Journal of Experimental Psychology: Applied
2001, Vol. 7, No. 3, 227–234

1076-898X/01/$5.00 DOI: 10.1037//1076-898X.7.3.227

Children's Attentional Skills and Road Behavior

George Dunbar
University of Warwick

Ros Hill
Aston University

Vicky Lewis
The Open University

Switching attention and concentration, 2 skills expected to be used by skillful pedestrians, were studied. A sample of 160 children (aged 4 years 3 months–10 years) played a computer game involving attention switching. To examine concentration, a subset of the children was distracted with a cartoon video while they attempted a difficult task that required matching familiar figures. The same subset was also observed crossing roads. Older children switched faster and were less distracted. Children who were better at switching were more likely to show awareness of traffic when about to cross a road. Children who maintained concentration when challenged by a distracting event crossed the road in a less reckless manner. Parents and educators designing safety programs should take into account the development of these skills.

Safe behavior in the traffic environment demands certain cognitive skills (Thomson, Tolmie, Foot, & McLaren, 1996). In one study in the United Kingdom, 69% of child pedestrian accidents were attributed to perceptual or cognitive error on the part of the victim (Carsten, Tight, Southwell, & Plows, 1989). In line with this view, studies have focused on abilities specific to road crossing, such as finding a safe place to cross or judging safe gaps in traffic (e.g., David, Foot, & Chapman, 1990; Demetre et al., 1992). However, Demetre et al. argued that differences in the performance of adults and children when making decisions about gaps in traffic were better explained by attentional lapses than by differences in timing skill. We examined the role of two general attentional skills. We hypothesised that failure to ignore potentially distracting events outside the current focus of attention, or failure to switch attention to the road crossing task when appropriate, are sources of risk. For example, if a child approaches the road talking to a friend, they both need to switch their attention away from the conversation and toward the road situation. Conversely, once their attention is focused on the road it is important that they are not distracted by further conversation.

Evidence of developmental changes in attention comes from Pearson and Lane (1991). They investigated children's ability to re-orient attention between auditory streams presented dichotically when signaled to do so by a tone. The children's task was to report the letters and numbers they heard in the attended stream. The error rate increased when the signal indicated that the child had to change which ear they were attending to, with a larger increase for 8-year-olds than for 11-year-olds. Pearson and Lane discussed this effect in terms of a quantitative increase in delay in the strategic reallocation of attention: The younger children can do it, it just takes them longer. This dichotic listening technique is the same as that used by Gopher and Kahneman (1971) and Avolio, Alexander, Barrett, and Sterns (1979) to study switching in adult participants, and does seem to tap skills relevant to attention.

In the present study, we aimed to take this research forward in four ways. First, we wished to use a task that focused more precisely on a specific hypothesized cognitive mechanism. Barrett and Shepp (1988; Shepp & Barrett, 1991) proposed two hypotheses to account for a range of experimental results demonstrating that older children perform better on tests of selective attention. First, older children might be more skillful at focusing on relevant material and ignoring irrelevant information. Alternatively, younger children's poorer performance might stem from difficulty in attending separately to different aspects of a complex, or integral, stimulus (Garner, 1974; Humphrey, 1982). Our first aim, then, was to focus specifically on the former of these possible mechanisms of attention switching. Our second aim was to examine both attention switching and concentration over a wider age range than has been previously examined.

George Dunbar, Department of Psychology, University of Warwick, Coventry, England; Ros Hill, Neurosciences Research Institute, Aston University, Birmingham, England; Vicky Lewis, Centre for Human Development and Learning, The Open University, Milton Keynes, England.

We thank the schools, parents, and children who participated in this study. This research was carried out at the University of Warwick under Contract S214K from the Department of the Environment, Transport, and the Regions. We received help from Deirdre O'Reilly at the department, and useful comments from Tony Chapman and others at various meetings, including a seminar at the University of Warwick organized by the Child Accident Prevention Trust and a symposium at the British Psychological Society Annual Conference in 1997. We acknowledge helpful assistance with data gathering and coding from Elaine Brown, Jo Furnivall, Corinna Grindle, and Ingram Wright.

Correspondence concerning this article should be addressed to George Dunbar, Department of Psychology, University of Warwick, Coventry CV4 7AL, United Kingdom. Electronic mail may be sent to g.l.dunbar@warwick.ac.uk.

If Demetre et al.'s (1992) suggestion that differences in attentional skill are related to judgments about when to cross roads is correct, then measures of attention switching and concentration should relate to behavior on the road. This was the third aim of the study. The children were covertly filmed crossing roads, and their observed behavior was related to their laboratory performance.

In addition, previous research has demonstrated that variables such as sex and cognitive style are associated with variation in accident risk (e.g., Avery & Jackson, 1993; Christie, 1995). Our fourth aim was to examine the influence of such variables. In particular, it has been argued that impulsivity is related to children's road-crossing skills (Sandels, 1974; Whitebread & Neilson, 1999).

Experiment 1: Switching Attention

Studies with adults have demonstrated the role of attention switching in the performance of complex tasks. In general, better attention-switching skills lead to better performance (Avolio, Kroeck, & Panek, 1985; Gopher, 1982; Kahneman, Ben Ishai, & Lotan, 1973). These skills can be measured using computer games (Mane & Donchin, 1989), and the ecological validity of such games has been demonstrated by their successful use, for example, in a training program involving Israeli Air Force pilots (Gopher, Weil, Barekt, & Caspi, 1988).

We devised a computer game to evaluate switching in children: the Frog Game. The Frog Game taps similar skills to those tapped by computer games used previously with adult participants, but with more familiar metaphors and reduced demands on motor skill and working memory. Our task operationalizes attention in a manner consistent with views that stress the role of attention in linking perception to appropriate action (e.g., Hasher & Zacks, 1988; Houghton & Tipper, 1994; Keele & Neill, 1978; Navon, 1989). On each trial, one of two possible hiding places appeared, a house or a train. The child pressed one key if the frog was hiding in the location shown, and another if it was not. The frog changed hiding place when a black border around the screen appeared or disappeared. Thus, when the border appeared, the mapping between targets and responses switched and the children had to inhibit a previously correct response. The border was described to children as a train track and was spatially separate from the target, namely the house or the train. Because of this separation, any difficulty that they had in switching could not be attributed to problems accessing the dimensional structure, or different aspects, of an integral stimulus.

Method

Participants

A total of 160 children participated, 40 from each of four age groups: *M* age 4 years 9 months, range 4 years 3 months–5 years 3 months; *M* age 5 years 7 months, range 5 years–6 years; *M* age 7 years 7 months, range 7 years–8 years; and *M* age 9 years 6 months, range 9 years 1 month–10 years. The children were balanced within each age group according to sex, parental educational level, and traffic experience. The selection was based on information obtained from a short questionnaire sent to more than 1,000 parents of appropriately aged children attending nine local urban and rural primary schools. Two categories of experience of traffic were distinguished: children who regularly walked or cycled to school and played on the street (high) and children who traveled to school by car or bus and rarely played on the street (low). Parental educational level was scored as high or low (with or without higher education or professional training). Schools were given a small monetary donation for each participating child. Parental permission for the children to take part was obtained through consent forms distributed through the schools.

Apparatus and Materials

The Frog Game was implemented using the Reaction Time (RT) experiment generator (Chute, 1994), running on an Apple Macintosh Power PC computer. On each trial, a small black and white image of either a house or a train appeared in one of six positions in the center of a 15-in. (38 cm) computer screen against a plain white background. On some trials, a thick black border (the train track) appeared as well. The track was a 1-cm thick black line drawn as a rectangle just inside the edge of the screen. Responses were entered via the keyboard. The [c] key was covered with a green sticker (yes, the frog is hiding there), and the [,] key was covered with a red sticker (not there). The software recorded the key pressed and response time.

Procedure

Children were taken one at a time from their classroom by a researcher into a quiet room at their own school. The child sat in front of the computer screen and the researcher introduced them to the game using a demonstration version of the program that introduced the features of the game step by step. It was explained that the object of the game was to catch the frog, but that the frog would hide. It would hide either in its house or, when the train track appeared, it would move from its house and hide on the train. To catch the frog, the child thus had to, in effect, follow the rules: If the train track was absent, press the green button when the house appears and the red button when the train appears; when the train track was present, press the green button when the train appears and the red button when the house appears. In the demonstration version only, the child saw a color image of a frog when it was caught. After going through the demonstration, the child's understanding was tested using a series of trials completed without time pressure. To proceed to the main experiment, they had to be correct on at least 6 of 8 practice trials and correctly report the rule at the end of the practice.

In the main experiment, the game switched between the two contexts (track present and track absent) four times. The child sat with their right-hand forefinger on the red key and their left-hand forefinger on the green key. In each block (set of trials between context switches) there were 12 trials, 6 house and 6 train, randomly ordered for each child. There was therefore an equal probability that the correct response after a switch would be the same as or different from the previous response (response homogeneity). On each trial, the stimulus remained on the screen until the child responded. There was a constant interval of 1,000 ms between the end of one trial and the appearance of the next target. When the background changed, it changed at the offset of the final trial of the preceding block. The game typically lasted 3–4 min.

Results

A total of 16 children did not achieve the criterion for participation. These were younger children (ten 4-year-olds and six 5-year-olds) and no data were recorded for them. For children who did participate in the main experiment, the analysis was restricted to the trial immediately preceding and following the first context switch (S1). Learning and fatigue effects that were not relevant to our hypotheses were observed on subsequent trials, and because type of switch and order were confounded, these order effects were difficult to interpret. In all, 20 children pressed an irrelevant key, such as the space bar, on either one of these trials. These mis-keyed responses are not readily interpretable and were not analyzed. Frequencies of incorrect response, defined narrowly as pressing the wrong key from the green or red choice, are shown in Table 1.

In the analysis of response time data, children who responded incorrectly on either critical trial were excluded. Three further participants with extreme individual response times on either trial were also excluded: two, a 4-year-old and a 5-year-old, were below 250 ms; a third, a 4-year-old, was more than 4 *SD*s above the age group mean.

We termed the difference before and after a context switch the (raw) *switching cost:* The larger the difference, the greater the effect of the switch. The mean, number, and standard deviation of response times for the remaining children are shown in Table 1. To increase the precision of this variable as a measure of switching specifically, we analyzed the residual switching cost after basic response time to the trials before the first context switch had been partialed out.[1] This measure is used in all subsequent analyses. A one-sample t test demonstrated a significant effect of cost, $t(100) = 6.16, p < .001, d = 1.23$. A three-way between-subjects analysis of variance (ANOVA), Sex (2) × Age (4) × Response Homogeneity (2), with switching cost as the dependent variable, found a significant main effect of age, $F(3, 85) = 6.11, p = .001$, $MSE = 1{,}310{,}460$, but no others, $p > .15$ in all cases except the three-way interaction Sex × Response Homogeneity × Age, $F(3, 85) = 2.42$, $p = .07$. Response homogeneity was whether the correct response was the same as on the preceding trial. In this and all subsequent ANOVAs reported, Method 1 adjustment was made for unequal cell size (Overall & Spiegel, 1969). Examination of residuals revealed two cases with extreme values (studentized residual > 3.0), but reanalysis with those excluded yielded the same pattern of effects. A planned linear contrast over the levels of age was significant, $F(1, 85) = 17.66, p < .001$. A priori pairwise contrasts found significant differences between the 4-year-old age group and each of the others, $t(34) = 2.55, p = .02$, $t(48) = 4.39$, $p < .005$, and $t(47) = 4.64, p = .005$, respectively, and between 5-year-old and 9-year-old children, $t(49) = 2.28, p = .03$, with a marginal difference between 5-year-old and 7-year-old children, $t(50) = 1.74, p = .09$, and no significant difference between the 7- and 9-year-old children. The pattern was the same if separate, rather than pooled, variances were used. The Frog Game produced clear age differences in performance between 4-year-olds and the other age groups, with a trend for switching cost to continue to decrease between 5 and 9 years.

Table 1
Incorrect Response Frequencies and Mean, Number, and Standard Deviations for the Switching Cost Variable by Age for the Frog Game

Variable	Age group (in years) 4–5	5–6	7–8	9–10
Mis-keyed responses at S1	6	6	3	5
Errors on trial before S1	4	4	2	0
Errors on trial after S1	4	4	3	3
n	17	19	33	32
Switching cost (raw, ms)				
M	2,230	899	510	377
SD	2,044	1,080	927	897
Switching cost (residual)				
M	1,462	87	−332	−486
SD	2,119	965	755	804

Note. Responses that wrongly selected the red or green key were classified as errors. Three 4–5-year-olds and one 7–8-year-old made an error on both the trial preceding and the trial following S1. Responses that selected other keys, such as the space bar, were classified as mis-keyed responses. Group sizes show the final numbers included in the inferential analyses, excluding those who made errors, who gave mis-keyed or extreme responses, or who failed to reach the criterion for participation; it is summary data for these children's switching costs that is shown. S = switch.

Experiment 2: Concentration Task

The term *distraction* has been used in a range of ways by different investigators (Humphrey, 1982), and it is important to clarify our usage. We define distractibility as the failure to maintain a relationship between data and process in the face of what Humphrey terms *environmental distractors:* "sources of . . . information which are not part of the task context or materials" (Humphrey, 1982, p. 736). Often distractibility is defined more generally to include task internal distractors, such as those found in laboratory tests of selective attention (Douglas & Peters, 1979), but there are important empirical differences between these manipulations. For example, Humphrey reported in her study that only preschool children were affected by environmental distraction. Environmental distraction in that study was provided by a mirror placed next to the primary task in which the children could see their own faces. In contrast, children as old as the second grade showed effects of internal distractors. In the present study, we focused on task external, environmental distractors, subjecting the children to a distracting event while engaged in an activity.

Method

Participants

Of the 160 children who played the Frog Game, 44 also took part in this study. These children were representative of the four age groups and, as far as possible with such numbers, balanced for sex, traffic experience, and level of parental education. They were also selected on the basis that their performance on the Frog Game was typical of children in their age group. The mean ages of the 44 children were 5 years 3 months, range 4 years 10 months–5 years 6 months ($n = 12$); 6 years 2 months, range 5 years 10 months–6 years 9 months ($n = 12$); 8 years 2 months, range 7 years 10 months–8 years 6 months ($n = 12$); and 10 years 2 months, range 9 years 9 months–10 years 8 months ($n = 8$).

Apparatus

The MFF-20 Matching Familiar Figures test (Cairns & Cammock, 1978) was presented on an Apple Macintosh Power PC computer, fitted with a touch screen. A television monitor and VHS video player were used to

[1] This was suggested by one of the referees, our original analysis having been based on raw switching cost. The correlation between this residual and the switching cost variable was high ($r = .975$, $n = 101$), and the outcomes of subsequent analyses, both the analysis of variance (ANOVA) reported in this section and the multiple regressions reported later in the article, were similar whether the raw or the residual variable was used.

present a recording of a children's cartoon that began with an introduction by the channel presenter and then the theme music for the cartoon. The television was placed on a low table about 2.5 m to the right of the computer, and facing the same wall but arranged so that the screen was not directly visible to the children unless they moved. Cameras linked to a recording console and Sony Hi 8 video recorder were used to film the child's behavior.

Procedure

Each child was tested individually. The child sat in front of the computer screen, and a researcher calibrated the touch screen with the child. The researcher then explained the task using standard instructions and went through two practice items with the child. Children were told that when they had completed this task, they could watch a cartoon on the television. The researcher then left the child alone in the room to complete the task.

On each trial, children had to select one of six images in the lower half of the visual display that matched a target image in the upper half of the display. They indicated their choice by pressing the touch screen with a plastic wand or, for a small number of children who found the wand difficult to use, their finger. The trial continued until either the children selected the correct image or they had made six incorrect choices. The latency for the first response and each subsequent response, as well as the identity of each item selected, was recorded by the computer program. After the 2 practice trials, there were 20 experimental trials. On the 15th experimental trial, the video player was switched to play from outside the room.

The procedure was designed to maximize the likelihood that children would be affected by environmental distraction. The primary task, although engaging and reinforced by the experimenter's demands, was carried out at the end of a relatively long session of testing, after the road observation described below and participation in a communication task lasting around 30–40 min late in the afternoon. In addition, the distracting event intruded after several minutes of relatively repetitive activity. Finally, the distraction was highly attractive and began with attention-getting cues designed by the creators of the program.

The study was carried out in a video suite at Warwick University. Permission of parents bringing their children to participate was obtained for audio or video recordings of their behavior and using material recorded secretly when this occurred. Afterward, parents and children were debriefed and shown illustrative portions of recordings made. Parents visiting the university were paid traveling expenses, and their children were given £5 book tokens.

Results

For 9 children, data were unavailable due to errors such as not setting the video correctly or running the wrong version of the primary task software, leaving data for 35 cases. Each child was scored for 12 of the 14 experimental trials preceding the distracting event. The 1st and 10th trials were omitted because inspection of the data revealed anomalous latencies that might be attributable to poor digitization of the images or perhaps, in the case of the first trial, to the fact that the researcher had not always completed his or her exit by the time the child initiated the 1st trial. Initial response latencies and number of errors for these trials were used as the basis for impulsivity scores using the method recommended by Salkind and Wright (1977). Children who responded quickly and made many errors got high scores for impulsivity. The equation is: Impulsivity = $z_{\text{error}} - z_{\text{latency}}$, where the quantities z_{error} and z_{latency} are the child's standardized scores for the mean number of errors and latency of initial response, respectively. These scores were used in the analysis of road behavior reported in Experiment 3. The effect of distraction was measured as the difference between the response time to the first trial after initiation of the distracting event and the mean response time for trials prior to this, with greater differences reflecting greater distraction.

Across the sample, there was a significant effect of distraction, $t(34) = 3.52$, $p = .001$, $d = 1.21$, and the mean falls with age, as indicated in Table 2. Although a two-way ANOVA, Age (4) × Sex (2), found no main effect of age, $F(3, 27) = 2.03$, $p = .13$, $MSE = 1{,}080{,}000$, when the data were log transformed[2] the effect of age was significant, $F(3, 27) = 3.50$, $p = .03$, $MSE = 0.52$. Neither the main effect of sex, $F(1, 27) = 1.75$, $p = .20$, nor its interaction with age, $F(3, 27) = 2.20$, $p = .11$, were significant. A planned linear contrast for different ages was significant, $F(1, 27) = 10.36$, $p = .003$. A priori pairwise contrasts found significant differences between the 4-year-old age group and the 7- and 9-year-olds, $t(16) = 2.24$, $p = .04$, and $t(11) = 2.84$, $p = .02$, respectively. No other pairwise differences were significant. In subsequent analyses, we use this log-transformed version of the distraction variable, although similar results are obtained if the raw data are used instead. A three-way factorial ANOVA, Age (4) × Sex (2) × Period (2), with mean number of errors per item, shown in Table 2, as the dependent variable, and with repeated measures on the levels of the period variable (the periods before and after distraction, respectively), found no significant main effects or interactions, $p > .12$ in all cases ($MSE = 0.58$ between subjects, 0.26 within subjects).

As an initial test of whether the distraction and switching measures represented distinct constructs, we looked at the relationship between them. The correlation between distraction and switching cost was not significant, $r = .28$, $p = .19$.

Experiment 3: Parent and Child Behavior on the Road

To relate road behavior to performance on the switching attention and concentration tasks, parents and children were observed crossing roads on the campus at the University of Warwick.

Method

Participants

The 44 children who participated in the concentration task were covertly observed crossing roads on campus both with and without a parent. These observations were recorded before they participated in the laboratory tasks. Two children and their parents did not take part because it was raining.

Apparatus and Procedure

Parents coming to campus were directed to park in a particular parking space approximately 30 m from the entrance to the Psychology Department, across a moderately busy two-way road. As participants crossed to the department, they were videotaped from two camera positions using Sony Hi 8 camcorders (Crossing A).

Participants were greeted at the entrance to the department by a researcher who fitted a Sony Walkman cassette recorder to the parent. The

[2] The log transformation was suggested by one of the referees, and without it the effect of age only approaches statistical significance, as noted. However, the outcomes of the multiple regression analyses were similar whether the raw or the transformed variable was used.

Table 2
Mean, Number, and Standard Deviations for the Distraction Variable

Variable	Age group (in years) 4–5	5–6	7–8	9–10
n	6	10	12	7
Distraction(s)				
M	21.02	15.35	6.96	1.28
SD	20.56	23.56	12.91	6.43
Errors on trials before				
M	1.95	1.81	1.25	1.05
SD	0.44	0.69	0.41	0.40
Errors on trials after				
M	1.82	1.75	1.66	1.63
SD	0.82	0.58	0.80	0.88

researcher then indicated that a trip to the shop would be necessary because she had not yet purchased some biscuits that would be needed later. The walk to the shop took approximately 5 min. During the walk, the researcher engaged the parent in conversation. A busy two-way road had to be crossed during this walk. This crossing was videotaped by a single camera (Crossing B). After buying the biscuits, and just before beginning the return journey, the child was given a letter and asked to post it in a nearby pillar-box (pillar-shaped mailbox). Finally, the researcher left the parent and child to return to the department together, indicating that she had to carry out a further errand before returning. As the parent and child returned across the busy two-way road, they were videotaped once more (Crossing C).

Results

Videos were initially coded in terms of the occurrence of specific categories of event. These categorizations were all in principle objectively verifiable as they involved physical events such as whether the child ran or walked across a road or whether the parent held the child's hand at a given point. Recordings were scored by two observers. Good levels of agreement were found; for example, for whether the child looked for traffic, $\kappa = .895$, and for whether the child was holding hands with their parent, $\kappa = .733$. Discrepancies were checked and resolved by a third observer. For a variety of reasons, videotapes were not always successfully made. For example, sometimes the parent arrived early and so filming of Crossing A was missed. Where a relevant portion of video material was unavailable, data were recorded as missing and were not included in subsequent analyses.

There were 15 different categories of observed event, and so we statistically reduced the data to a smaller number of variables to make subsequent inferential analysis manageable. A principal components analysis with varimax rotation was carried out on the observations of the two episodes involving the child crossing a busy road with a parent (Crossings A and C). A scree plot suggested three components, but four produced more readily interpretable results, and so this solution was selected. Component loadings are shown in Table 3, together with the percentage of variance each accounted for and subjective rough labels suggested by the pattern of loadings. Component scores were used as dependent variables in analyses using the experimental measures of attention as predictors. Bivariate correlations between these components and the attention variables are shown in Table 3.

Multiple regression was used to evaluate the relationship between the measures of attention and each road behavior component. The principal findings are summarized in Table 4. The potential predictors were age, sex, parental education, traffic experience, the impulsivity measure, and the measures of distraction and switching attention. None of the variables was significant in a standard multiple regression for the first component, parent marshals, and forward statistical regression (with the criterion for entry to the equation set at a significance level of .10, and the criterion for removal set at .12) selected no variables. There were no

Table 3
Rotated Loadings of Road Behavior Observations on Components Derived by PCA (.35 Cutoff)

Observation	First component	Second component	Third component	Fourth component
Parent looks for traffic but doesn't stop at curb	−0.87	—	—	—
Parent looks for traffic and does stop at curb	0.84	—	—	—
Child looks for traffic but doesn't stop at curb	−0.68	—	−0.42	—
Child lets go of hand while crossing	−0.59	—	0.44	—
Child doesn't look for traffic but does stop at curb holding hands	0.51	0.36	—	−0.67
They cross holding hands	—	0.85	—	—
Already holding hands	—	0.79	—	—
Child looks for traffic and stops at curb not holding hands	—	−0.65	—	—
Child steps out before parent	—	−0.56	—	—
Child steps out after parent	—	—	0.82	—
They step out together	—	0.50	−0.70	—
Child looks for traffic and stops at curb holding hands	—	—	—	0.86
Child runs/skips across the road	—	—	0.39	−0.50
Parent seeks hand	—	—	0.35	—
Child doesn't stop at curb or look for traffic	−0.45	—	0.42	—
% of variance explained	20.32	19.67	13.80	10.80
Subjective rough label	parent marshals	together/holding hands	child sallies forth	child looks at traffic
Correlation with switching cost	.25	.16	.21	−.41
Correlation with distraction	−.13	.49	.40	−.07

Note. PCA = Principal components analysis.

Table 4
Summary of Regression Analyses Relating Measures of Attention to Road Behavior

Road behavior component and predictor	β	sr^2	t
2. Together/holding hands, R^2 = .756, $F(7, 16)$ = 7.06**, MSE = 0.45			
Distraction	.36	.07	2.11*
Sex	.41	.13	2.89*
Age	−.34	.07	2.17*
Impulsivity	−.35	.07	2.13*
Parental education	.28	.05	1.89
Switching cost	−.24	.04	1.64
Traffic experience	.04	.00	0.30
3. Child sallies forth, R^2 = .349, $F(2, 27)$ = 7.22**, MSE = 0.71			
Distraction	.48	.20	2.89**
Education	−.54	.26	3.27**
4. Child looks at traffic, R^2 = .209, $F(2, 23)$ = 3.05, MSE = 0.77			
Switching cost	−.39	.15	2.09*
Traffic experience	−.23	.05	1.22

Note. No predictors were significant for Component 1, parent marshals. For Components 3 and 4, the results shown are for the restricted models. For Component 2, the inclusive model is shown.
* $p \leq .05$. ** $p < .01$.

significant bivariate correlations between any of the variables and this component.

For the second road-behavior component, together/holding hands, standard multiple regression was used to model relationships with age, sex, education, traffic experience, the impulsivity measure derived from the MFF, defined as $z_{\text{error}} - z_{\text{latency}}$, switching cost, and the distraction variable. The results are summarized in the first panel of Table 4. Distraction accounted for significant unique variance, $sr^2 = .07$, $p = .05$, and the overall fit of the final model was significant, $p < .001$. As indicated in Table 4, the coefficients were significant for sex, $p = .01$, age, $p = .05$, and impulsivity, $p = .05$, and there was an effect of education that approached significance, $p = .08$. Younger children, girls, more easily distracted children, and, as a marginal tendency, children with a better educated parent, had higher scores for the second component, together/holding hands.

Standard multiple regression was used to evaluate the relationship between the distraction measure and the third component, child sallies forth. The other variables entered were age, sex, education, traffic experience, impulsivity, and switching cost. The coefficient for distraction was not significant, $\beta = 0.17$, $p = .51$, and impulsivity was the only predictor to approach significance, $\beta = 0.40$, $p = .11$, with $R^2 = .484$, $F(7, 16) = 2.14$, $MSE = 0.64$, $p = .10$. There was a bivariate correlation between impulsivity and distraction, $r = .42$, $N = 24$, $p = .02$, and so there is overlap between these variables. There was a bivariate relationship between age and the third component, with younger children tending to have higher scores, $r = -.46$, nominal $p = .01$, but age also correlated with impulsivity, $r = -.35$, nominal $p = .05$. In a restricted model with only distraction and parental education as predictors, shown in Table 4, their coefficients were significant, $p = .008$ and $.003$, respectively, with the unique variation for the distraction measure accounting for 20% of the variance of the third component.

Standard multiple regression was used to evaluate the relationship between switching cost and the fourth component, child looks at traffic. The other variables entered were age, sex, education, traffic experience, impulsivity, and the distraction task measure. Neither the overall fit of the inclusive model, $R^2 = .396$, $F(7, 16) = 1.50$, $MSE = 0.76$, $p = .24$, nor the coefficient for switching cost in this model, $\beta = -0.40$, $p = .10$, were significant. Traffic experience, which was not significant in this model, $p = .13$, approached significance in models based on the untransformed data (see footnote 1). In a restricted model with only switching cost and traffic experience as predictors, shown in Table 4, the coefficient for switching cost was significant, $p = .05$, although the coefficient for traffic experience was not, whether transformed or untransformed data were used. The unique variance of switching cost was statistically significant and accounted for approximately 15% of the variance of the fourth component, child looks at traffic.

General Discussion

Both attention switching and concentration, as operationalized here, demonstrated substantial age-related variation, with younger children much less effective than older children. Switching and concentration also appear to be distinct skills, with only a moderate, nonsignificant, correlation between them, although both develop with age. Each was related to different aspects of road behavior. Children who were able to switch attention more rapidly in the computer game were more likely to appear to look at traffic when they were about to cross a road. Children who were less able to concentrate when challenged by a distracting event tended to be more impulsive, and more impulsive children tended to cross the road in a less controlled manner. Finally, concentration, but not switching, correlated with impulsivity.

Given the empirical distinctions between these skills, it will be useful to attempt to characterize them more precisely. Ridderinkhof, van der Molen, Band, and Bashore (1997) have reported studies using Garner (1974) interference and Erikson flanker paradigms to investigate the relative importance of different aspects of what might be broadly termed *selective attentional skill* in the development of performance in such tasks. Garner interference consists of two effects: performance decrements when an irrelevant dimension of a stimulus varies orthogonally with the relevant dimension (interference), and performance improvements when the irrelevant dimension's values correlate with the target dimension (redundancy). Ridderinkhof et al. found that Garner interference decreased with age, for both integral and separable dimensions. This suggests that access to the dimensional structure of complex stimuli is not the primary source of these age differences. In the flanker paradigm, participants respond to a target stimulus that is flanked in the presentation array by stimuli that can signify congruent or incongruent responses to that required by the target. For example, the target might be an arrow pointing left, requiring the left-hand key to be pressed, and the flankers might be either arrows also pointing left or arrows pointing to the right. Typically, incongruent flankers produce interference. Using this paradigm, Ridderinkhof et al. found that time uncertainty (linked to response activation) and discriminability (linked to perceptual filtering) did not interact with age-related reductions in the effect of incongruent flankers upon response to the target. However, stimulus–response (S–R) compatibility (pressing the right key for a left-pointing arrow, e.g.) did interact with age. These results suggest that the key functional step in processing lies in S–R translation. We would suggest (a) that the processes we have characterized as switching, and operationalized in the Frog Game, are largely constituted by processes of S–R translation in a situation in which there are competing S–R mappings, and (b) that this is similar to the competition found in the flanker paradigm. This also bears a close affinity to the characterization of selective attention by Houghton and Tipper (1994, p. 57) in their model: "selection involves the binding of information in target object representations . . . to variables associated with response schemas." Attention serves to link perception with action in the contextually appropriate way.

The relationships between switching, impulsivity, and concentration raise interesting theoretical questions. There is scope for work to further tease out the relationships between them and, indeed, their relationships with other attentional skills. Previous research with adults has distinguished a number of attentional mechanisms, although in some cases these are defined in ways that are closely tied to a specific experimental paradigm. It is likely that a particular attentional function, such as concentrating, can be achieved using different mechanisms or, indeed, combinations of mechanisms. For example, Watson and Humphreys (1997) characterized a process they termed *visual marking* and distinguish it empirically from a number of other attentional processes, such as inhibition of return or feature map inhibition. Visual marking allows simplification of visual search by inhibiting search to locations where distractor stimuli are continuously present. Thus, visual marking could serve as a tool for concentration. Watson and Humphreys gave an account of visual marking in terms of goal maintenance and speculate that this implies frontal involvement. It would be interesting to chart further the developmental pattern of changes in the use of different mechanisms to achieve attentional functions. Such an analysis has the potential to identify successful alternative strategies for achieving attentional functions that, for example, are less constrained by maturational influences or are more amenable to training.

If switching and concentration do generalize across domains, as our evidence suggests, then it may be that training on abstract tasks that exercise these skills will transfer to road behavior. This view is supported by previous research that has looked at the effect of playing video games on the development of strategies for divided attention (Greenfield, de Winstanley, Kilpatrick, & Kaye, 1994). There is also evidence from previous studies with adults demonstrating that attentional skills can be trained and brought under voluntary control (reviewed in Gopher, 1993). For example, Gopher et al. (1988) have demonstrated that systematic practice with a computer game was associated with a doubled success rate for personnel on an Israeli military pilot training program. Kramer, Larish, and Strayer (1995) examined the role of variable-priority training strategies on dual task performance and found that this produced improvements that transferred to novel tasks for both young and older adults. It seems likely, therefore, that computer games could be developed that incorporate demands upon these skills in abstract form, and that variable-priority training that improved performance on the games would influence the deployment of attentional skills in practical environments. However, confirmation of this does, of course, require further research. Given the associations with road behavior we have demonstrated, finding ways of improving these skills would have practical importance.

Another approach to training that holds promise relates to the development of metacognitive abilities. Our results indicate a link between concentration and impulsivity. Borkowski, Peck, Reid, and Kurtz (1983) have argued that the advantages less impulsive children show on a range of cognitive tasks are in fact mediated by their ability to articulate beliefs about memory processes. An approach such as this was advocated recently by Whitebread and Neilson (1999) in relation to road-crossing behavior. Miller and Byrnes (1997) examined the role of factors such as the accuracy of children's beliefs about their abilities and found a relationship with risk-taking behavior in tasks requiring mathematical or physical skill. There is some evidence, then, that helping children regulate their cognitive skills might prove an effective way of addressing the deficits we have identified.

The youngest children we studied had weaker concentration and switching skills, which we found were related to road-crossing behavior. Children who were poorer on these tasks were less skilled at dealing with the road environment. This implies that young children may be at greater risk in the road environment without additional help, although our evidence does not allow us to quantify the risk associated with these factors. Such young children should be closely supervised, or the road environment should be modified to accommodate their needs (e.g., with very low speed limits or the physical separation of vehicles and pedestrians). To the extent that development is constrained by maturation (Stuss, 1992), the implication is that an emphasis on measures such as these will be needed in the long term. Further research is required to establish the extent to which training interventions can promote these skills. However, our research points to the importance of two specific cognitive skills that should be considered in the planning of road safety training.

References

Avery, J. G., & Jackson, R. H. (1993). *Children and their accidents.* London: Edward Arnold.

Avolio, B. J., Alexander, R. A., Barrett, G. V., & Sterns, H. L. (1979). Analyzing preferences for pace as a component of task performance. *Perceptual and Motor Skills, 49,* 667–674.

Avolio, B. J., Kroeck, K., & Panek, P. (1985). Individual differences in information processing ability as a predictor of motor vehicle accidents. *Human Factors, 25,* 71–82.

Barrett, S. E., & Shepp, B. E. (1988). Developmental changes in attentional skills: The effect of irrelevant variations on encoding and response selection. *Journal of Experimental Child Psychology, 45,* 382–399.

Borkowski, J. G., Peck, V. A., Reid, M. K., & Kurtz, B. E. (1983). Impulsivity and strategy transfer: Metamemory as mediator. *Child Development, 54,* 459–473.

Cairns, E., & Cammock, T. (1978). Development of a more reliable version of the matching familiar figures test. *Developmental Psychology, 14,* 555–560.

Carsten, O. M. J., Tight, M. R., Southwell, M. T., & Plows, B. (1989). *Urban accidents: Why do they happen?* Basingstoke, England: AA Foundation for Road Safety Research.

Christie, N. (1995). *The high risk child pedestrian: Socio-economic and environmental factors in their accidents.* (Transport Research Laboratory Report 117). Crowthorne, Berkshire, England.

Chute, D. L. (1994). *MacLaboratory for psychology, (Version 3)* [Computer software]. Pacific Grove, CA: Brooks/Cole.

David, S. S. J., Foot, H. C., & Chapman, A. J. (1990). Children's sensitivity to traffic hazard in peripheral vision. *Applied Cognitive Psychology, 4,* 481–489.

Demetre, J. D., Lee, D. N., Pitcairn, T. K., Grieve, R., Thomson, J. A., & Ampofo-Boateng, K. (1992). Errors in young children's decisions about traffic gaps: Experiments with roadside simulations. *British Journal of Psychology, 83,* 189–202.

Douglas, V. I., & Peters, K. G. (1979). Toward a clearer definition of the attentional deficit in hyperactive children. In G. A. Hale & M. Lewis (Eds.), *Attention and cognitive development* (pp. 173–247). New York: Plenum Press.

Garner, W. R. (1974). *The processing of information and structure.* Potomac, MD: Erlbaum.

Gopher, D. (1982). A selective attention test as a predictor of flight training. *Human Factors, 24,* 173–183.

Gopher, D. (1993). The skill of attention control: Acquisition and execution of attention strategies. In D. E. Meyer & S. Kornblum (Eds.), *Attention and performance IX* (pp. 299–322). Cambridge, MA: MIT Press.

Gopher, D., & Kahneman, D. (1971). Individual differences in attention and the prediction of flight criteria. *Perceptual and Motor Skills, 33,* 1335–1342.

Gopher, D., Weil, M., Barekt, T., & Caspi, S. (1988). Fidelity of task structure as a guiding principle in the development of skill trainers based on complex computer games. *Proceedings of the 32nd Annual Meeting of the Human Factors Society* (pp. 1266–1270). Anaheim, CA: Human Factors Society.

Greenfield, P. M., de Winstanley, P., Kilpatrick, H., & Kaye, D. (1994). Action video games and informal education: Effects on strategies for dividing visual attention. *Journal of Applied Developmental Psychology, 15,* 105–123.

Hasher, L., & Zacks, R. T. (1988). Working memory, comprehension, and aging: A review and a new view. *The Psychology of Learning and Motivation, 22,* 193–225.

Houghton, G., & Tipper, S. P. (1994). A model of inhibitory mechanisms in selective attention. In D. Dagenbach & T. H. Carr (Eds.), *Inhibitory processes in attention, memory and language* (pp. 53–112). London: Academic Press.

Humphrey, M. M. (1982). Children's avoidance of environmental, simple task internal, and complex task internal distractors. *Child Development, 53,* 736–745.

Kahneman, D., Ben Ishai, R., & Lotan, M. (1973). Relation of a test of attention to road accidents. *Journal of Applied Psychology, 58,* 113–115.

Keele, S. W., & Neill, W. T. (1978). Mechanisms of attention. In E. C. Carterette & M. P. Friedman (Eds.), *Handbook of perception* (Vol. 9, pp. 3–47). New York: Academic Press.

Kramer, A. F., Larish, J. F., & Strayer, D. L. (1995). Training for attentional control in dual task settings: A comparison of young and old adults. *Journal of Experimental Psychology: Applied, 1,* 50–76.

Mane, A. M., & Donchin, E. (1989). The Space Fortress Game. *Acta Psychologica, 71,* 17–22.

Miller, D. C., & Byrnes, J. P. (1997). The role of contextual and personal factors in children's risk taking. *Developmental Psychology, 33,* 814–823.

Navon, D. (1989). The importance of being visible: On the role of attention in a mind viewed as an anarchic intelligence system: 1. Basic tenets. *European Journal of Cognitive Psychology, 1,* 191–213.

Overall, J. E., & Spiegel, D. K. (1969). Concerning least squares analysis of experimental data. *Psychological Bulletin, 72,* 311–322.

Pearson, D. A., & Lane, D. M. (1991). Auditory attention switching: A developmental study. *Journal of Experimental Child Psychology, 51,* 320–334.

Ridderinkhof, K. R., van der Molen, M. W., Band, G. P. H., & Bashore, T. R. (1997). Sources of interference from irrelevant information: A developmental study. *Journal of Experimental Child Psychology, 65,* 315–341.

Salkind, N. J., & Wright, J. C. (1977). The development of reflection–impulsivity and cognitive efficiency. *Human Development, 20,* 377–387.

Sandels, S. (1974). *Why are children injured in traffic?* (The Skandia Report 2). Stockholm: Skandia Insurance Co.

Shepp, B. E., & Barrett, S. E. (1991). The development of perceived structure and attention: Evidence from divided and selective attention tasks. *Journal of Experimental Child Psychology, 51,* 434–458.

Stuss, D. T. (1992). Biological and psychological development of executive functions. *Brain and Cognition, 20,* 8–23.

Thomson, J. A., Tolmie, A., Foot, H. C., & McLaren, B. (1996). *Child development and the aims of road safety education: A review and analysis.* London: Department of Transport.

Watson, D. G., & Humphreys, G. W. (1997). Visual marking: Prioritizing selection for new objects by top-down attentional inhibition of old objects. *Psychological Review, 104,* 90–122.

Whitebread, D., & Neilson, K. (1999). Learning to cross the road: Cognition in action. *The Psychologist, 12,* 403–405.

Received August 24, 1998
Revision received May 29, 2001
Accepted May 30, 2001 ■