Differentiating prospective control information for catching in at-risk and control adolescents

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This paper investigated the use of prospective control in catching and how the results can be used as a sensitive tool to detect diffuse signs of brain dysfunction. A detailed analysis of 286 catching movements of eight adolescents (two males, six females [four very-low-birthweight (VLBW), one small for gestational age (SGA), and three appropriate for gestational age]; mean age 14y 5mo [SD 6mo]; range 14–15y) was performed blind for this purpose. The moving target approached the participants from the side at three different, non-constant accelerations. The results showed that three adolescents used less advanced timing strategies that involved the lower-order variables of distance or velocity to govern movement initiation of at least one of their hands. Two of these were preterm VLBW and one was term SGA. The remaining adolescents, on the other hand, all relied on the higher-order variable of time-to-contact to initiate their hand movements, and were, therefore, considered low-risk. These results were compared with the cerebral magnetic resonance imaging results of the adolescents. The findings show that timing strategy pinpoints successfully those adolescents at risk of neurological problems. It was, therefore, concluded that the skill of using prospective information for catching can be used as a tool to detect diffuse signs of motor dysfunction, which are not readily detected by standard behavioural tests alone.

Catching a moving object is a complex task as it involves the coordination of trunk, eye, head, and hand movements as well as advanced timing skills. To catch successfully a moving object one needs to anticipate its future trajectory. This, in turn, requires prospective control of head, eye, arm, and hand movements.1 Visual information on the object’s velocity and its rate of change is necessary for the precise control of motor acts aimed at a moving target.2 In addition, information from the visual system has to be integrated with proprioceptive and haptic information.3

Successful reaching and catching thus require different perceptual subsystems, all of which must be functioning properly, in addition to prospective movement control. Because of their complexity, catching tasks are ideally suited to study the integrity of the central nervous system in neurologically at-risk individuals. The results of these studies might be successfully applied to the fields of (early) diagnosis and rehabilitation.

Van der Meer and her colleagues studied healthy term4 and preterm infants4 during the second half of the first year catching a moving toy to investigate the prospective timing strategies used. The preterm infants showed signs of a delayed catching and reaching development and poorer anticipation skills even when corrected for prematurity. Yet, by the age of 48 weeks, most of the preterm infants had caught up with their term peers and were using effective timing strategies that involved the higher-order variable of time-to-contact to time their catching actions. Two preterm infants, however, kept on using the less sophisticated timing strategy based on the lower-order variable of distance, and were later diagnosed as suffering from mild to moderate cerebral palsy (CP).

For the present study, preterm very-low-birthweight (VLBW; <1500g), term small for gestational age (SGA; <10th centile at term), and term appropriate for gestational age (AGA) control adolescents (>10th centile at term) were tested at the age of 14 to 15 years. We investigated whether there were any differences in the three groups of adolescents’ use of prospective control information in a catching task. The aim of the present study was to test a sophisticated tool to blindly detect diffuse signs of brain dysfunction based on differences between adolescent participants in timing strategy, and to compare these results with the participants’ qualitatively assessed cerebral magnetic resonance imaging (MRI) results.

Method

Participants

Preterm VLBW, term SGA, and term AGA adolescents were tested at the age of 14 to 15 years. Since birth, all participants had been taking part in a longitudinal, population-based project in which they were tested at regular intervals on a wide range of tests to evaluate the possible adverse effects of being VLBW or SGA.5–9 At age 14, participants were called in again and a total of 196 adolescents underwent several different tests,10,11 including MRI on 55 preterm VLBW, 54 SGA, and 66 term AGA adolescents.12,13 It was at this age that our laboratory was asked to contribute to the project by testing in detail the use of prospective control information for catching in eight adolescents (two males, six females). Participants for this study were recruited from the University Hospital in Trondheim, St Olav’s Hospital, Norway. The study was approved by the Norwegian Regional Ethics Committee. All participants gave their informed consent. The experiment was conducted blind; the birth status, gestational age, birthweight,
and the MRI results of the participants were not known to the experimenters until after the analyses of the data were completed.

APPARATUS
The participant was seated facing a 250cm × 12.5cm horizontal track with a mounted platform. The platform (11.5cm long, 12.5cm wide), with the target placed in the middle, was driven by a computer. The target travelled under three different (non-constant) accelerations towards the catching location, reaching a final velocity of 55cm/s, 105cm/s, and 150cm/s at the catching location. The respective accelerations at the catching location were 23cm/s² (ACC1), 83cm/s² (ACC2), and 164cm/s² (ACC3).

Two chairs were set up opposite each other on either side of the track and connected with a wooden board resting on the armrests, fastened by Velcro. The wooden board ensured that the participant only moved his or her hand straight ahead and not to the side to catch the target. The target was a reflective marker (4cm in diameter) fastened to the platform on the track by Velcro.

To record hand movement in three dimensions, a reflective marker 1cm in diameter was placed on the web between the participant’s thumb and index finger. Five infrared cameras (ProReflex Motion Capture Unit 240) were used to record the movement of the target and hand at 240Hz, one recording lasting for 10s. In addition, the trials were videotaped.

PROCEDURE
The experiment was conducted in the Developmental Neuroscience Laboratory, Department of Psychology, Norwegian University of Science and Technology, Trondheim. When the participants arrived at the laboratory, the short Norwegian version of the Edinburgh Handedness Inventory was administered to determine the participants’ preferred hand.

After taking part in four different experiments in the laboratory, the participants were allowed to rest for 15 minutes and were offered some refreshments. The catching experiment was conducted after the break, about 1 hour into the experimental session. The participant was asked to sit down in one of the chairs, whereupon the hand markers were fastened. The participant was then instructed to rest his or her arm on the armrest, to move forward, and to catch the target in the catching location between his or her thumb and index finger.

The data capture program was set to start recording just before the target started to move. Six trials were conducted for each of the three acceleration conditions. This resulted in 18 trials for each hand, presented in random order, and 36 trials in total. The participants were randomly assigned to start with either their preferred or non-preferred hand. After the first 18 trials with one hand, the camera opposite the participant had to be moved to the opposite side of the track for the remaining 18 trials with the other hand. The whole experiment lasted about 20 minutes.

MEASURES
Time points analyzed for each trial were: (1) target started to move, as indicated by an increase in the target’s velocity, \( T_p \); (2) hand started moving forward, as indicated by a steady increase in velocity (y-coordinate) of the hand marker, \( T_{MS} \); (3) position of target at \( T_{MS} \), \( Z_{target} \); (4) velocity of target at \( T_{MS} \), \( V_{target} \); and (5) arrival of the target at the catching location, \( T_{CL} \). From these time points the higher-order variable of time-to-contact \( T_{target} = T_{MS} - T_{CL} \).

The means and standard deviations (SD) of the raw data and of the computed measure were then calculated for each participant and for each experimental condition. Each mean and SD was computed over six values.

Results
TIMING STRATEGY
A total of 286 successful catches were recorded. What prospective perceptual control variable governed initiation of the reaching action? Four possible perceptual control variables that may have governed the initiation of the hand were considered, where initiation of hand movement was indicated by a steady increase in velocity (y-coordinate) of the hand marker on the web. They were: (1) initiation occurs a certain time (\( T_o \)) after the target has started to move; (2) it occurs when the target is a certain distance (\( Z_{target} \)) from the catching location; (3) it occurs when the target reaches a certain velocity (\( V_{target} \)); and (4) it occurs a certain time-to-contact (\( T_{target} \)) before the target is due to arrive at the catching location.

To determine which perceptual control variable most likely governed the initiation of the hand movement, the variable that showed the least variability was sought. Since the putative governing variables were measured in different units (centimetres, seconds, centimetres per second), the SD could not be used to compare variability. What was required was a dimensionless quantity. The choice fell on the index of dispersion, which can be defined as the SD divided by the mean. A small index of dispersion indicates little variation across accelerations and hands. The index of dispersion of each perceptual control variable was computed across the three different target accelerations and the two hands for each participant separately.

In Table I the lowest indices of dispersion for each of the five variables are highlighted for each participant, and the statistical significance of these variables indicated. In general, the table shows that the participants used different strategies to govern initiation of hand movement. Participant TS initiated his hand movements when the target was a certain distance, \( Z_{target} \), away from the catching place (\( t(3) = 5.28, p < 0.01 \)). It was found that \( V_{target} \) was used by SS (\( t(3) = 3.551, p < 0.05 \)) and KK (\( t(3) = 2.468, p < 0.05 \)) to govern movement initiation of their non-preferred hand. HH had the lowest index of dispersion for \( T_{target} \) but this was not significantly lower than the other variables (\( t(3) = 1.740, ns \)). The other four participants, VA, CJ, RE, and LE, all started their hand movements a certain time \( T_{target} \) before the target was due to arrive at the catching place.

ADDITIONAL BACKGROUND INFORMATION ON THE PARTICIPANTS
AND SUMMARY MRI RESULTS
After the analyses of the data were completed we received information on the participants’ gestational age, birthweight, birth status, the qualitatively assessed cerebral MRI pathology results, and the centile for the score they had obtained on the Movement-ABC including their raw scores on the subtests for manual dexterity, ball skills, and balance (Table I).

In this paper, participants TS, SS, and KK were classified as at-risk for neurological problems based on their results for timing strategy. As shown in Table I, these adolescents were either
term SGA (TS) or preterm VLBW (SS and KK). Interestingly, TS had the best possible raw score of 0 on the Movement-ABC subtest for ball skills, whereas he used the least sophisticated timing strategy in the present catching experiment. The remaining participants were all classified as low-risk based on their timing strategy. Two of these adolescents (VA and CJ) were, however, preterm VLBW (Table I) and must, therefore, be considered as normally functioning, healthy, preterm adolescents. It is, however, important to note VAs low centile on the Movement-ABC, which was mainly due to the scores on the balance tasks. The remaining three participants (HH, LE, and RE) were correctly identified as term AGA controls.

When comparing the results of the present experiment with the MRI results, the following was found (Table I). TS (term SGA) had dilation of the ventricular system and reduced white matter tissue. SS (preterm VLBW) also had a dilated ventricular system, both focal bilateral occipitally and diffusely of the left ventricle. In addition, SS had reduced white matter tissue and pathology in the corpus callosum. KKs (preterm VLBW) MRI results showed no abnormality whatsoever, whereas control participant HHs (term AGA) MRI results showed dilation of the ventricular system and mildly dilated subarachnoidal spaces. In addition, CJ (preterm VLBW) and RE (term AGA) were found to have dilation of the ventricular system. Finally, control participant LE (term AGA) had normal MRI results, whereas VAs (preterm VLBW) results were missing as he had not consented to MRI of the brain.

Discussion
This study set out to test a sophisticated tool to detect diffuse signs of brain dysfunction based on the differences between preterm VLBW and term SGA and AGA control adolescents in timing strategies. The results will now be summarized and interpreted in the light of the participants’ clinical background information. Finally, the consequences of these results for detecting (early) brain dysfunction will be discussed.

TIMING STRATEGY
The results showed that three participants used a lower-order variable to govern the initiation of their hand movements for at least one of their hands. TS used the lower-order variable \( T_{\text{target}} \) to govern the movement of both his hands, i.e. he started moving his hand when the target was a certain distance away from the catching location. For the movement initiation of their non-preferred hand, participants SS and KK relied on the lower-order variable of \( V_{\text{target}} \), i.e. they started moving their hand when the target reached a certain velocity. Relying on the lower-order variables of \( T_{\text{target}} \) and \( V_{\text{target}} \) can have two different effects. If one starts the hand movement when the target has reached a short distance from the catching location or a relatively high velocity, this might work reasonably well for ACC1, but these strategies will cause larger timing errors as the acceleration increases for ACC2 and ACC3, i.e. the hand arrives at the catching location too late to catch the target. If one, however, picks a long distance from the catching location or a low target velocity to govern initiation of the hand movement then this will work well for ACC2 and ACC3, but such strategies will cause major problems at the slowest acceleration as the hand arrives at the catching location long before the target.

The remaining five adolescents (HH, VA, CJ, RE, and LE) all used the higher-order variable of \( T_{\text{target}} \) to govern initiation of their hand movements, indicating that they started to move their hand when the target was a certain time away from the catching location. This strategy ensured them always

Table I: Indices of dispersion for the four putative variables governing movement initiation of the hand (\( T_d \), \( Z_{\text{target}} \), \( V_{\text{target}} \), and \( T_{\text{target}} \)). A small index of dispersion indicates little variability across the conditions and is, in turn, interpreted as the variable that is being controlled by the participant. The lowest index of dispersion is highlighted for each participant and its statistical significance indicated (\( p<0.05 \) and \( p<0.01 \)). The three participants above the horizontal line were classified as adolescents at risk for neurological problems, because they were shown to use the lower-order perceptual variables of \( Z_{\text{target}} \) and \( V_{\text{target}} \) to time their catching action. Further, gestational age, birthweight, birth status, cerebral MRI pathology (ventricular dilatation, white matter reduction, and corpus callosum thinning), and the score for the Movement-ABC (in centiles) for each participant are given. Raw scores in parentheses for the subtests for manual dexterity (maximum=15), ball skills (maximum=10), and balance (maximum=15) are given. A higher score on the Movement-ABC indicates a higher level of impairment. The score is then interpreted in the light of centile norms. The centile indicates the number of children who fall below a particular raw score. Children under the fifth centile are considered to have definite motor problems. Scores between the fifth and fifteenth centile suggest a certain degree of difficulty that is borderline.

<table>
<thead>
<tr>
<th>Participants</th>
<th>Lower-order variables</th>
<th>Higher-order variable</th>
<th>Gestational age</th>
<th>Birthweight</th>
<th>Birth status</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>( T_d )</td>
<td>( Z_{\text{target}} )</td>
<td>( V_{\text{target}} )</td>
<td>( T_{\text{target}} )</td>
<td></td>
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<tr>
<td>TS</td>
<td>0.402</td>
<td>0.223\textsuperscript{b}</td>
<td>0.306</td>
<td>0.309</td>
<td>Term</td>
</tr>
<tr>
<td>SS</td>
<td>0.442</td>
<td>0.455</td>
<td>0.262\textsuperscript{a}</td>
<td>0.312</td>
<td>24 wks</td>
</tr>
<tr>
<td>KK</td>
<td>0.405</td>
<td>0.503</td>
<td>0.320\textsuperscript{c}</td>
<td>0.536</td>
<td>50 wks</td>
</tr>
<tr>
<td>HH</td>
<td>0.425</td>
<td>0.235</td>
<td>0.276</td>
<td>0.207</td>
<td>Term</td>
</tr>
<tr>
<td>VA</td>
<td>0.401</td>
<td>0.525</td>
<td>0.514</td>
<td>0.313\textsuperscript{b}</td>
<td>28 wks</td>
</tr>
<tr>
<td>LE</td>
<td>0.390</td>
<td>0.528</td>
<td>0.468</td>
<td>0.293\textsuperscript{b}</td>
<td>Term</td>
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<tr>
<td>CJ</td>
<td>0.420</td>
<td>0.426</td>
<td>0.345</td>
<td>0.540\textsuperscript{a}</td>
<td>27 wks</td>
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<tr>
<td>RE</td>
<td>0.421</td>
<td>0.415</td>
<td>0.354</td>
<td>0.345\textsuperscript{a}</td>
<td>Term</td>
</tr>
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</table>

\( ^{\text{a}}p<0.05; ^{\text{b}}p<0.01; ^{\text{c}}\text{mild diffuse bilateral dilation of the lateral ventricles}; ^{\text{d}}\text{focal dilation and edging of the occipital horns of the lateral ventricles}; ^{\text{e}}\text{unilateral dilation of left occipital horn of the lateral ventricle. SGA, small for gestational age; AGA, appropriate for gestational age.} \)

the same amount of movement time to perform their reaching actions, enabling them to catch the target in the designated catching location with the smallest timing error.

All three participants who relied on a lower-order variable to govern movement initiation of at least one of their hands (TS, SS, and KK) were treated by us as being at-risk for neurological problems. This diagnosis was consistent with the clinical background information on the participants, as TS was an adolescent born term SGA, and SS and KK were both preterm VLBW. In addition, the MRI results showed that TS and SS had dilated ventricular systems and reduced white matter tissue. KK’s MRI results, on the other hand, showed no abnormalities. The remaining five participants (HH, VA, CJ, RE, and LE) were all treated as low-risk adolescents based on the advanced timing strategy they used. Three of these participants (HH, RE, and LE) were term AGA controls, but the MRI results showed dilation of the ventricular system for both HH and RE. The remaining two participants (VA and CJ) were preterm VLBW, but were functioning just as well as the controls. CJ’s MRI results also showed a dilated ventricular system, whereas VA’s MRI results were missing.

These results accord with the previous findings of Van der Meer et al., who found that by the end of the first year most preterm babies relied on the higher-order variable of time-to-contact (T_{time}) to shift their gaze and to initiate their catching movements. However, the two preterm infants who continued to use the lower-order variable of distance (Z_{time}) to time their actions, were later on officially diagnosed as having mild and moderate CP. This fits our present results, as all term AGA adolescents were seen to use a higher-order variable to initiate their hand movements, whereas two of the preterm VLBW participants and the term SGA adolescent relied on lower-order variables. The remaining two preterm VLBW participants were using the same advanced strategy as the controls.

**USING PROSPECTIVE CONTROL INFORMATION FOR CATCHING TO DETECT (DIFFUSE) SIGNS OF BRAIN DYSFUNCTION**

So far, we have pointed out differences in timing strategy between adolescents at-risk for neurological problems and normally functioning low-risk participants. Based on their use of timing strategy, the same three participants (TS, SS, and KK) were considered to be at-risk for neurological problems and turned out to have been born preterm VLBW or term SGA. The remaining five participants were classified as low-risk adolescents based on their timing strategy, and were seen to be either term AGA controls or normally functioning, healthy, preterm VLBW adolescents.

Thus, the timing strategy used to initiate the hand movement in our catching task might serve as an important method to detect diffuse signs of brain dysfunction. However, the experiment will need to be performed on a greater number of participants. This will make it possible to establish norms for the different groups to minimize the risk of classifying suspects wrongly. It is also important to keep in mind that the terms ‘normally functioning’ and ‘low-risk’ used in this paper only apply to the studied catching task.

Despite the small number of participants, the attention given to the catching performance of the individual adolescent revealed some interesting discrepancies between the conclusion drawn based on the Movement-ABC and the measure in this study that affects three out of eight participants. First, term SGA adolescent TS had the best possible score of 0 for the subtest ball skills on the Movement-ABC, whereas he employed the least sophisticated timing strategy in our comparable catching task. Likewise, preterm VLBW participant VA, despite a Movement-ABC score of 5% which was mainly due to a poor score on the balance subtest, performed equally well on our catching task as the term AGA adolescents. Finally, term AGA control participant HH, with the highest overall score on the Movement-ABC, displayed MRI pathology and scored borderline on timing strategy. We therefore argue that the Movement-ABC is not ideally suited to differentiate between at-risk and low-risk individuals. By only using the Movement-ABC, two adolescents (i.e. one quarter of the participants) would be wrongly diagnosed, which is clearly undesirable.

Consequently, our method would be best suited as a detailed way of investigating exactly what the underlying problem is with certain at-risk individuals. In particular, children with not so clear-cut but suspected motor dysfunctions, who nevertheless fail to show up on standard behavioural assessments such as the Movement-ABC, might benefit from the proposed method. In the long term, it might be possible to develop simpler tests which are easier to analyze and that manage to tap into prospective control. An advantage of the present method is that because ample attention is given to the performance of the individual child, intervention programmes better tailored to the individual needs of the child can be devised.

### Table I: continued

<table>
<thead>
<tr>
<th>Cerebral Ventricular dilation</th>
<th>MRI White matter reduction</th>
<th>Pathology Corpus callosum thinning</th>
<th>Movement-ABC Score</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Yes</strong>&lt;sup&gt;a&lt;/sup&gt;</td>
<td>Yes</td>
<td>No</td>
<td>&lt;1% (14/0.8)</td>
</tr>
<tr>
<td><strong>Yes</strong>&lt;sup&gt;b&lt;/sup&gt;</td>
<td>Yes</td>
<td>No</td>
<td>&lt;1% (12/7.9)</td>
</tr>
<tr>
<td><strong>No</strong></td>
<td>No</td>
<td>No</td>
<td>5% (4/3.5/6)</td>
</tr>
<tr>
<td><strong>Yes</strong>&lt;sup&gt;c&lt;/sup&gt;</td>
<td>No</td>
<td>No</td>
<td>95% (0.0/5.0)</td>
</tr>
<tr>
<td><strong>No</strong></td>
<td>No</td>
<td>No</td>
<td>5% (5/1.5/7)</td>
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<tr>
<td><strong>Yes</strong>&lt;sup&gt;d&lt;/sup&gt;</td>
<td>No</td>
<td>No</td>
<td>65% (0/3.0)</td>
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<tr>
<td><strong>Yes</strong>&lt;sup&gt;e&lt;/sup&gt;</td>
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<td>No</td>
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<td><strong>Yes</strong>&lt;sup&gt;f&lt;/sup&gt;</td>
<td>No</td>
<td>No</td>
<td>29% (0/2/5)</td>
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</table>

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**References**


European Academy of Childhood Disability
19th Annual Meeting
Development and Differentiation in Childhood Disability
Groningen, the Netherlands June 14–16 2007

The Meeting will focus on children and adolescents with disabilities, in particular on their development and possibilities to achieve their full potential as adults in modern society. The theme will cover issues in three main areas of paediatric rehabilitation. It will provide the opportunity: (1) to learn from typical and atypical patterns in the development of children and adolescents with specific disorders; (2) to evaluate the pros and cons of old and new professional concepts; and (3) to learn from the ever-changing, complex and multicultural environment in Europe and across the world. The Meeting should point the way forward for us to promote and extend research in all aspects of childhood disability.

**Keynote lectures and workshops will include:**

- Neurodevelopmental events in the human cerebral cortex
- Programming of the brain by early nutrition?
- Nature and nurture in motor development
- Childhood disability in a developmental and differential perspective
- New attitudes and advances in paediatric rehabilitation
- Participation and inclusion of children with disabilities
- To treat or not to treat in childhood disability: are there limitations to treatment?

New to the meeting is the opportunity for members to apply to present an Instructional Course, or an Oral Presentation on a specific topic in the scientific programme. Also, this year, posters will be presented during a guided ‘poster walk’.

President of the meeting: Mijna Hadders-Algra

For more information see the website: www.eacd2007.nl