red.

Real-life accidents happen under circumstances similar to the ones observed here, as indicated in several studies of child cyclists. Several investigators studying the patterns of serious accidental injuries sustained by child cyclists (Fife et al., 1983; Nixon, Clacher, Pearn, & Corcoran, 1987; Williams, 1976) found that the most common kind of car/bicycle collision occurred when a child, suddenly and without warning, cycled into the path of an oncoming automobile on the near side of the road. Under these conditions, the car driver would in many cases have had little chance of discovering the cyclist until it was too late to avoid a collision. The responsibility for the accident is then usually ascribed to the cyclist. However, the accident risk in these encounters is further aggravated by car drivers' not being fully aware of this kind of cyclist behavior. For this reason, Summala, Pasanen, Raesaenen, and Sievaenen (1996) suggested that drivers develop a visual scanning strategy that concentrates on the detection of frequently occurring major hazards at the expense of visual information associated with less frequent risks. Collisions with suddenly appearing cyclists would seem to fall into the latter category.

Missed signals and overshootings are both potential causes of accidents in real traffic. In the absence of other information, one might presume that both are caused by the same factors, but the results demonstrate that this is not the case, as, for instance, only overshooting is significantly correlated to cycling speed. There is some indication that some children “favor” one kind of mistake, but not both. A joint analysis of these serious mistakes shows a clear increase with age at the shorter stopping range, when the children are subjected to a greater task load, but a decrease with age at the longer range, where decision time is longer and the task load is smaller.

Although the youngest children generally made fewer mistakes, their cycling skills were fairly rudimentary. For instance, stopping the bicycle by placing one or both feet on the ground is normally a fairly inefficient strategy, which mainly the younger children employed, probably because they had not yet learned to make efficient use of the bicycle brakes. When employed at long range, especially at slow speed, this mode was fairly successful, whereas at short range it often resulted in the cyclist overshooting. Observation of the video recordings also showed that some of the youngest children carefully anticipated the signal changes, reducing their speed or braking at a distance of several meters, sometimes to a standstill, when approaching a crossing.

A cyclist's performance in a given traffic situation is determined not only by his or her motor and perceptual capabilities, as some researchers have implied (Drury & Daniels, 1980). Motivational factors determine how these abilities are utilized, and the need for attention to the task at hand is often overshadowed by other objectives, in ways that significantly affect children's accident proneness. It has been pointed out (Peterson,
Brazeal, Oliver, & Bull, 1997; Peterson et al., 1994) that as children grow older, they gain confidence as cyclists, at the same time as their fear of possible dangerous consequences decreases. Diminished apprehension with regard to the consequences of one’s actions, as well as changes in attitudes toward the social desirability of daring and spectacular actions, may lead to increased risk taking. Consequently, older children do not always perform better, even though their physical and cognitive capacity is superior to that of younger children.

The children in the present study were aware that they would not come to any serious harm if they happened to stretch the safety rules. This knowledge may have contributed to making their risk acceptance higher and lowered their vigilance. In real traffic, very few such mistakes actually lead to accidents, probably because there is no vehicle present at that particular moment. Children’s beliefs in their own invulnerability and actions resulting from such beliefs can have fatal consequences. Most accidents actually happen in environments where there is not much traffic, where children feel safe, and where they feel that playful risk taking does not matter.

The simulated and danger-free traffic environment in which the children’s cycling behavior was studied allowed good control of the experimental conditions and observation. The results confirm and complement those of earlier, comparable studies (Peterson et al., 1997; Peterson et al., 1994; Peterson et al., 1995). They demonstrate that children often ignore safety rules while cycling and that they will make mistakes, some children more than others, but can also learn to avoid these mistakes. As has been shown in earlier research (van Schagen & Broekhuis, 1994), learning from experience may, in this context, be considerably more effective than theoretical knowledge. However, all things considered, parents and others responsible for children’s safety should exercise extreme caution and think twice before letting children cycle in dangerous traffic.

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References


Briem, V. (2003a). Barns säkerhet i trafiken. [Children’s traffic safety]. Unpublished manuscript (final report to Vinnova, the Swedish agency for innovation systems).


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