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Planning and Control in a Manual Collision Avoidance Task by Children with Hemiparesis

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We examined whether deficits in planning and control during a manual collision avoidance task in children with hemiparesis are associated with damage to the left or right hemisphere (LHD and RHD). Children pushed a doll across a scale-size road between two approaching toy cars. Movement onset and velocity served as indicators of planning and control. In Experiment 1, children with hemiparesis collided more frequently, and controlled velocity less appropriately compared to typically-developing children. Children with LHD initiated their movement later than children with RHD. Experiment 2 compared the preferred and non-preferred hand of children with LHD and RHD. Children with RHD crossed less with their non-preferred hand, while children with LHD initiated later than children with RHD. Moreover, the groups showed differences in velocity control. It is argued that planning deficits may be related to LHD. The hypothesized association between control deficits and RHD, however, was not confirmed.

Key Words: left-hemisphere damage, right-hemisphere damage, perception, movement initiation, velocity, road crossing

Individuals with spastic hemiparesis demonstrate deviant movement patterns compared to typically-developing individuals. By and large, these deviant movement patterns are investigated using tasks in which participants had to reach and grasp for stationary objects. There are, however, only a few studies that examined interceptive actions in individuals with hemiparesis. A distinctive feature of interceptive actions, such as hitting and catching, is that the temporal characteristics of the movement are enforced by the object to be intercepted. These studies reported differences in movement initiation and overall success as compared to typically-

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developing individuals, while adjustments to target perturbations were found to be surprisingly accurate (Van der Weel, Van der Meer, & Lee, 1996; Van Thiel, Meulenbroek, Smeets, & Hulstijn, 2002). The avoidance of objects is similarly constrained, yet the goals are clearly different than for interceptive actions. The present study explores the capabilities of individuals with hemiparesis dealing with moving objects that must be avoided.

Collision avoidance requires three key components, namely (a) accurate perception to decide which action would be appropriate; the subsequent action requires (b) precise preparation and initiation of the movement, and (c) continuous spatio-temporal adjustments to changes in position and direction of the object to be avoided. The first component involves perceptual-cognitive processes, whereas the latter two involve movement planning and control processes. Essentially, successful collision avoidance necessitates that the perception and action components are appropriately tuned to each other. Collision avoidance is pertinent in pedestrian road-crossing. After having found a safe place to walk across the road (e.g., Ampofo-Boateng & Thomson, 1991), the pedestrian must decide whether it is safe to cross between two oncoming vehicles or whether it is more prudent to await another gap (Lee, Young, & McLaughlin, 1984). Once the pedestrian decides to cross, he/she must precisely time the onset of walking. To avoid colliding with the foregoing vehicle, onset must not be too early. At the same time, onset must not be too late, because then the pedestrian cannot reach the far curb before the successive vehicle crosses his/her path. Finally, when the pedestrian has started walking, the spatio-temporal characteristics of locomotion must continuously be geared to the motion of the vehicles (Te Velde, Van der Kamp, & Savelsbergh, 2003). Numerous studies have sought to understand how individuals succeed (or fail) to safely cross a traffic-filled road. In particular, vulnerable road-users such as primary school children have received much attention (e.g., Connelly, Cognaglen, Parsonson, & Isler, 1998; Demetre, Lee, Pitcairn, Grieve, Thomson, & Ampofo-Boateng, 1992; Lee et al., 1984; Plumert, Kearney, & Cremer, 2004; Simpson, Johnson, & Richardson, 2003; Te Velde, Van der Kamp, Barela, & Savelsbergh, 2005). Experimentation, however, has been complicated by obvious safety limitations. This commonly resulted in research designs that did not incorporate all three components of collision avoidance.

Recently, we have developed a manual collision-avoidance task that retains the key perception and action components (Te Velde, Van der Kamp, & Savelsbergh, 2005). The task comprised a scale-size road-crossing situation, in which adults and children pushed a doll across the street between two approaching toy vehicles. The temporal gap between the two vehicles was manipulated. The younger children crossed less, but collided more often than the older children and adults. This indicates that perceptual decision making and the subsequent action were less appropriately tuned in the younger children. Evaluation of the action showed that all groups initiated the movement at the very moment the first toy vehicle traversed the future path of the doll. After movement onset, participants had to regulate the doll's velocity to the time that remained until the second vehicle traversed the doll's path, which was varied during the experiment. To describe the children's velocity control, the required velocity model for interceptive actions (RV model; Peper, Bootsma, Mestre, & Bakker, 1994) was modified. The modified RV model expresses the future position of, in this case, the hand-held doll at the moment that the second vehicle would cross the doll's path. The doll's anticipated future position is based on the doll's and vehicle's current positions and velocities. Accordingly, the model describes for every instant the doll being on a collision or a non-collision course with the second vehicle. This provides a continuous measure of whether the doll has attained the velocity required to reach the far curb without colliding. We observed that younger children attained the required velocity closer to the collision area. In addition, the younger children's velocity control left relatively small (safety-) margins to clear the collision area, particularly for small inter-vehicle gaps. Hence, the modified RV model indicated that the young children were less proficient on the collision avoidance task because they geared velocity less appropriately to the motion of the object to be avoided.

The previous discussion draws both on a distinction between visual processes for perception and action (Milner & Goodale, 1995) and on the distinction between visual processes for planning and control. In a recent formulation of the latter dichotomy (Glover, 2002, 2004; Glover & Dixon, 2001), planning encompasses the selection of an action and its initial kinematic parameterization. According to Glover (2004) this includes the timing of movement onset and initial movement characteristics. In the collision avoidance task at hand, the planning system would facilitate the perceptual decision making of when to start the crossing movement, and perhaps initial parameterization of velocity. Control, instead, encompasses the on-line adjustment or correction of the spatio-temporal parameters of the movement. In the present collision avoidance task this would entail the control of the future position through adjustment of movement velocity after movement onset.

The planning and control distinction has recently fuelled discussion on specific disturbances in planning and control in individuals with damage to either the left or the right hemisphere (LHD or RHD; Haaland, Prestopnik, Knight, & Lee, 2004; Rushworth, Nixon, Wade, Renowden, & Passingham, 1998; Steenbergen, Meulenbroek, & Rosenbaum, 2004). Steenbergen and colleagues have suggested that the deviant movement patterns in individuals with hemiparetic cerebral palsy could relate to different constraints imposed during movement planning (e.g., Mutsaarts, Steenbergen, & Bekkering, 2005; Mutsaarts, Steenbergen, & Meulenbroek, 2004; Steenbergen, Hulstijn, & Dortmans, 2000). For instance, when individuals with hemiparetic cerebral palsy have to grasp a bar and subsequently rotate it, they often use a grip orientation that is incompatible with the rotation requirements of the task. In contrast to typically-developing individuals, individuals with hemiparesis only take the initial orientation of the grip into account. They do no not anticipate or plan the final hand orientation. In a recent study, Steenbergen et al. (2004) made an important qualification to this claim. It was observed that planning was more adversely affected in individuals with LHD than in individuals with RHD. A complementary finding was reported by Te Velde, Savelsbergh, Barela, & Van der Kamp (2003). Children with cerebral palsy were asked to walk across a lab-based road in front of a slowly approaching bike. Children with RHD made more risky decisions to cross the road than children with LHD. Moreover, they did not appear to increase their walking speed to compensate for the unsafe decisions. These findings might suggest that control is more adversely affected in individuals with RHD than in individuals with LHD (see also Haaland et al., 2004).

The purpose of the present study is to provide further evidence for differential planning and control deficits in individuals with LHD and RHD, respectively.

Therefore, in Experiment 1 typically-developing children and children with LHD and RHD were compared on the manual collision avoidance task (c.f., Te Velde et al., 2005). If the conjecture is correct that planning is more adversely affected in children with LHD, then this would result in more deviant movement onset patterns in these children. Furthermore, if control is more adversely affected in children with RHD, then this would result in less appropriate movement control after the onset of the movement in these children. In addition, it was examined whether the perceptual judgments to cross between two moving objects were appropriately tuned to the action processes. In this respect, it is important to note that deficits in planning (e.g., relatively late movement onset) might be easier to compensate for than deficits in control (e.g., relatively late attainment of the required velocity), which might make children with RHD more vulnerable to collisions.

Experiment 1

Methods

Participants. Eleven children with left hemiparesis (i.e., primarily damage to the right hemisphere, RHD; mean age = 11.4 ± 3.1 years, mean estimated cognitive age according to school level = 9.8 ± 2.8 years), 11 children with right hemiparesis (i.e., primarily damage to the left hemisphere, LHD; mean age = 11.2 ± 2.8 years, mean estimated cognitive age according to school level = 9.4 ± 2.2 years), and 22 typically-developing control children (mean age = 9.6 ± 2.5 years) volunteered to participate. The children with hemiparesis all had mild to moderate spastic hemiparesis and were able to complete the task according to the instructions. Precautions were taken that cognitive ability did not influence movement performance. To match the estimated cognitive age, the children were selected on the basis of school level. A line bisection task (e.g., Ishiai, Furukawa, & Tsukagoshi, 1989), which was repeated nine times, showed that none of the hemiparetic children had a noticeable neglect. The Motor-Free Visual Perception Test, third edition (MVPT-3, Colarusso & Hammill, 2003) did not indicate differences in spatial perception between the children with LHD or RHD. The magnitude of the left visual hemi-field was significantly smaller, however, in children with RHD compared to children with LHD. The individual characteristics of the children are summarized in Table 1. Written informed consent was obtained from children's parents prior to the experiment. This experiment was approved by the ethical committee of the Vrije Universiteit Medical Centre and in accordance with the Declaration of Helsinki.

Tasks and Apparatus. A scale-size road on which children manually pushed a doll between two consecutively approaching toy cars was used (Figure 1). Children were sitting in front of a table on which the scale-size road was painted. The road was 6 m long and 0.25 m wide with painted curbs (0.05 m wide) on both sides. The doll (Playmobil) was attached to a rod that extended underneath the table through a slot in the table. By grasping and moving the rod underneath the table the children moved the doll as if the doll walked across the road. The doll's movement path will be denoted as the doll's track. Two small vehicles (length 0.15 m, width 0.065 m) were placed on two supports that were moved by two mechanically driven conveyor belts (length 3 m each, width 0.05 m). These were sequentially positioned under

Table 1 Individual Characteristics of Each Participant

Children with hemiparesis										Control children (matched)	
Name	Lesion	Age (yrs)	Corr. Age	Gender	Neglect	Left field***	Right field	MVPT-3	Severity	Age (yrs)	Gender
KRBO	LHD	8.2	8.0	F	10.0	80	80	133	MI	7.9	F
ANHL	LHD	6.2	6.2	F	10.0	70	70	76	MI	6.3	F
RUBO	LHD	8.9	6.7	F	10.0	70	60	117	---	7.3	F
FRBO*	LHD	11.5	9.0	M	9.3	30	30	88	MO	9.4	M
DAHL	LHD	13.5	12.8	F	9.5	80	80	145	MI/MO	12.8	F
BRHL	LHD	11.7	7.5	M	10.5	60	40	69	MO	7.7	M
ROHL	LHD	15.6	10.5	M	10.0	70	50	83	MO	10.5	M
THBO	LHD	11.9	11.0	M	10.1	90	80	104	MI	10.2	M
AGBO*	LHD	9.3	8.5	M	9.9	80	40	126	MI	8.3	M
MXBO*	LHD	11.7	10.0	M	9.8	80	80	145	MI	10.4	M
WEBO*	LHD	14.3	13.5	M	9.5	80	80	142	---	13.0	M
KACO**	LHD	10.7	10.7	M	---	---	---	---	MO		
TEBO	RHD	7.6	6.5	F	10.2	60	60	92	MI	6.3	F
VEBO	RHD	6.6	6.5	F	10.1	40	80	115	MI/MO	6.3	F
JEHL	RHD	7.5	6.5	M	9.9	50	60	72	MI	6.8	M
KIBO*	RHD	13.5	11.5	F	8.9	30	30	79	MO	11.4	F
MABO*	RHD	15	13.0	F	10.3	70	70	104	MI/MO	13.4	F
TWHL	RHD	11.1	7.0	M	11.2	30	70	55	MO	7.2	M
DAVU*	RHD	13.5	12.0	M	10.2	60	60	142	MI	11.5	M
DABO*	RHD	13.8	13.2	F	10.4	70	80	104	MI	13.2	F
MIVU*	RHD	10.1	8.8	M	9.3	70	70	95	MI	8.8	M
NIVU*	RHD	11.6	11.0	F	9.8	80	80	108	MI	11.0	F
MRBO*	RHD	14.8	12.0	M	9.1	10	60	100	MI/MO	12.1	M

Note. Name, (four-letter code); Lesion, (LHD or RHD); Corr. Age, (corrected age according to school level); Gender, (M: male, F: female); Neglect, (indication in centimeters of the middle of a 20 cm line, measured from the left—average of 9 measures); Left field, (size of the left visual field, measured in horizontal degrees from the midline); Right field, (size of the left visual field, measured in horizontal degrees from the midline); MVPT-3, (standard scores on the MVPT-3); Severity, (MI: mild; MO: moderate, according to a questionnaire filled out at home by the parents); *children that participated in both Exp. 1 and 2; **child that only participated in Exp. 2; ***significant group effect ($p < .05$); --- indicates missing data.

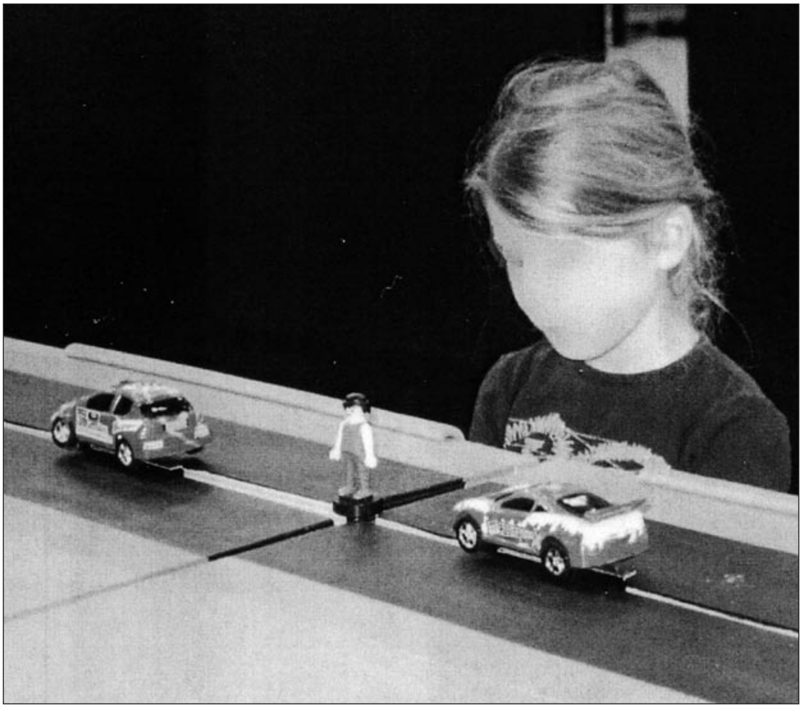

Figure 1—The experimental setup; the child sitting in front of the table moves the doll by means of the rod underneath the tabletop between the two approaching vehicles.

the tabletop. A slot in the table exactly in the middle of the road, through which the supports slid while standing on the running conveyor belts, made it look as if the two vehicles were driving along the road. The vehicles' movement path will be denoted as the vehicles' track. Approximately 0.02 m was left clear between the two conveyor belts to make space for the rod on which the doll was attached to cross the vehicles' track.

A potentiometer connected to the rod collected position data of the doll. Two Opto switches (comprising an infrared source and an integrated photo detector) were positioned underneath the curbs along the road at 1.75 m before and after the intersection with the doll's track. Passage of the supports on which the vehicles were positioned through these Opto switches interrupted the light beams. The Opto switches thus provided the moments the vehicles were at 1.75 m before and after the intersection point. These measures together with the known velocity of the vehicles were used to calculate the moment the vehicles crossed the intersection point. Data of the potentiometer and both Opto switches were synchronized and collected at a sampling rate of 500 Hz (Labview, National Instruments). A video camera was placed in front of the children to record their behavior.

Procedure and Design. Prior to the experiment, the children were allowed to push the doll across the road without the approaching vehicles at comfortable movement speed and at maximum movement speed to become familiar with the doll's "movement abilities." Then they received instructions for the experiment. The task was to move the doll across the road from the near curb between the two approaching toy vehicles to the far curb without colliding with either vehicle. If crossing between the two vehicles was considered impossible, children were instructed to move the doll across the road after the second vehicle had passed. If a collision occurred, children were politely reminded not to collide, and to pretend that they were crossing the road themselves.

Each child performed 36 trials with a total duration of approximately 30 min. For the children with hemiparesis, the vehicles approached from their ipsilesional side, and for the control children the vehicles approached alternately from the left and from the right. Three constant velocities of the vehicles (0.50, 0.75, and 1.00 m/s) and three inter-vehicle distances (0.15, 0.30, and 0.45 m) were presented, resulting in nine different conditions (seven different inter-vehicle timegaps), each of which was repeated four times. Conditions were randomly ordered within four blocks for children with hemiparesis and within two blocks for the typically-developing children. For the typically-developing children, each condition was repeated in two successive trials.

Dependent Variables and Data Analyses

Perception: Crossings and Collisions. The percentage of crossings (the number of trials in which the children tried to push the doll between the vehicles divided by the total number of trials, multiplied by 100) and the percentage of collisions (the number of collisions divided by the number of crossings, multiplied by 100) were determined for each child in each condition. To compare the children with hemiparesis to the typically-developing children, the intra-individual means of the percentage of crossings were submitted to a 2 (group: children with hemiparesis vs. typically-developing children) × 3 (vehicle velocity: 0.50 vs. 0.75 vs. 1.00 m/s) × 3 (inter-vehicle distance: 0.15 vs. 0.30 vs. 0.45 m) ANOVA with repeated measures on the last two factors. Further, intra-individual means of the percentage of collisions were submitted to a 2 (group: children with hemiparesis vs. typically-developing children) × 2 (vehicle: first vs. second) × 3 (vehicle velocity: 0.50 vs. 0.75 vs. 1.00 m/s) × 3 (inter-vehicle distance: 0.15 vs. 0.30 vs. 0.45 m) ANOVA with repeated measures on the last three factors. Similar ANOVAs with repeated measures on the percentages of crossings and collisions were performed to compare children with LHD and RHD. In cases where the sphericity assumption was violated (i.e., for $\varepsilon < 1.0$), Greenhouse-Geisser adjustments of the *p*-values were reported. Post hoc comparisons were performed using the Tukey HSD test ($p < .05$).

Movement Initiation. Children initiate their movements in relation to the first vehicle (Te Velde et al., 2005). Movement initiation, therefore, was defined in terms of the time and distance between the leading vehicle and the doll's track. It was determined only for trials in which children tried to move the doll between the vehicles. Time-to-intersect (*Tti*) is the time(s) between the moment of the doll's movement initiation and the moment at which the rear of the first vehicle reaches the doll's track. Distance-to-intersect (*Dti*) is the distance (m) between the rear of the first vehicle and the doll's track when the doll's movement is initiated. Because children did not cross on all occasions, particularly not for the short inter-vehicle timegaps, factor-ANOVA on individual means for the different conditions was deemed inappropriate. Therefore, *Tti* and *Dti* were compared between children with and without hemiparesis and between children with LHD and RHD for each inter-vehicle timegap separately (0.20, 0.30, 0.40, and 0.60 s) by performing nonparametric Mann-Whitney U-tests. Not all the children crossed at each inter-vehicle timegap. Hence, rather than submitting the individual means, we used the data from all crossing attempts. Children who cross frequently are somewhat overrepresented compared to individuals who cross less.

Velocity Control. The modified version of the RV model (Te Velde et al., 2005) was used to gain insight into the control of movement velocity after initiation. Because it has previously been established that velocity control is related to the second vehicle (Te Velde et al., 2005), the present analyses did not consider that by moving very fast the doll might collide with the leading vehicle. To avoid a collision with the second vehicle, a minimum velocity is required until the doll clears the collision area [Figure 2; the boundaries of the collision area are determined by dimensions of the vehicle (width 6.5 cm) and the doll (width 3.5 cm)]. To establish when the doll moves at the required velocity (i.e., is on a non-collision course), the future position of the doll at the moment that the second vehicle would cross the doll's track was determined. This future position was calculated by taking the doll's current distance from the intersection point with the vehicles' track and the distance the doll would travel until the second vehicle reached the intersection. This is captured in the following formula:

$$x(t) = x\_doll(t) - (v\_doll(t) * ti\_vehicle(t)) \quad (1)$$

In Equation 1, $x(t)$ is the future distance between the doll and the vehicles' track at the moment the second vehicle would cross the doll's track given the doll's current position and velocity; $x\_doll(t)$ is the current distance between the doll and the vehicles' track (positive until the intersection is reached, and then negative); $v\_doll(t)$ is the current velocity of the doll; $ti\_vehicle(t)$ is the current time until the second vehicle intersects the doll's path (positive until the intersection point is reached, and then negative). Given the dimensions of the collision area (as determined by the dimensions of the doll and the vehicles; Figure 2), the doll is on a non-collision course when the future position of the doll falls outside the collision area, that is, when $x(t) < -0.05$. If, however, $x(t) > -0.05$, then the minimum required velocity is not met and, hence, the doll is on a collision course. The doll's velocity, $v\_doll(t)$, should be controlled in such a way that, while pushing the doll across the road, the resulting $x(t)$ falls outside the collision area at the moment the vehicle would cross the doll's track. To avoid collisions, the required velocity should at the latest be attained at the moment the doll enters the collision area (i.e., when $x\_doll(t) = 0.05$ m). Examples of a safe and an unsafe crossing between the two vehicles are given in Figure 3.

As indices of velocity control, we first determined where the minimum required velocity was attained by establishing the doll's distance from the intersection at which the future position of the doll would fall outside the collision area the moment the vehicle would reach the doll's track (i.e., x_{rv}). Secondly, we determined a safety margin by establishing the future position at the moment the second vehicle would reach the intersection for the moment the doll reached the intersection (i.e., x_f). For each inter-vehicle timegap separately (0.20, 0.30, 0.40, and 0.60 s) x_{rv} and x_f were compared between children with and without hemiparesis and between children with LHD and RHD by performing Mann-Whitney U-tests, including the data from all crossing attempts.

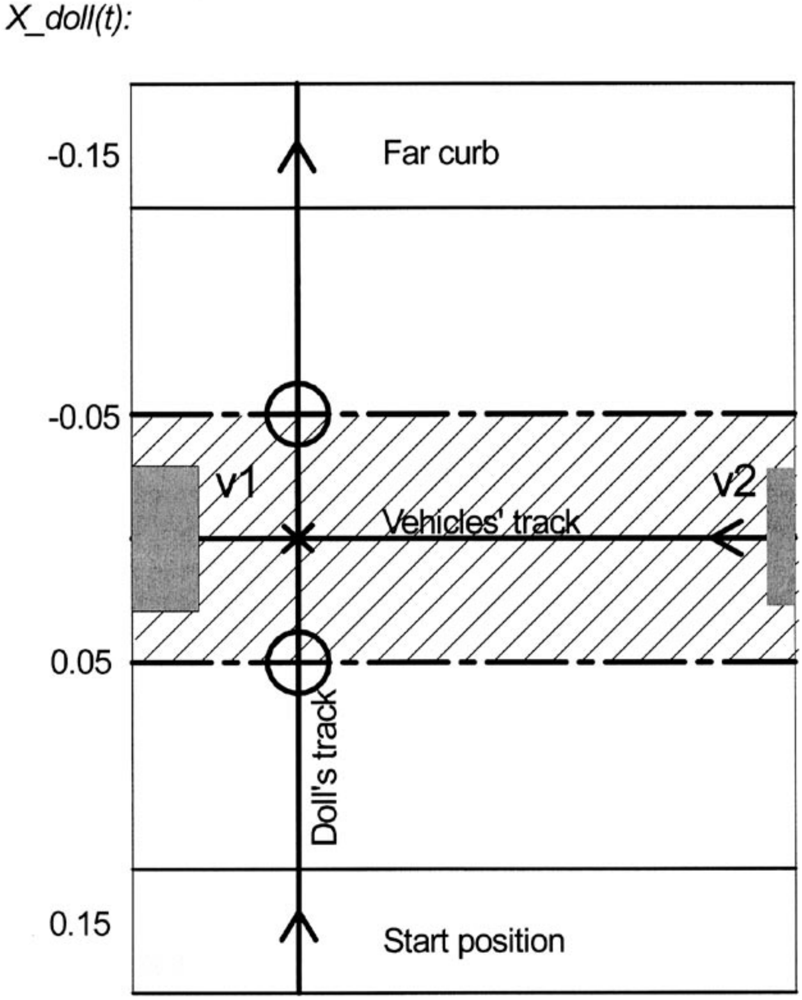

Figure 2—Schematic representation of the doll (circle), the vehicles (squares v1 and v2), the doll's track (*x_doll* from the start position at 0.15 m to the far curb at –0.15 m), the vehicle's track (at *x_doll* = 0.00 m), and the collision area (hatched area).

Results

Perception: Crossings and Collisions

The percentage of crossings was significantly higher for the typically-developing children (68.3%) than for the children with hemiparesis [52.1%; $F(1, 42) = 5.49$, $p < .05$, $\eta_p^2 = .12$]. Significant effects of velocity [$F(2, 84) = 77.06$, $p < .01$, $\eta_p^2 = .65$], distance [$F(2, 84) = 160.48$, $p < .01$, $\eta_p^2 = .79$], and velocity by distance [F(4,

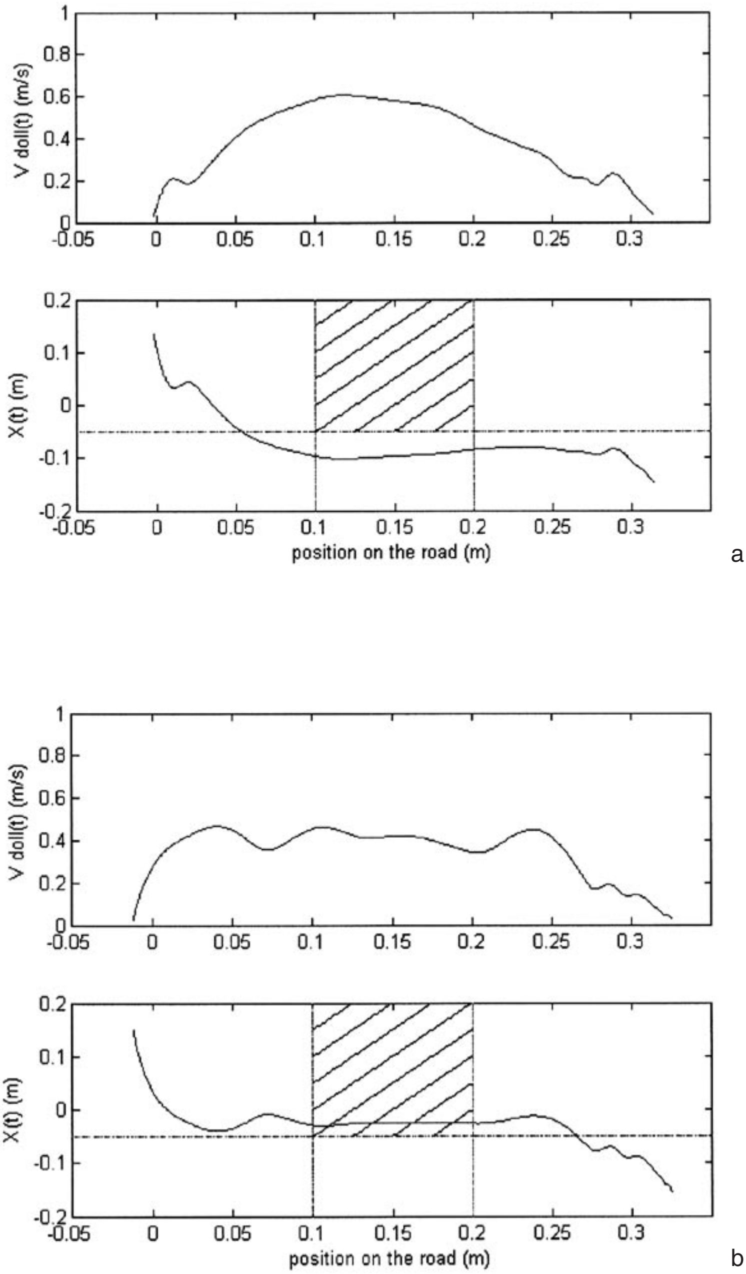

Figure 3—Typical examples of velocity profiles, *v_doll(t)*, and estimated future positions, *x(t)*, as a function of the doll's position on the road (upper and lower panels respectively). The hatched area between the two vertical lines reflects the collision area. The horizontal line reflects the (safety-) margin of –0.05 m. For a safe crossing (a), *x(t)* becomes smaller than –0.05 before the doll reaches the collision area, and for an unsafe crossing (b), *x(t)* remains larger than –0.05, even in the collision area.

168) = 2.81, $p < .05$, $\eta_p^2 = .06$] on the percentage of crossings showed that both groups crossed more often when the vehicles approached relatively slow and the inter-vehicle gap was relatively large. None of the comparisons between children with LHD and RHD were significant.

The percentage of collisions was higher for children with hemiparesis (6.6%) than for their typically-developing peers [2.7%; $F(1, 42) = 6.67$, $p < .05$, $\eta_p^2 = .14$]. A significant effect of vehicle [$F(1, 42) = 15.03$, $p < .01$, $\eta_p^2 = .26$] showed that in both groups the children collided more often with the second vehicle than with the first. This was particularly true for the small inter-vehicle distance, as was indicated by a significant distance effect [$F(2, 84) = 10.36$, $p < .01$, $\eta_p^2 = .20$] and a significant vehicle by distance interaction [$F(2, 84) = 5.20$, $p < .05$, $\eta_p^2 = .11$].

The only significant difference between children with LHD and RHD on the percentage of collisions was shown by the interaction between group and velocity [$F(2, 40) = 4.56$, $p < .05$, $\eta_p^2 = .19$]. Post hoc comparisons indicated that children with LHD collided more often for the intermediate vehicle velocity (v = 0.75), whereas children with RHD collided more often for the fast vehicle velocity (v = 1.00).

Movement Initiation

Table 2 displays the means and standard deviations of Tti and Dti for the seven inter-vehicle timegaps. The comparison of children with and without hemiparesis did not reveal significant differences. The data suggest that for the short inter-vehicle timegaps the children with RHD initiated earlier than the children with LHD. Only for the inter-vehicle timegap of 0.30 s the comparisons of Dti and Tti were significant (Z = 2.05, $p < .05$ and Z = 2.50, $p < .05$, respectively).

Velocity Control

The criteria set for the modified RV model (i.e., $x_{rv} < 0.05$ and $x_f < -0.05$) were met in 93% of the 951 trials in which the typically-developing children and the children with hemiparesis safely crossed in between the vehicles. For the 85 unsafe trials, all criteria were met only once. The modified RV model was therefore considered a valid descriptor of the continuous changes in movement velocity for the task under investigation.

Figure 4a depicts x_{rv} as a function of the inter-vehicle timegap. It can be seen that for decreasing inter-vehicle timegaps the position where children attained the required velocity became closer to the collision area. In fact, for the smallest inter-vehicle timegap the children were on a collision course (i.e., they reached the required velocity when they were already in the collision area). Likewise, Figure 4b shows that with decreasing inter-vehicle timegaps, the future position x_f shifted into the direction of the collision area, indicating that the safety margin decreased, and was too small for the smallest inter-vehicle timegap. The higher percentage of collisions for the conditions with small inter-vehicle timegaps, thus, might be associated with less appropriate velocity control.

Figure 4 also suggests that children with hemiparesis attained the required velocity closer to the collision area and that x_f was smaller compared to control children. Only for the inter-vehicle timegap of 0.40 s was the difference for x_f significant. That is, for the inter-vehicle timegap of 0.40 s, the future position x_f was significantly closer to the collision area for the children with hemiparesis than

Table 2 Means (and standard deviations) of the Temporal and Spatial Indices of Movement Initiation, *Tti* and *Dti*, for the Seven Inter-Vehicle Timegaps for Control Children, Children with Hemiparesis, Children with Left Hemisphere Damage (LHD), and Children with Right Hemisphere Damage (RHD)

	Tti				*Dti*			
Timegap	Control	Hemiparesis	LHD	RHD	Control	Hemiparesis	LHD	RHD
0.15	–0.21 (0.16)	–0.22 (0.09)	–0.18 (0.06)	–0.26 (0.11)	–0.21 (0.16)	–0.22 (0.09)	–0.18 (0.06)	–0.26 (0.11)
0.20	–0.21 (0.13)	–0.26 (0.20)	–0.21 (0.16)	–0.32 (0.24)	–0.16 (0.10)	–0.20 (0.15)	–0.16 (0.12)	–0.24 (0.18)
0.30	–0.20 (0.15)	–0.22 (0.16)	–0.18 (0.15)*	–0.26 (0.16)*	–0.14 (0.10)	–0.14 (0.11)	–0.11 (0.09)*	–0.18 (0.11)*
0.40	–0.16 (0.16)	–0.20 (0.18)	–0.19 (0.17)	–0.21 (0.19)	–0.12 (0.12)	–0.15 (0.14)	–0.15 (0.13)	–0.16 (0.14)
0.45	–0.13 (0.11)	–0.13 (0.11)	–0.13 (0.12)	–0.13 (0.10)	–0.13 (0.11)	–0.13 (0.11)	–0.13 (0.12)	–0.13 (0.10)
0.60	–0.19 (0.24)	–0.19 (0.15)	–0.20 (0.17)	–0.18 (0.12)	–0.12 (0.15)	–0.12 (0.09)	–0.12 (0.11)	–0.11 (0.07)
0.90	–0.18 (0.23)	–0.19 (0.17)	–0.21 (0.15)	–0.17 (0.19)	–0.09 (0.12)	–0.09 (0.09)	–0.10 (0.08)	–0.09 (0.09)

Note. Smaller values indicate that children initiated when the first vehicle was already closer (i.e., later). *significant difference, $p < .05$

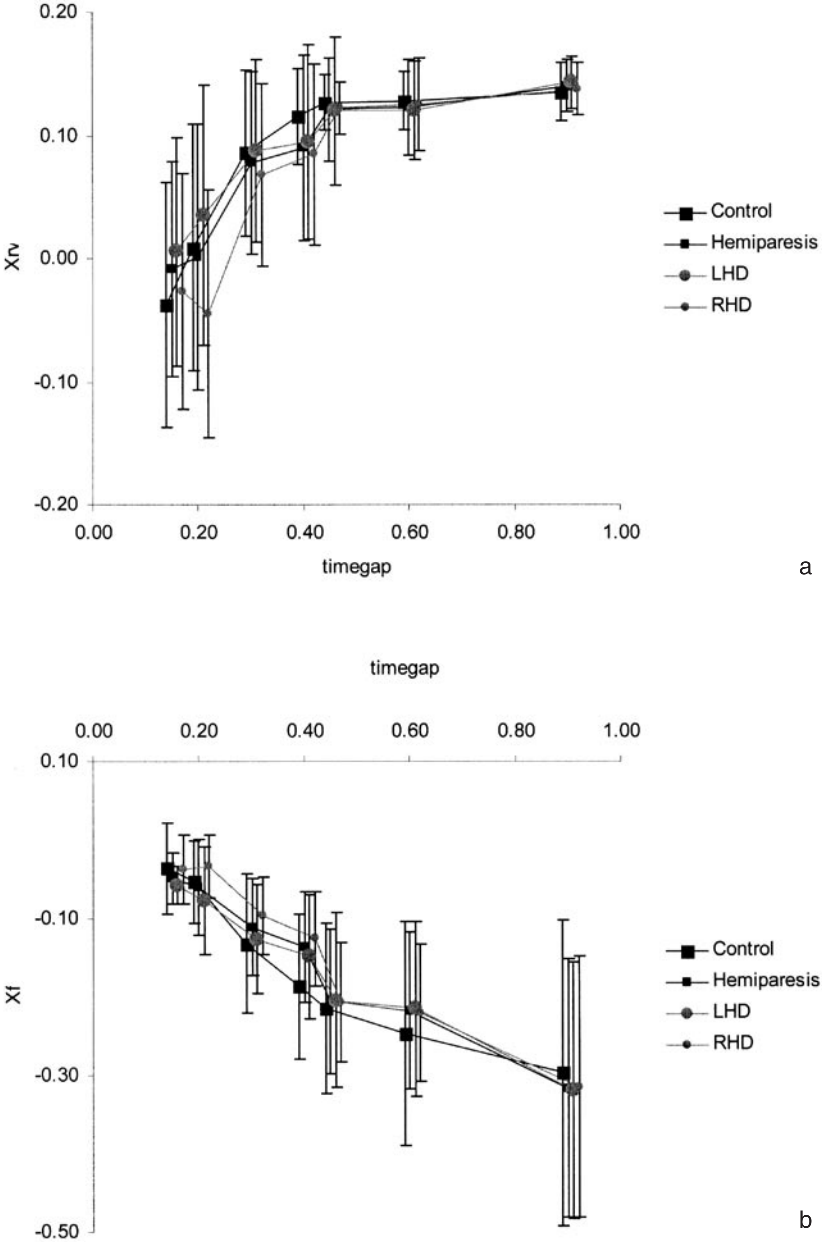

Figure 4—Means and standard deviations of the two indices of velocity control, x_{rv} (a) and x_f (b), as a function of the inter-vehicle timegap for control children, children with hemiparesis, children with LHD, and children with RHD. $x_{rv} < 0.05$ and $x_f > -0.05$ suggest insufficient velocity control.

for control children (Z = 2.71, $p < .05$). The difference for x_{rv} just failed to reach significance ($p = .065$). Figure 4 might also be interpreted as showing that children with RHD attained the required velocity closer to the collision area and that x_f was smaller compared to children with LHD, but these differences were not significant ($p = .059$ and $p = .063$ for the inter-vehicle timegap of 0.30 s).

Discussion

Experiment 1 compared manual collision avoidance of typically-developing children and children with LHD and RHD. Children with hemiparesis crossed less frequently than their typically-developing peers. This could indicate that children with hemiparesis were somewhat more cautious in deciding to cross. Although the children with hemiparesis crossed less frequently, however, they collided more often with the toy cars than their typically-developing peers. Thus, the perceptual judgments of the children with hemiparesis were relatively unsafe, which might be interpreted as perception being less appropriately attuned to the action capabilities. Te Velde et al. (2003) reported that it was mainly the children with RHD who made unsafe decisions to cross in front of an approaching bike. The present study, however, did not discern such differences between children with LHD and RHD.

Children with hemiparesis did not differ from typically-developing children with respect to movement onset, suggesting that the planning component of action was not adversely affected when considering the hemiparetic children as a group. In addition, the children with hemiparesis controlled velocity less safely than their typically-developing peers, although only for the inter-vehicle timegap of 0.40 s. It remains difficult, therefore, to unequivocally attribute the higher percentage of collisions in children with hemiparesis to deficits in the planning or control of action.

The comparisons between the children with LHD and RHD, however, provided some evidence that children with LHD could exhibit deficits in planning as movement initiation was relatively late for the timegap of 0.30 s. This suggests that the planning of action might have been affected in children with LHD relative to the children with RHD (Haaland et al., 2004; Rushworth et al., 1998; Steenbergen et al., 2004). The proposition that children with RHD would show a higher incidence of deficits in control (Te Velde et al., 2003; Haaland et al., 2004) was not statistically supported, however, Figure 4 might suggest that velocity control was relatively unsafe in children with RHD.

The children performed the task with their preferred side. Although the preferred hand is also affected to some extent (e.g., Van Thiel, Meulenbroek, Hulstijn, & Steenbergen, 2000), primarily focusing on this hand ignores the deficits in action capabilities of the non-preferred hand. To obtain a more lucid picture of planning and control deficits in relation to the primary side of the lesion, Experiment 2 compared the performance on the manual collision avoidance task between the preferred (i.e., ipsilesional) and non-preferred (i.e., contralesional) hand in children with LHD and RHD. Hypotheses are similar to Experiment 1, with the distinction that the effects are expected to be most pronounced for the non-preferred hand. Thus, it is expected that planning (e.g., movement onset) is adversely affected in children with LHD and that control after movement onset (e.g., velocity control) is less appropriate in children with RHD. In contrast to Experiment 1, in which the toy cars only approached from the ispilesional side, in Experiment 2 the toy cars also approached from the contralesional side. This manipulation was included because even a minor reduction of the visual field might become apparent in movement behavior (e.g., Barton, Behrmann, & Black, 1998; Netelenbos & Van Rooij, 2004; Schatz, Craft, Koby, & Debaun, 2004; Tant, Kuks, Kooijman, Cornelissen, & Brouwer, 2002), although the tests on hemianopia and hemineglect suggested that most children could perceive objects in both visual hemi-fields rather well.

Experiment 2

Method

Participants. Seven children with left hemiparesis (RHD; mean age = 13.7 ± 1.8 years, mean estimated cognitive age according to school level = 12.1 ± 1.9 years) and five children with right hemiparesis (LHD; mean age = 12.2 ± 2.0 years, mean estimated cognitive age according to school level = 11.0 ± 1.9 years), indicated with an asterisks (*) in the first column of Table 1, agreed to participate a second time. These children were chosen as they had demonstrated a longer concentration span during Experiment 1. Child "KACO" only participated in Experiment 2. Both groups contained one child whose visual field was bilaterally reduced and one child whose contralateral visual field was reduced; the other children did not demonstrate clear hemianopia. According to the line bisection task, none of the children had noticeable neglect.

Tasks and Apparatus. The same task and apparatus as in Experiment 1 was used.

Procedure and Design. During this experiment, each child performed 80 trials with a total duration of approximately 75 min. Half of the children moved the doll with the preferred hand during the first 40 trials, whereas the other half of the children first used their non-preferred hand. Vehicles approached alternately from the children's ipsilesional and contralesional side. Half of the children started with the vehicles approaching from the ipsilesional side, the other half started with the vehicles approaching from the contralesional side. Five different velocity-distance combinations were presented, namely v = 0.50 m/s, d = 0.30 m; v = 0.75 m/s, d = 0.15 m; v = 0.75 m/s, d = 0.30 m; v = 0.75m/s, d = 0.45 m; and v = 1.00 m/s, d = 0.30 m. Each combination was repeated four times within each of the four "hand-approach side" conditions. The velocity-distance combinations were randomly ordered within 16 blocks.

Dependent Variables and Data Analyses

Perception: Crossings and Collisions. The percentages of crossings and collisions were determined (see Experiment 1). Intra-individual means of the percentage of crossings were submitted to a 2 (group: LHD vs. RHD) × 2 (hand: non-preferred vs. preferred) × 2 (vehicle approach side: contralesional vs. ipsilesional) × 5 (velocity-distance combination) ANOVA with repeated measures on the last three factors, and the intra-individual means of the percentage of collisions to a 2 (group) × 2 (vehicle) × 2 (hand) × 2 (vehicle approach side) × 5 (velocity-distance combination) ANOVA with repeated measures on the last four factors. In the case that the sphericity assumption was violated (i.e., for $\varepsilon < 1.0$), Greenhouse-Geisser adjustments of the *p*-values were reported. Post hoc comparisons were performed using the Tukey HSD test ($p < .05$).

Movement Initiation. The moments of movement initiation (Tti and Dti) were determined for each child for both hands, and both vehicle approach sides. Comparisons for Tti and Dti were made between children with LHD and RHD, the preferred and non-preferred hands, and between the ipsi- and contralesional vehicle approach side for each inter-vehicle timegap separately (0.20, 0.30, 0.40, and 0.60 s) by using Kruskal-Wallis tests, including the data from all crossing attempts. Post hoc comparisons between groups (within hand and vehicle approach side) and between hand and vehicle approach side (within group) were performed using Mann-Whitney U-tests.

Velocity Control. The two indices for movement velocity control (i.e., x_{rv} and x_f) were determined for each child, for both hands, and both vehicle approach sides. For each inter-vehicle timegap separately (0.20, 0.30, 0.40, and 0.60 s) x_{rv} and x_f comparisons were made between children with LHD and RHD, the preferred and non-preferred hand, and between the ipsi- and contralesional vehicle approach side by using Kruskal-Wallis tests, including the data from all crossing attempts. Post hoc comparisons between groups (within hand and vehicle approach side) and between hand and vehicle approach side (within group) were performed using Mann-Whitney U-tests.

Results

Perception: Crossings and Collisions

Significant effects of hand [$F(1, 10) = 6.99$, $p < .05$, $\eta_p^2 = .41$] and hand by group [$F(1, 10) = 11.96$, $p < .01$, $\eta_p^2 = .56$] indicated that the children with RHD crossed significantly less when they used their non-preferred hand (60%) than when they used their preferred hand (75%). This difference was not found for the children with LHD (79% and 77%, respectively). The vehicle approach side did not affect the percentage of crossings, but the children did cross more in trials with relatively larger inter-vehicle timegaps [$F(4, 40) = 21.10$, $p < .01$, $\eta_p^2 = .68$].

The analyses did not reveal any significant main effects of group, hand, or vehicle approach side for the percentage of collisions. The significant velocity-distance combination effect [$F(4, 40) = 4.42$, $p < .05$, $\eta_p^2 = .31$] and the hand by velocity-distance combination interaction [$F(4,40) = 4.94$, $p < .05$, $\eta_p^2 = .33$] showed, however, that when using their preferred hand, the children collided mainly for the v = 0.75 m/s, d = 0.15 m combination (i.e., the smallest inter-vehicle timegap), while collisions were distributed more equally across different velocity-distance combinations when using their non-preferred hand.

Movement Initiation

Because the primary analysis showed no effects for vehicle approach side, a re-analysis was conducted in which vehicle approach side was removed as a factor. Table 3 displays the means and standard deviations of Tti and Dti for the four inter-vehicle timegaps. It suggests that children with LHD initiated later than children with RHD. The comparisons of Tti and Dti for the preferred hand for the inter-vehicle timegaps of 0.30 and 0.60 s were significant (p values < .05). The comparisons between the non-preferred hand failed to reach significance (for the inter-vehicle timegap of 0.30 s, $p = .055$).

Table 3 Means (and standard deviations) of the Temporal and Spatial Indices of Movement Initiation, *Tti* and *Dti,* for the Four Inter-Vehicle Timegaps for Children with Left Hemisphere Damage (LHD) and Right Hemisphere Damage (RHD) Using the Preferred (pref) and Non-Preferred (n-pref) Hand

	Tti				*Dti*			
Timegap	**LHD pref**	**LHD n-pref**	**RHD pref**	**RHD n-pref**	**LHD pref**	**LHD n-pref**	**RHD pref**	**RHD n-pref**
0.20	-0.23 (0.11)	-0.17 (0.11)	-0.24 (0.09)	-0.23 (0.12)	-0.17 (0.08)	-0.13 (0.08)	-0.18 (0.07)	-0.18 (0.09)
0.30	-0.15 (0.11)*	-0.13 (0.10)	-0.22 (0.14)*	-0.23 (0.19)	-0.15 (0.11)*	-0.13 (0.10)	-0.22 (0.14)*	-0.23 (0.19)
0.40	-0.21 (0.12)	-0.16 (0.14)	-0.20 (0.13)	-0.22 (0.13)	-0.16 (0.09)	-0.12 (0.10)	-0.15 (0.10)	-0.17 (0.10)
0.60	-0.21 (0.14)*	-0.16 (0.18)	-0.21 (0.19)*	-0.17 (0.14)	-0.13 (0.10)*	-0.10 (0.11)	-0.12 (0.10)*	-0.10 (0.09)

Note. Smaller values indicate that children initiated when the first vehicle was already closer (i.e., later). *significant difference, $p < .05$

Velocity Control

Because the primary analysis showed no effects for vehicle approach side, a re-analysis was conducted in which vehicle approach side was removed as a factor. Figure 5 depicts x_{rv} and x_f as a function of the inter-vehicle timegaps. Generally, for the shorter inter-vehicle timegaps, x_{rv} and x_f were smaller, indicating that the required velocity was attained closer to the collision area and relatively small (safety-) margins were left to clear the collision area. The higher percentage of collisions occurred for the conditions with short inter-vehicle timegaps, and thus, might be related to less appropriate velocity control.

Figure 5 suggests that velocity control of children with LHD differed from that of children with RHD, particularly for the short inter-vehicle timegaps. For the preferred hand, however, no differences between children with LHD and RHD were found, which is consistent with Experiment 1. By contrast, for the non-preferred hand the children with LHD reached the required velocity earlier (i.e., larger x_{rv}) than children with RHD. This was significant for the inter-vehicle timegap of 0.20 and 0.30 s (Kruskal-Wallis tests and subsequent Mann-Whitney U-tests p values $< .05$), but not for the inter-vehicle timegap of 0.40 s ($p = .054$). Moreover, for the non-preferred hand, the future position x_f was significantly larger for children with LHD than for children with RHD, which was significant for inter-vehicle timegaps of 0.20, 0.30, and 0.40 s (all p values $< .05$).

Figure 5 also suggests differences between the hands within groups. The Kruskal-Wallis and subsequent Mann-Whitney U-tests revealed that the children with LHD reached the required velocity earlier on the road when they used their non-preferred hand (i.e., their non-preferred hand displays relatively cautious control) for inter-vehicle timegaps of 0.20 and 0.30 s (both p values $< .05$). Moreover, for the children with LHD the future position of the doll was aimed further from the

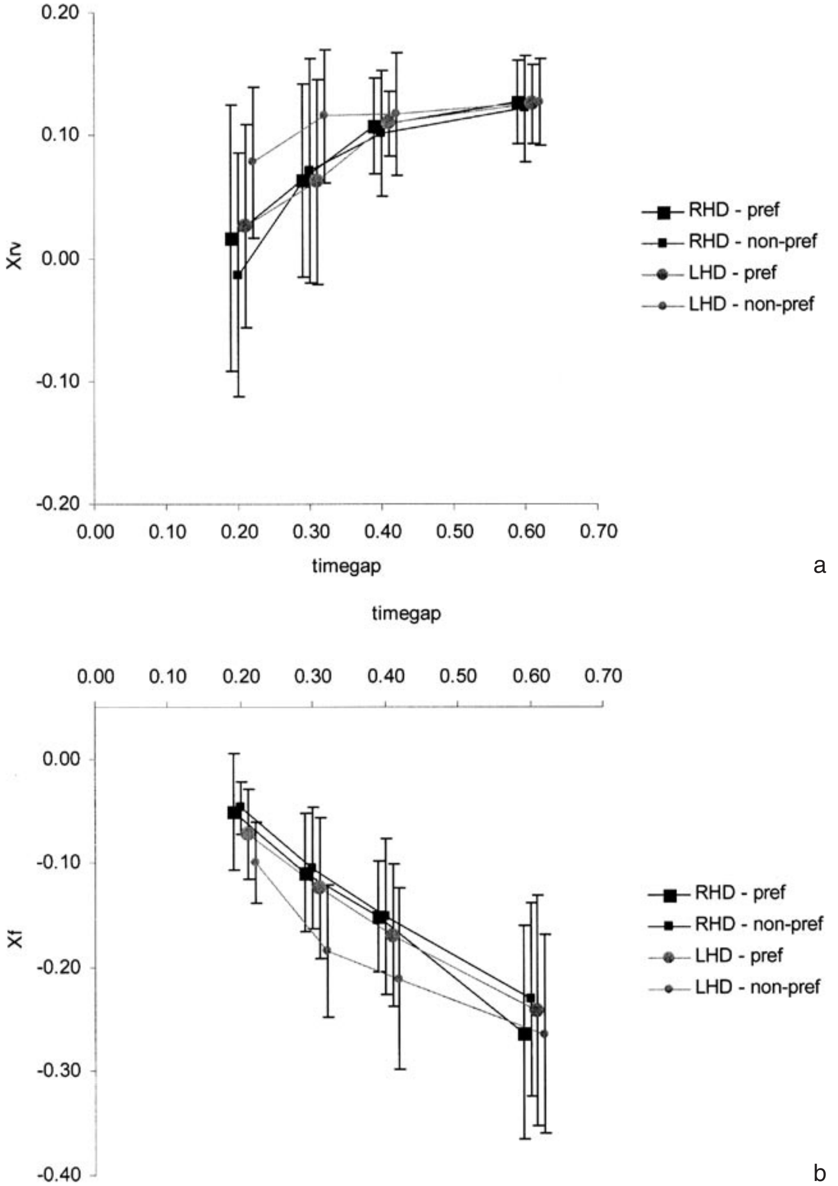

Figure 5—Means and standard deviations of the two indices of velocity control, x_{rv} (a) and x_f (b), as a function of the inter-vehicle timegap for children with LHD and RHD using the preferred and non-preferred hand. $x_{rv} < 0.05$ and $x_f > -0.05$ suggest insufficient velocity control.

collision area for inter-vehicle timegaps of 0.20, 0.30, and 0.40 when they used their non-preferred hand (i.e., x_f was larger; all p values < .05). Differences between the hands of children with RHD were not significant.

Discussion

Children with RHD crossed less frequently with their non-preferred than with their preferred hand. By contrast, children with LHD crossed as much with their preferred as with their non-preferred hand. Finally, when using their non-preferred hand, the children with RHD crossed less than the children with LHD. Thus, only children with RHD seemed to take the impoverished action capabilities of their non-preferred hand into account when deciding to cross the road. The percentage of collisions, however, was comparable for both groups and for both the preferred and non-preferred hand. Hence, the perceptual decisions to cross the road appeared equally attuned to the action capabilities in both groups.

Children with LHD seemed to initiate their movement relatively late compared to children with RHD, particularly for their preferred hand. Interestingly, the comparisons of the non-preferred hand did not reveal significant differences. This provides at least partial support for the hypothesis that planning of action is adversely affected in individuals with LHD (Steenbergen et al., 2004).

The results on the control of the movement after onset proved more ambiguous. As in Experiment 1, the findings confirmed the increased risk for a collision with decreasing inter-vehicle timegap. The comparison between children with LHD and RHD did not yield differences for the preferred hand. When the children used their non-preferred hand, however, the children with RHD attained the required velocity closer to the collision area for the small inter-vehicle timegaps. In addition, the safety margin at the moment the doll crossed the vehicle's track was smaller for children with RHD in particular for the non-preferred hand. These findings might suggest that control of movement after onset is adversely affected in children with RHD compared to children with LHD (Te Velde et al., 2003), but only for the non-preferred left hand.

Yet, the results can also be interpreted otherwise. Paradoxically, the children with LHD reached the required velocity for a safe crossing earlier with their non-preferred than with their preferred hand. That is, they behaved more safely with their non-preferred hand. It might be that the children tried to compensate for late initiation (Table 3). In that case, the differences between children with LHD and RHD might not be a reflection of control deficits in children with RHD, but could suggest that children with LHD overcompensated after initial planning errors. Neither alternative can be ruled out on the basis of the present study.

General Discussion

Planning in Children with LHD

The collision avoidance behavior indicated planning deficits in children with LHD, but not in children with RHD. This corroborates the findings in recent studies by Haaland et al. (2004), Mutsaarts et al. (2005), Rushworth et al. (1998), and Steenbergen et al. (2004). Moreover, this supports the findings for left hemispheric dominance in action planning in typically-developing individuals as well (Johnson-Frey, Newman-Norlund, & Grafton, 2004; Schluter, Krams, Rushworth, & Passingham, 2001). Planning, however, has a very broad meaning both theoretically and empirically. Glover (2004), for instance, refers to planning as including the selection of an appropriate target, the selection of an appropriate movement, and beyond these also the initial kinematic parameterization of the movement (cf., Goodale & Milner, 2004). Empirical work has used the selection of the appropriate action (e.g., Rushworth et al., 1998) or the selection of the appropriate posture or movement (e.g., Steenbergen et al., 2004; Mutsaarts et al., 2004) to assess planning, while other studies (Haaland et al., 2004; Mutsaarts et al., 2005; Schluter et al., 2001) have used reaction time as an indicator of planning. Almost every single study maintains its own characterization of planning, the present study being no exception. That is not to say, however, that similarities are absent. Both the observed increases in reaction time, and the late movement onset found in the present study suggest that children with LHD take longer before starting an action, suggesting an impairment in the initial parameterization of the movement. In addition, the decision whether to act is connected to response selection and to a lesser degree to the selection of the appropriate movement or posture. The observation, therefore, that children with LHD did not take their impoverished action capabilities into account when deciding whether to cross with their non-preferred hand is consistent with previously reported impairments in selecting an appropriate action or movement posture. These observations might be interpreted to support the contention that LHD is associated with a general planning deficit. It should be mentioned that the number of participants in the present study is low. In addition, because we performed separate tests for each inter-vehicle timegap there is an increased chance of Type-I errors. Taken together, the findings must be interpreted with some care.

Control in Children with RHD

We did not find unambiguous support that children with RHD are more susceptible to movement control deficits. Although velocity control after movement onset of children with RHD can be interpreted as less appropriate than in their peers with LHD, alternative interpretations in terms of overcompensation in children with LHD cannot be precluded. The latter interpretation could find some support in the work of Haaland et al. (2004). They argued that LHD might be associated with a deficit in selecting the optimal velocity for a given context. Our LHD children might have planned a high initial velocity to compensate for a somewhat late movement onset, although this was not evident for their non-preferred hand. In Haaland's interpretation, RHD is associated with deficits in end-point spatial accuracy. Our RHD group did not confirm such an interpretation. Haaland's reasoning, however, is in part based on the claim that control only involves spatial parameters of the movement (see Glover, 2004). This idea originates from studies that chiefly examined reaching to and grasping stationary objects. Evidence from interceptive actions that include temporal constraints, however, shows that not only spatial, but also temporal parameters (e.g., timing, speed) can be adjusted on-line to satisfy the task constraints during the control phase of an interceptive action (Brenner & Smeets, & deLussanet, 1998; Caljouw, Van der Kamp, & Savelsbergh, 2005; Schenk, Mair,

& Zihl, 2004). Nonetheless, even with such an extended definition of control, the present study cannot substantiate the conjecture that RHD would be associated with deficits in movement control.

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