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Influence of Virtual Reality Training on the Roadside Crossing Judgments of Child Pedestrians

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The roadside crossing judgments of children aged 7, 9, and 11 years were assessed relative to controls before and after training with a computer-simulated traffic environment. Trained children crossed more quickly, and their estimated crossing times became better aligned with actual crossing times. They crossed more promptly, missed fewer safe opportunities to cross, accepted smaller traffic gaps without increasing the number of risky crossings, and showed better conceptual understanding of the factors to be considered when making crossing judgments. All age groups improved to the same extent, and there was no deterioration when children were retested 8 months later. The results are discussed in relation to theoretical arguments concerning the extent to which children's pedestrian judgments are amenable to training.

Keywords: child, pedestrian, injury, training, education

It is well established that children suffer an exceptionally high pedestrian injury rate relative to adults at all levels of severity (Rodriguez & Brown, 1990; Singh & Yu, 1996; U.K. Department for Transport, 2002a). Children aged 5–9 years, for example, typically suffer four times the injury rate of adults, despite far lower levels of exposure to traffic and therefore to risk. Not surprisingly, pedestrian education programs have long been advocated as one means of improving children's ability to cope with traffic but, historically, with limited success. Traditionally, the problem has been cast in terms of children's limited knowledge about traffic and the rules needed to interact with it. However, knowledge enhancement approaches fail to capture the complexity of the pedestrian task, and interventions aimed at increasing knowledge per se typically make little, if any, impact on children's traffic behavior (Rothengatter, 1981; Thomson, 1991; Zeedyk, Wallace, Carcary, Jones, & Larter, 2001). This has led to reappraisal of the aims of road safety education and much discussion as to what can be realistically achieved with children of different ages (e.g., Chapman, 1998; Duperrex, Bunn, & Roberts, 2002; Schieber & Vegega, 2002; Thomson, Tolmie, Foot, & McLaren, 1996).

More recent research characterizes pedestrian competence in terms of skill rather than knowledge and emphasizes the psychological processes underlying skilled pedestrian behavior (e.g., Thomson et al., 1996). Research has also started to focus on the metacognitive processes by which these skills are deployed (e.g., Whitebread & Neilson, 2000). Correspondingly, studies addressing pedestrian skills directly, usually through practical training in real or simulated traffic environments, have proved surprisingly fruitful. Skills that have been improved in this way include crossing at parked cars and intersections (Rothengatter, 1981, 1984; Thomson & Whelan, 1997), using designated crossings (Tolmie et al., 2003), identifying roadside dangers (Ampofo-Boateng et al., 1991; Thomson et al., 1992; Thomson & Whelan, 1997), sensitizing children to information specifying the intended behavior of other road users (Tolmie et al., 2002), and even reducing roadside impulsivity (Gerber, Huber, & Limbourg, 1977). In all these cases, practical training has led to substantial and relatively robust improvements in the behavior of children as young as 5 years old.

Visual Timing and the Negotiation of Traffic Gaps

Although such findings are encouraging, it is not yet clear whether all pedestrian skills are equally amenable to training. One skill that has proved particularly contentious is the ability to estimate the time-to-arrival of approaching vehicles with an intended crossing point. This skill becomes critical once the pedestrian starts to cross busy streets where it is not feasible to follow the common advice to wait until the road is clear before crossing. In such cases, the pedestrian must learn to detect the time available for crossing (dependent on the temporal size of gaps between vehicles) and relate this to the time required to cross (dependent on factors such as road width and the pedestrian's potential speed of movement). If the time available were greater than the time required, then crossing would be possible in principle—although the wise pedestrian would set a safety margin to take account of estimation errors or unforeseen events. Crossing busy roads thus depends on pedestrians' sensitivity to optical variables specifying time-to-contact, on their ability to use this information to calibrate their activity, and on their capacity to make strategically appropriate decisions.

How these competences develop and the extent to which they might be promoted through intervention has been the source of much controversy. One long-standing and influential line of argument is that children lack the ability to make accurate spatiotemporal judgments until the age of 9–10 years. This argument follows in part from reported age trends in studies of distance and velocity perception (e.g., Hoffman, Payne & Prescott, 1980; Salvatore, 1974) but rests more fundamentally on the supposed inability of the preoperational and early concrete operational child to conceptualize the interrelationship between variables (Piaget, 1955). For example, when asked to determine which of two trains will arrive at a destination first, children tend to fixate on only one variable (distance typically taking precedence over velocity). As a result, they often misjudge which train will arrive first (Piaget, 1969). Several authors have invoked these characteristics in accounting for the high rate of child pedestrian injuries (e.g., Cross, 1988; Cross & Mehegan, 1988; Kenchington, Alderson, & Whiting, 1977; Sandels, 1975).

An alternative line of thinking with its roots in the ecological theory of perception (Gibson, 1979) holds that time-to-contact judgments are essentially perceptuomotor in nature and do not depend on higher order cognition of the sort described by Piaget. Moreover, time-to-contact is directly specified within the dynamic optic array and does not need to be derived from information about distance and velocity in the first place. For example, Lee (1976) has demonstrated that the time-to-contact of an approaching surface is visually specified by the inverse of the rate of dilation of the surface on the retina. Because this information is independent of information about the surface's absolute distance or velocity, the argument is that time-to-contact does not need to be computed, only detected. In support of this, numerous studies show that accurate timing is possible where flow information is present but distance information is excluded (e.g., McLeod & Ross, 1983; Schiff & Detwiler, 1979; Todd, 1981).

The ecological analysis offers a far more optimistic prognosis regarding the potential of training, because it does not see visual timing as dependent on the attainment of concrete operational thought. Instead, it argues that what children lack is sensitivity to the relevant optical variables, together with opportunities for perceptuomotor calibration (Lee, Young, & MacLaughlin, 1984). If training were to provide such opportunities in a realistic but safe manner, the suggestion is that performance should improve, even in very young children.

Unfortunately, empirical studies of children's timing judgments have generated conflicting results regarding these opposing points of view. Most studies do report some improvement following training but the findings are compromised by disagreement as to the scale of improvements and even as to which aspects of performance need improving. For example, a number of authors argue that children overestimate the size of traffic gaps and therefore tend to judge dangerously small gaps as safe. Van Schagen (1988) presented children with traffic gaps of between 4 and 11 s and asked them to indicate which ones through which it would be safe to cross. Untrained 7-year-olds showed little discrimination, nominating almost 65% of what the author considered to be unsafe gaps (<7 s) as safe whereas at the same time judging 16% of longer gaps to be unsafe. Similarly, by using film sequences Vinje (1982) asked 7-year-olds to indicate the last possible moment at which it would be safe to cross. She rated 88% of the accepted gaps as too short. Through the use of video clips, Pitcairn and Edelmann (2000) also reported a marked readiness in 7-year-olds to accept "tight fits." Such findings suggest serious deficiencies in young pedestrians' visual timing judgments.

On the other hand, studies requiring children to make more natural judgments at the roadside have produced markedly different results. By using the "pretend road" method (in which children observed traffic on a real road but crossed an adjacent "pretend" one), Lee et al. (1984) estimated that only 9% of children's crossings could be considered tight fits, which compared favorably with the 7% made by adults. Studies that have used comparable roadside methodologies have reported similar rates (e.g., Demetre et al., 1992; Demetre et al., 1993; Young & Lee, 1987). Indeed, far from finding a bias toward hazardous decision making, these studies all report a bias in the opposite direction, with children missing many perfectly safe opportunities to cross. This tendency was so marked that Demetre et al. (1993) were sometimes forced to admonish children for missing opportunities in order to get them to make crossing decisions at all. Studies that have used unobtrusive observation to assess children's road crossing under natural conditions have also revealed surprisingly low numbers of hazardous decisions (e.g., Routledge, Howarth, & Repetto-Wright, 1976).

Conceptual and Metacognitive Considerations

Such findings are not easy to reconcile with the view that children's difficulties in crossing busy roads reduce to an inability to estimate the time available for crossing. They are, however, consistent with an alternative view that the problem may be more metacognitive in nature, reflecting limitations in knowing how to deploy basic perceptuomotor competences, rather than limitations in the competences themselves. For example, the reduction in missed opportunities that occurs with age may reflect the development of anticipatory behavior, with children starting to look ahead for gaps in the approaching traffic stream and preparing their crossing decisions in advance. Younger children tend not to look at gaps at all, concentrating instead on individual vehicles, and often focus on irrelevant variables, such as the vehicle's model or color, in preference to relevant variables, such as its speed, distance, or direction of travel (Tolmie, Thomson, Foot, McLaren, & Whelan, 1998). Experienced pedestrians also tend to cross as soon as a suitable gap arrives, thereby maximizing the size and safety of the gap, whereas younger children procrastinate before starting to cross. These long "starting delays" mean not only that many crossing opportunities are missed altogether but also that gaps that were initially safe may become dangerous by the time the child decides to accept them. A similar trend has recently been reported in child cyclists attempting to cycle through traffic gaps at an intersection. Plumert, Kearney, and Cremer (2004) found that, although children accepted gaps of the same size as adults, their crossings were much riskier because they delayed much longer before initiating the crossing. Such behavior points to crude strategic thinking and decision making, rather than limited perceptual abilities, as the key problem in novice pedestrians. Correspondingly, shifts in the former aspects of performance are by far the most commonly reported improvements following roadside training, making trained children's behavior more like that of adults

(Demetre et al., 1992, 1993; Whitebread & Neilson, 2000; Young & Lee, 1987).

If this is correct, then training needs to offer more than opportunities for sensory–motor practice: It needs to address children's conceptual thinking about the task and the strategies they use to solve it. Most training programs have been remarkably weak in this regard, leaving it largely up to the children to decide what to do, with trainers intervening as little as possible. For example, the guidance offered by Young and Lee (1987) and Demetre et al., (1993) was restricted to occasionally admonishing children when they made obvious errors. It is, of course, possible that children's strategic thinking would improve through practice, even without intervention from the trainer. However, there seems to be no reason why these issues should not be addressed explicitly. Indeed, encouraging children to cross through gaps in the traffic stream involves such a fundamental shift in what most children have hitherto been taught that this would seem to be essential. Otherwise, the child is placed in a conflict situation between what the trainer now expects him or her to do (cross through gaps if they are safe), and what adults have always expected him or her to do in the past (never cross at all if vehicles are approaching).

The Present Study

In the present study, we constructed a training program that explicitly addressed the conceptual and strategic issues involved in learning to cross through traffic gaps. We also assessed the extent to which improved conceptual and strategic thinking would generalize to children's behavioral judgments at the roadside. According to Karmiloff-Smith's (1992) influential account of development through representational redescription, explicit conceptual understanding enhances cognitive flexibility, enabling the child to transfer learning to novel problems, conditions, or environments. Moreover, such learning tends to be robust, and performance can therefore be expected to remain stable, or even improve, in the longer term. In the context of pedestrian behavior, this is particularly important, as much concern has been expressed over the robustness of improvements following purely sensory–motor practice (Demetre et al., 1993). Thus, a program explicitly addressing the conceptual side of the task may have advantages both in terms of generalization of learning and stability of learning over time.

To promote conceptual learning, a training environment that allows children to explore ideas in a safe but realistic fashion must be found. Although the roadside is often considered the optimal context (Ampofo-Boateng & Thomson, 1990), the reflection and discussion needed to promote conceptual growth are difficult to address there as conditions change so rapidly. For this reason, we developed a computer-simulated traffic environment to replace the real one. On the negative side, the sensory–motor experience provided by such a simulation is clearly a poor proxy for that provided by the roadside. Nevertheless, it was hypothesized that the opportunities provided for conceptual growth would override limited sensory–motor experience and would transfer to behavioral judgments made in real traffic.

In addition to physical milieu, care must be taken in the choice of instructional method because some promote conceptual understanding much more effectively than do others. In general, such understanding is most likely to develop where children collaborate in solving problems and least likely to occur where too much direct instruction is provided by trainers (Doise & Mugny, 1979; Wood, 1986). Although pedestrian training programs typically advocate one-to-one interactions between adults and children, this is probably not the optimal way to promote pedestrian skill development. In recognition of this, we devised a teaching method in which adults would work with children in small groups by using an interactional style designed to encourage children to work together as independently as possible but with the adult acting as facilitator. The approach, which attempts to capitalize on the strengths of the peer collaboration method while retaining a useful level of adult input, has previously been found superior to either adult–child or peer collaboration methods per se in improving children's roadside visual search (Tolmie et al., 1998; Tolmie, Thomson, & Foot, 2000). The approach has therefore been implemented in the present study.

Finally, because baseline levels of skill vary as a function of age (Lee et al., 1984), and because of the controversy regarding the extent to which these skills can be acquired at all by children under 9 years of age, it was decided to run the program with three age groups in the critical range of 7 to 11 years old. In addition to the theoretical controversy, these data are important from a practical point of view because, even if all age three groups show improvement, it is not necessarily the case that they will improve equally. By showing the improvements to be expected at different ages, the study may also assist in determining the optimal age at which such training might best be introduced. The study thus addressed the following hypotheses:

> *Hypothesis 1:* Training should result in improved conceptual understanding of the crossing task and the factors to be considered in making crossing judgments.
>
> *Hypothesis 2:* Training should also lead to improved roadside behavior—that is, there should be significant transfer of learning from computer to roadside.
>
> *Hypothesis 3:* Improvements will persist at long-term follow-up—that is, trained children should continue to perform better than at pretest on both behavioral and conceptual measures.
>
> *Hypothesis 4:* Improvements may be more marked in older children who start from a higher pretest baseline. However, significant improvement should be evident in all age groups.

Method

Design

Before training began, children were individually pretested at the roadside in order to establish baseline levels of skill. These tests were repeated immediately after training (Posttest 1). We ran a long-term follow-up 8 months later (Posttest 2). Control children from matched schools also undertook the roadside tests but did not receive training.

Training consisted of four sessions at the computer, each lasting approximately 30–40 min, held at roughly weekly intervals. Children were trained in groups of 3, as far as possible by the same volunteer trainer.

Participants

Participating children were equally drawn from two areas of the city of Glasgow. The first was a large, peripheral housing scheme with a long history of social and economic deprivation. The other had a more mixed socioeconomic profile. Two schools, one in each area, hosted the training program. Two matched schools in each area acted as controls. Criteria used in matching were school size, geographical location, catchment area, and socioeconomic index.

Children aged 7, 9, and 11 years ($N = 129$) undertook the training program. Of these, a 70% sample ($N = 94$) was pre- and posttested at the roadside. They also undertook the long-term follow-up test. The sample was balanced for gender within each age group, otherwise selection was randomized. A group of control children ($N = 49$) was pre- and posttested at the same time as were trained children. A separate control group ($N = 46$), recruited from the second matched control school in each area, undertook the delayed follow-up test. Mean ages of trained children were 7.1, 9.2, and 11.2 years. The control children who undertook the pretest and Posttest 1 were aged 7.2, 9.1, and 11.1 years. The control children who undertook Posttest 2 were aged 7.2, 9.1, and 11.1 years.

Software Design and Training Environment

Children were trained with a computer-simulated traffic environment incorporating realistic 3-D scenes, animation routines, and interactive features. The software was authored with Macromedia Director 6.0 for the PC platform with a Pentium II running at 233 MHz and the Windows 98 operating system. Runtime versions of the software were developed that would run successfully on low-end machines such as might be found in some schools. The simulation took the form of a small town neighborhood in which child characters were required to undertake a variety of journeys. On each, the character(s) would be confronted with busy roads that had to be crossed. Participants' task was to help the character do so safely. To do this, they had to observe the traffic, decide on a point when it would be safe for the character to step out, and initiate the crossing by pressing a designated button. The computer would then take command and provide feedback in two ways. If the selected gap was adequate (see the *Scoring* section for definitions), participants would see the character cross through the approaching traffic and reach the far curb. If the gap was smaller than this (a tight fit), the computer would emit the sound of screeching brakes, the action would freeze, and the character's ghost would depart his or her body and drift across the road. Trainers used this feedback to initiate discussion among the children. Crossings could be repeated to permit multiple attempts at the same problem. The action could also be paused so that discussion could take place online.

All action was shown from an elevated, semiaerial viewpoint so that participants could see sufficiently far along the road in both directions from a single screenshot. In previous studies, we found that performance with such viewpoints has mirrored performance from a roadside viewpoint (Tolmie et al., 1998). Each traffic animation ran on a continuously repeating loop lasting 20 s. Vehicle speeds were set so that, relative to the scale of the roads and surroundings, they corresponded to speeds of approximately 30 mph (48km/hr). Each loop contained a number of gaps that were large enough to cross through, together with many that were not. Children made crossing decisions by clicking a large *go* button at the foot of the screen. A *pause* button enabled the action to be stopped at any time. A further button allowed the crossing to be restarted from the beginning. Information on characters' walking speed was available by observing them walk along the street to the starting point of each crossing.

Each training session presented between eight and nine crossing problems. These were strung together into a story to provide a rationale for the activity (e.g., two children go to the play park, one falls and has to be helped home, the friend comes back to retrieve their bicycles, and so on). Each session was designed to emphasize specific factors that need to be taken into account (e.g., variations in road width, traffic speed or density, the pedestrian's potential speed of movement). Scenarios also increased in complexity across training sessions.

Trainers

Mothers ($N = 35$) of the children in the schools volunteered to take part in the study. Recruitment was undertaken in consultation with head teachers and by means of the letters sent to parents requesting permission for their children to take part in the study. Each volunteer took responsibility for a minimum of two groups of 3 children. Although an effort was made to ensure that trainers worked with the same children, in practice there was some variation in the composition of groups from week to week. Volunteers trained only other people's children: A trainer's own child was always allocated to another trainer.

Volunteers themselves received a half-day training course aimed at ensuring that they understood the objectives of the program, became familiar with the software, and gained experience of the teaching methods. They also received guided practice in working with children. Emphasis was placed on the use of language appropriate to the age of the children, directing children's activity in the required nondidactic manner (e.g., without giving constant commands or instructions), and scaffolding children's activity so that they would increasingly take responsibility for their own progress as they moved through the program. Volunteers also received a short reference manual.

Training Objectives

The training objectives were to (a) encourage children to focus on time rather than distance–speed per se; (b) improve understanding of the time required–time available distinction, and the factors that cause this to vary; (c) encourage anticipation and forward planning; (d) maximize the safety of accepted gaps by minimizing starting delays; (e) set appropriate safety margins and avoid making tight fits.

Training Procedure

During each session, trainers guided the children through the problems of the day. At each location, children were encouraged to observe the traffic and try to identify points when it would be safe for the character to cross. A child was then selected from the group and asked to make a crossing decision. The remaining children acted as discussants. Selection was systematic so that all children had equal opportunities to take the lead. Discussants were encouraged to comment on the lead child's crossing decision and, if appropriate, make suggestions as to how it might be improved. When agreement was reached, the lead child was allowed to make the character cross. Trainers encouraged further discussion in light of the feedback subsequently provided by the computer.

The trainer's aim was to listen to children's reasoning, guide their thinking in appropriate directions, and avoid imposing solutions. Trainers took a fairly proactive role during the early trials but were expected to fall increasingly into the background as training proceeded. The nature of trainers' interventions also changed over time. For example, in later trials children often experienced examples relating back to issues raised in earlier sessions. Trainers drew children's attention explicitly to such connections.

Finally, children were continuously alerted to the danger of actually crossing busy roads. Trainers emphasized this from time to time during training and, at the end of each session, a warning message was displayed on screen for trainers to read out. Documentation sent to parents also emphasized that they should continue to accompany children in accordance with government guidelines.

Pre- and Posttesting Procedure

Children were individually tested at roadside locations close to their school. Timing judgments were assessed on busy, two-lane roads with a relatively continuous traffic flow. For safety reasons, quieter roads of identical width were used to calculate children's crossing times. All roads had a speed limit of 30 mph (48 km/hr). There were no parking bays on any of the roads, and no vehicles were ever parked nearby during testing. To ensure that conditions were standardized as far as possible, testing always took place at fixed times of day and experimenters initiated trials only when appropriate traffic flow was present.

On the busy road, children stood at the curbside with a clear view of traffic in both directions. They then estimated when it would be safe to step out and indicated this by raising their arm and shouting "Now!" A continuous video recording, showing these signals in relation to the movement of passing vehicles, was made for each child. Ten judgments were recorded, or fewer if the child did not initiate 10 crossings within the 20-min testing period. In practice, almost all children made 10 judgments and none made fewer than 8.

Children's actual crossing times were measured by asking them to cross the quiet road at normal walking speed on five occasions. The time taken, from the moment they stepped out until the moment they stepped on to the far curb, was recorded by stopwatch. A measure of estimated crossing time was calculated by asking children to visualize themselves crossing the road without actually doing so. Children signaled the points at which they started and completed each of five mental crossings. To avoid contamination, estimated crossings were made before actual crossings. Children were closely supervised at all times during these tests.

To assess children's conceptual understanding, an interview was held with each child immediately after roadside testing. The interview was open-ended but began with the framing question, "On a busy road, with cars going past all the time, how do you decide when it's safe to cross?" Interviewers were looking for evidence of understanding the importance of four variables: time available for crossing; time required to cross; the need to focus on gaps not just vehicles; and the need to look ahead and anticipate crossing opportunities. If children said something that implied awareness of one of these variables, follow-up questioning was used to determine the extent to which the child understood why the variable was important. Care was taken never to suggest the variables to the child, and follow-up questioning was used only if a variable was mentioned spontaneously in children's speech. All interviews were tape recorded for subsequent coding.

Scoring

During transcription of the videos, a time record was made of the passage of all vehicles past the child's projected crossing line. This consisted of recording the point at which the front of each passing vehicle crossed the line, together with the point at which the child raised an arm. The point at which the rear of the immediately preceding vehicle passed the line was also recorded, together with the arrival of the next approaching vehicle. The following performance measures were derived from these data.

Estimated and actual crossing times. These were based on the medians[1] of the five estimated and the five actual crossing times.

Accepted gap size. This is the temporal size of any gap nominated by the child as safe. Its size was defined from the moment the rear of a vehicle passed the projected crossing point until the same point was passed by the front of the next vehicle.

Starting delay. This corresponds to the time the child allowed to elapse after the rear of the leading vehicle had passed before raising an arm to indicate they would start crossing.

Missed opportunities. A missed opportunity was defined as a rejected gap more than twice as long as the time required by the child to cross the road. The time required was based on the median of the five trials that the child had taken to walk across a road of the same width.

Tight fits. A tight fit was deemed to have occurred when the time available was less than twice the time required to cross the lane in question. For example, when the next approaching vehicle was in the near-side lane, a tight fit occurred if the time available was less than the time required to cross both lanes (e.g., the car passed before the child reached the far curb). Tight fits do not usually correspond to the child being knocked down, but rather represent "close calls."

Conceptual understanding. The tape-recorded interviews were coded according to whether children showed evidence of understanding the importance of four variables: (a) the need to focus on gaps in the traffic flow, (b) the concept of time available for crossing, (c) the concept of time required for crossing, and (d) the need to anticipate opportunities to cross. If the child identified one of these variables and follow-up questioning showed that the child understood the variable's importance, then the child was allocated one point. Because there were four variables, children's scores ranged from 0 to 4. Scoring reliabilities were assessed separately for each variable by comparing the ratings of two independent raters on a randomly selected 10% sample of interviews. Reliabilities were .92, .82, .87, and .90, respectively. Reliability of the overall scores was .87.

Table 1
Results of Analysis of Variance on Pretest Scores for Each Variable

Dependent variable	*df*	*F*	*MSE*	Cohen's *f*
Group				
Actual crossing times	1	0.36	2.389	.05
Estimated crossing times	1	2.02	7.321	.12
Accepted gap size	1	0.25	44.402	.03
Starting delay	1	2.07	2.622	.12
Missed opportunities	1	1.59	22.857	.11
Tight fits	1	1.35	3.365	.10
Conceptual score	1	2.20	0.539	.12
Age				
Actual crossing times	2	0.99	2.389	.12
Estimated crossing times	2	0.80	7.321	.11
Accepted gap size	2	0.09	44.402	.03
Starting delay	2	8.42**	2.622	.36
Missed opportunities	2	0.28	22.857	.06
Tight fits	2	5.81**	3.365	.30
Conceptual score	2	3.12*	0.539	.22
Age × Group				
Actual crossing times	2	0.11	2.389	.04
Estimated crossing times	2	0.96	7.321	.12
Accepted gap size	2	1.85	44.402	.17
Starting delay	2	1.09	2.622	.12
Missed opportunities	2	1.32	22.857	.14
Tight fits	2	0.20	3.365	.05
Conceptual score	2	2.14	0.539	.18

Note. *df* (error) = 134.
$^{*} p < .05$. $^{**} p < .01$.

Results

Because preliminary analysis on each measure revealed no significant main effect of gender and no significant interactions, it has not been reported here.

Skill Levels Prior to Training

Baseline levels of skill prior to the intervention were assessed by means of children's pretest scores on each of the seven perfor-

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[1] Equivalent results are obtained if the mean is substituted for the median in these analyses.

mance measures. The data are illustrated in Figures 1–4. The results of analyses of variance (ANOVAs) with age and experimental group as variables are summarized in Table 1. There was no significant effect of experimental group on any of the seven measures and no significant interactions, suggesting that participants were well matched at the start of the study. Significant effects of age were found for three variables: starting delay, tight fits, and conceptual understanding. Starting delay decreased with age, showing that older children exploited gaps better by stepping out more promptly once a gap they intended to accept had arrived. Figure 1 shows that older children also made fewer tight fits. Figure 2 shows they had a better conceptual grasp of the factors to be considered when making crossing decisions and understood better why these factors are important.

There were no significant age trends on the remaining variables at pretest. Figure 3 shows that all children tended to reject traffic gaps unless the gaps were very large. They were therefore much more likely to miss safe opportunities to cross than to commit tight fits (see Figure 1). This conservative tendency is perhaps just as well, as estimated crossing times were quite poor in all age groups. Whereas children actually required an average of 6.4 s to cross the road, Figure 4 shows that, on average, they believed they required 1.2 s less than this. This bias would predispose children to overestimate the number of gaps they could safely cross through.

Effect of Training on Performance

For each variable, the effect of training was assessed by a two-way ANOVA with age (7, 9, 11) and test phase (pretest, Posttest 1, Posttest 2) as variables. Control performance was assessed by a two-way ANOVA with age (7, 9, 11) and test phase (pretest, Posttest 1) as variables. Because a different control group undertook the delayed posttest, Posttest 2 performance was compared with pretest performance separately.

Actual and Estimated Crossing Times

These data are presented in Figure 4, and results of the ANOVAs are presented in Table 2. For actual crossing times in the trained group, there was no significant main effect of age but there was a significant effect of test phase, with crossing times decreasing from an average of 6.4 s at pretest to 5.8 s at Posttest 2. Trained children thus crossed somewhat faster. It may be that the program led children to cross more decisively and appreciate from training that crossing should involve firm action. In the control group, there were no significant main effects or interactions. Comparison of pretest and Posttest 2 performance in the control groups yielded a *d* value of .11 (Cohen, 1988).

For estimated crossing times, identical analyses revealed no significant effects in either trained or control children (for Posttest

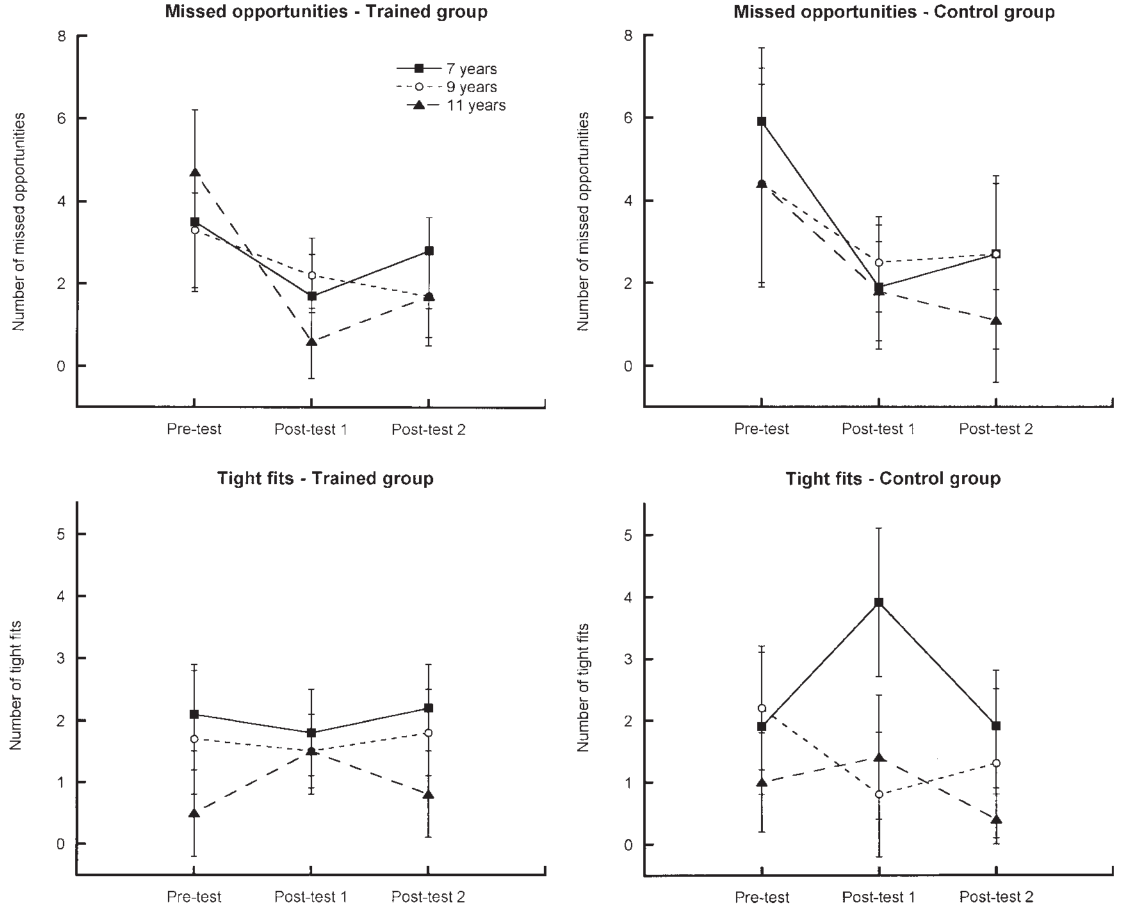

Figure 1. Mean number of missed opportunities and tight fits in trained and control children as a function of test phase. Error bars indicate 95% confidence intervals.

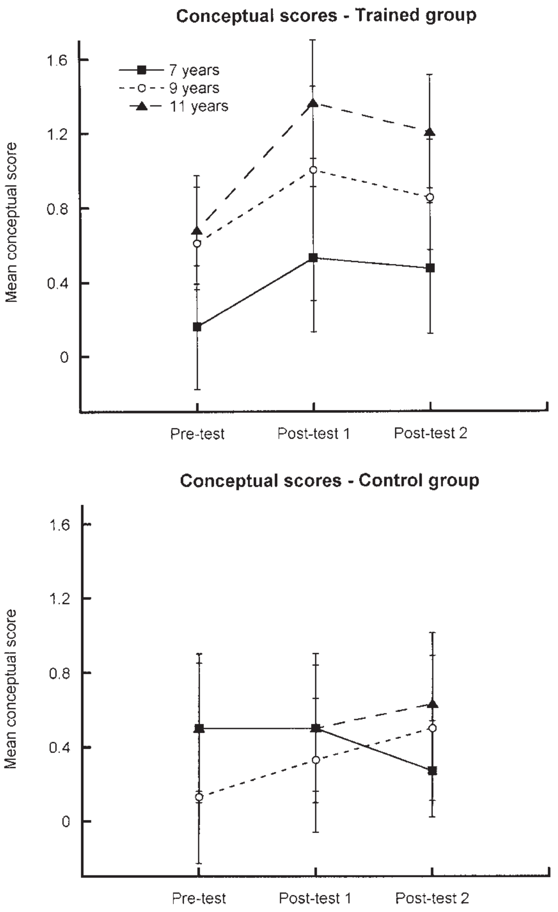

Figure 2. Conceptual scores for trained and control children as a function of age and test phase. Error bars indicate 95% confidence intervals.

2 vs. pretest performance in control children, $d = .03$). Thus, training did not cause children to modify their estimates of the time required to cross. This is not surprising as the program was not designed to modify these judgments and did not offer explicit opportunities to do so. However, Figure 4 shows that because actual crossing times decreased in the trained group, there was a better fit between estimated and actual crossing times than there had been at pretest. This small improvement was absent in the control group.

Accepted Gap Size and Starting Delay

The data on these variables are presented in Figure 3. ANOVA results are presented in Table 3. In the trained group, there was a significant main effect of test phase on both accepted gap size and starting delay. Figure 3 shows this is because trained children now accepted smaller gaps and also exploited gaps better by stepping into them more smartly. In controls, the effect of test phase was not significant (performance at Posttest 2 vs. pretest: accepted gaps, $d = .3$; starting delay, $d = .19$).

Missed Opportunities and Tight Fits

Data on these measures are presented in Figure 1. ANOVA results are presented in Table 4. For missed opportunities in the trained sample, there was a significant main effect of test phase, together with a significant Age × Test Phase interaction. Figure 1 shows the main effect is due to children missing fewer opportunities to cross after training than before. The interaction appears to be the result of changes in the rank order of the three age groups across test phases. However, there is no indication that these changes particularly favored the older children. For tight fits, there was no significant effect of test phase but there was a significant effect of age. Figure 1 shows this is because older children made fewer tight fits across all test phases.

For missed opportunities in the control group, there was also a significant main effect of test phase but no significant effect of age and no significant interaction. Performance at Posttest 2 was also superior to that at pretest ($d = .62$). For tight fits, there was no significant effect of test phase but there was a significant effect of age and a significant Age × Test Phase interaction. As in the trained sample, the age effect was due to the fact that older children generally made fewer tight fits across all test phases. The interaction appears to be due to the fact that, at Posttest 1, the 7-year-old controls actually made more tight fits than at pretest. This finding is not part of a general age trend, however, because scores for the separate control group who undertook Posttest 2 were very similar to pretest scores ($d = .29$).

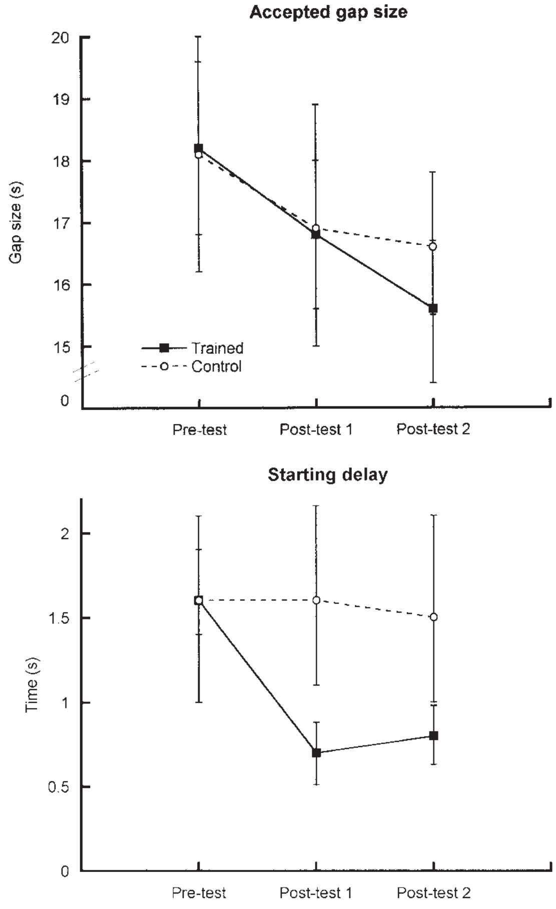

Figure 3. Mean accepted gap size and starting delay (in seconds) as a function of test phase. Error bars indicate 95% confidence intervals.

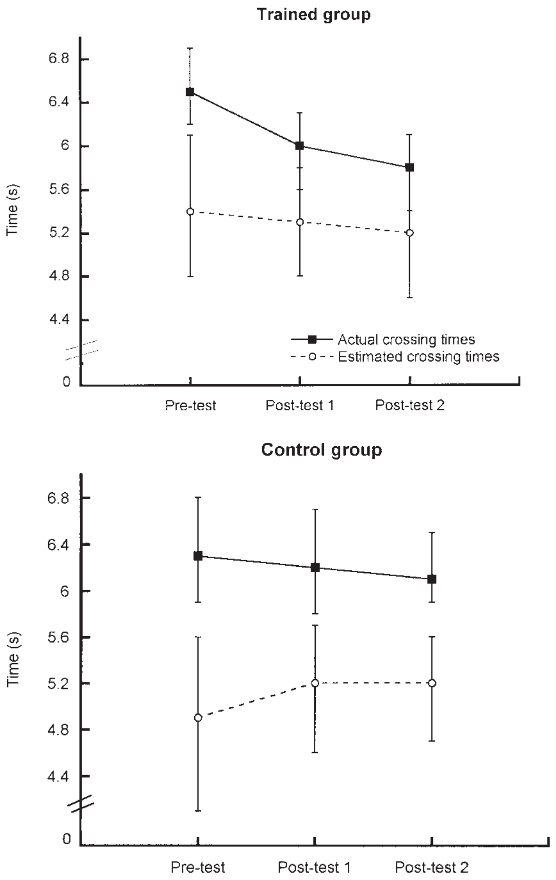

Figure 4. Mean actual and estimated crossing times (in seconds) for trained and control children as a function of test phase. Error bars indicate 95% confidence intervals.

Effect of Training on Conceptual Measures

Scores for conceptual understanding are presented in Figure 2. Results of the ANOVAs are presented in Table 5. In the trained group, there were significant main effects of both test phase and age but no significant interaction. Figure 2 shows this is because all age groups benefited from training to about the same degree. In control children, there was no significant effect of either factor. Comparison of Posttest 2 performance with that at pretest also showed a similar level of performance ($d = .21$).

Integration Between Behavioral and Conceptual Measures

It was hypothesized that transfer of learning from computer to roadside would likely reflect improvement in children's conceptual understanding of the task rather than improvements in the sensory-motor aspects of performance because training did not explicitly provide opportunities for the latter. The improved conceptual scores in trained children are consistent with this, but it remains unclear how these relate to the behavioral changes that were observed. In an effort to explore this relationship, we decided to examine the correlations between conceptual and behavioral performance at different phases of the program. If conceptual improvement were at least partially driving behavioral improvement, we would expect the correlation between conceptual and behavioral scores to improve with training. If, on the other hand, conceptual and behavioral performance were improving independently of each other, there would be no reason to expect a strengthening of this relationship.

Pearson correlations were calculated between conceptual score and each of the six behavioral measures at each test phase. These are presented in Table 6. There were no significant correlations in either group at pretest suggesting no clear relationship between a child's conceptual understanding of the task and his or her behavior at this stage. However, in the trained group, significant (one-tailed) correlations emerged at Posttest 1 for three variables: actual crossing time, estimated crossing time, and starting delay. By Posttest 2, there were significant correlations for four variables:

Table 2
Analysis of Variance Results for Effect of Training on Actual and Estimated Crossing Times

	Actual crossing time				Estimated crossing time			
Source	*df*	*F*	*MSE*	Cohen's *f*	*df*	*F*	*MSE*	Cohen's *f*
Trained								
Age (A)	2	.20	0.96	.08	2	1.26	14.59	.20
Error (A)	66		4.86		66		11.58	
Phase (P)	2	8.42**	6.18	.36	2	0.28	0.66	.06
A × P	4	1.12	0.82	.19	4	0.74	1.73	.15
Error (A × P)	132		0.73		132		2.34	
Control								
Age (A)	2	0.55	1.86	.16	2	0.80	3.88	.20
Error (A)	41		3.36		41		4.87	
Phase (P)	1	1.32	0.85	.18	1	2.91	8.53	.27
A × P	2	1.75	1.13	.29	2	0.44	1.28	.15
Error (A × P)	41		0.65		41		2.93	

** $p < .01$.

Table 3

Analysis of Variance Results for Effect of Training on Accepted Gap Size and Starting Delay

	Accepted gap size				Starting delay			
Source	*df*	*F*	*MSE*	Cohen's *f*	*df*	*F*	*MSE*	Cohen's *f*
				Trained				
Age (A)	2	1.11	55.33	.19	2	4.79**	10.18	.39
Error (A)	65		49.86		65		2.13	
Phase (P)	2	5.55**	75.26	.29	2	19.64**	16.17	.55
A × P	4	0.68	9.25	.15	4	2.22	1.83	.26
Error (A × P)	130		13.55		130		0.82	
				Control				
Age (A)	2	0.29	12.01	.29	2	3.29*	21.07	.40
Error (A)	41		42.11		41		6.41	
Phase (P)	1	2.27	65.24	.24	1	1.47	3.43	.19
A × P	2	2.86	82.15	.37	2	1.09	2.54	.23
Error (A × P)	41		28.70		41		2.33	

* $p < .05$. ** $p < .01$.

actual crossing time, starting delay, accepted gap size, and missed opportunities. Alignment between conceptual and behavioral measures thus emerged following training, and the relationship remained significant 8 months later.

In control children, these relationships were almost entirely absent. None of the behavioral variables correlated significantly with conceptual performance at any of the test phases, with the exception of actual crossing times where there was a significant correlation at Posttest 2. However, this correlation appears to be in the wrong direction; whereas, in trained children, higher conceptual scores are associated with crossing faster, in controls they are associated with crossing more slowly. Thus, this one alignment between conceptual and behavioral performance in controls does not seem to reflect improved strategic thinking or behavior.

Discussion

The principal hypotheses were that a program of conceptually oriented training with a computer-simulated traffic environment would lead to improvements in children's conceptual understanding of the crossing task and that these improvements would generalize to children's behavioral judgments at the roadside. Both these hypotheses appear to have been confirmed. Not only did children's conceptual scores improve, improvements were found on four of the six behavioral measures. Trained children crossed faster and more positively, and their estimation of the time needed to cross became better aligned with their actual crossing times. They were able to accept smaller traffic gaps without any significant increase in the number of risky crossings and, as a result,

Table 4

Analysis of Variance Results for Effect of Training on Missed Opportunities and Tight Fits

	Missed opportunities				Tight fits			
Source	*df*	*F*	*MSE*	Cohen's *f*	*df*	*F*	*MSE*	Cohen's *f*
				Trained				
Age (A)	2	.60	272.06	.14	2	3.93*	2550.46	.35
Error (A)	65		452.28		65		649.86	
Phase (P)	2	17.80**	3769.00	.52	2	1.43	229.34	.15
A × P	4	2.79*	448.49	.29	4	1.61	333.44	.21
Error (A × P)	130		206.67		130		160.89	
				Control				
Age (A)	2	0.56	14.81	.17	2	4.20*	20.36	.45
Error (A)	41		26.37		41		4.85	
Phase (P)	1	18.24**	281.44	.68	1	0.95	2.77	.15
A × P	2	0.90	13.89	.21	2	6.61**	19.34	.57
Error (A × P)	41		15.43		41		2.93	

* $p < .05$. ** $p < .01$.

Table 5
Analysis of Variance Results for Effect of Training on Conceptual Scores

	Trained				Control			
Source	*df*	*F*	*MSE*	Cohen's *f*	*df*	*F*	*MSE*	Cohen's *f*
Age (A)	2	10.21**	7.90	.56	2	1.16	0.70	.24
Error (A)	65		0.78		41		0.60	
Phase (P)	2	5.88**	3.15	.30	1	0.29	9.41	.08
A × P	4	0.82	0.44	.12	2	0.30	9.68	.13
Error (A × P)	130		0.54		41		0.33	

** $p < .01$.

missed many fewer safe opportunities to cross. They also made much better use of gaps by stepping out promptly once the leading car had passed. This suggests better anticipation and forward planning, as well as increased concentration on relevant variables during the decision-making process. Effect sizes were generally moderate according to Cohen's (1988) criteria, although larger effects were observed in the case of missed opportunities and starting delays.

These outcomes seem more than satisfactory for a program consisting of four 30-min training sessions. In fact, the short-term improvements compare well with those reported by roadside training studies, even though the latter have typically used 50% more training sessions (e.g., Demetre et al., 1993; Young & Lee, 1987). More significantly, the long-term benefits substantially surpass those previously reported, where improvements have typically diminished to a much lower level (e.g., Ampofo-Boateng et al., 1991) or have even disappeared altogether at delayed posttest (e.g., Demetre et al., 1993). Overall, the findings suggest that the approach taken by the present study was well judged.

In the control group these trends were all absent, with one exception: The number of missed opportunities decreased to about the same extent as in the trained group. It is not quite clear why this happened. It may partly reflect our more cautious definition of what constitutes a missed opportunity. Previous authors have generally defined a missed opportunity as any gap greater than 1.5 times the child's total crossing time (Demetre et al., 1992, 1993; Lee et al., 1984; Pitcairn & Edelmann, 2000; Young & Lee, 1987). However, where the next approaching car is in the far lane, this means that children would be deemed to have missed an opportunity if they rejected a gap only 50% greater than their crossing time. Thus, rejecting a 9-s gap would be considered a missed opportunity in the case of a 6-s crossing. We felt children should be allowed to set a larger safety margin before deeming them to have missed a safe opportunity, and so we substituted the more conservative definition of 2 times total crossing time. This makes a better fit for interactions with far-side vehicles but is rather generous in the case of vehicles in the near-side lane. It is possible that even untrained children would realize during the course of testing that some of these very long gaps could safely be passed through.

However, the fact that this reduction was not matched by significant changes in any of the other measures shows that it was not part of a more general improvement in traffic judgments. Indeed, at Posttest 1 there was a significant increase in tight fits among the 7-year-olds. This unexpected finding may be due to the fact that, at Posttest 1, some control children had become noticeably bored. It may be that they simply started to "go sooner" as a means of shortening the test session. This would, of course, reduce the number of missed opportunities but increase the number of tight fits. This interpretation is supported by the fact that Posttest 2 scores (obtained from the second control group, who were tested only once) were very similar to pretest scores.

We suggested that the driving force for change was likely to be the trained child's improved conceptual grasp of the crossing task. The pattern of correlations observed at each test phase provides some support for this view. Whereas at pretest there was no significant correlation between conceptual understanding and any of the behavioral variables, by Posttest 1 a clear alignment was

Table 6
Correlations Between Conceptual Score and Behavioral Measures at Each Test Phase

	Trained			Control		
Variable	Pre (*n* = 94)	PT1 (*n* = 78)	PT2 (*n* = 65)	Pre (*n* = 46)	PT1 (*n* = 40)	PT2 (*n* = 48)
Actual crossing times	.11	−.26**	−.18*	−.11	.28	.33*
Estimated crossing times	.02	.23**	.09	0	−.05	.25
Accepted gap size	−.02	−.07	−.26**	−.06	.12	.13
Starting delay	−.09	−.25**	−.27**	−.18	.04	−.05
Missed opportunities	.01	−.13	−.18*	−.26	−.20	−.26
Tight fits	.07	.16	−.04	.03	.14	.02

Note. Pre = pretest; PT1 = Posttest 1; PT2 = Posttest 2.
* $p < .05$. ** $p < .01$.

discernible in the trained group. Thus, those with better conceptual scores (correctly) judged that they needed longer to cross the road, crossed faster, had shorter starting delays, and accepted smaller traffic gaps. By Posttest 2, they missed fewer safe crossing opportunities as well. This increased alignment between conceptual and behavioral performance is thus consistent with Karmiloff-Smith's (1992) account of domain-general development. According to this account, children's abilities improve as the representations underpinning performance become more explicit, permitting adaptive learning in one context to become cognitively more available in others. The model carries two implications that are particularly helpful in interpreting the present findings. The first is that robust behavioral improvements tend to be accompanied by increased awareness of, and capacity to report verbally on, the character of performance. This is, of course, exactly the pattern observed over time in our trained sample. The second is that greatest impact should be achieved by assisting explicitly in the redescription and integration of the child's representations. From this perspective, a central factor in the program's success is likely to be volunteers' deliberate attempts to encourage children to make the basis of their decisions explicit, make conscious links between situations, and discuss points among themselves. We believe that other training programs might well benefit from incorporating such features into the training process.

From a theoretical point of view, the present findings are wholly inconsistent with the widespread view that children's ability to deal with moving traffic situations is biologically curtailed until the age of 9–10 years by their limited ability to integrate variables such as distance and velocity (Cross & Mehegan, 1988; Kenchington et al., 1977; Sandels, 1975). If this were correct, then our 7-year-olds (and perhaps our 9-year-olds) should not have benefited from training. At the very least, they should have benefited much less than the 11-year-olds. In fact, there was no significant interaction between age and test phase for any of the variables except missed opportunities, where 11-year-olds showed slightly more improvement at Posttest 1. Thus, although older children did perform somewhat better at pretest, this conferred almost no advantage in terms of training outcome. The findings do not support the view that training should be deferred until some putative stage of cognitive development is reached. From a practical viewpoint, there seems no reason why training should not begin as early as 7 years.

In this respect, the findings are much more consistent with the ecological view, which holds that learning will occur if children are offered the right kind of experience. For ecological theorists, this means perceptuomotor practice in an appropriate (preferably roadside) context, so that children can become attuned to the "affordances" of traffic (Gibson, 1979; Lee et al., 1984). Although we are sympathetic to this line of thought, we argue that the ecological approach suffers from an overemphasis on the sensory-motor aspects of the task and underestimates the conceptual and strategic issues that are involved in pedestrian decision making. Our study was not designed to provide opportunities for sensory-motor practice. Instead, we focused squarely on conceptual and strategic issues. Not only did this lead to transfer of learning, the learning proved much more robust than that reported by programs based on sensory-motor practice. Indeed, the improvements reported by Demetre et al. (1993) disappeared altogether when children were retested several months later. The authors were forced to consider whether the temporary advantage that training provided in the short-term justified the considerable investment required to mount the program. By contrast, our substantially shorter program generated improvements that were still evident 8 months later, and some aspects of performance (crossing times, accepted gap size, correspondence between conceptual and behavioral measures) may have continued to improve.

It is, of course, important not to exaggerate the benefits of the program. The fact that children continued to underestimate the time required for crossing is an important problem not previously reported in studies of pedestrian behavior. It is interesting to note that a similar trend has recently been reported in child cyclists crossing at intersections (Plumert et al., 2004). Training also did not reduce the number of tight fits. Although the definition of tight fit used by the present study was more conservative than that used by most previous authors (being more akin to what Demetre et al., [1993] call *short gap acceptance*), it seems obvious that children should be encouraged to set safety margins that eliminate acceptance of such gaps. Future interventions may wish to place more emphasis on these aspects of performance.

Nevertheless, the study shows that even young children can derive lasting benefit from training. It is also worth emphasizing that, in the present study, training was not provided by highly qualified staff such as teachers, researchers, or other "experts" but by ordinary people with no special qualifications other than that they were parents. There is much to recommend engaging ordinary members of the community in the process of road safety education. Indeed, this approach now represents a key policy aim in some countries, notably the United Kingdom (U.K. Department for Transport, 2002b). The present findings would seem to offer strong support for this position.

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