Article to be published in Clinical Psychological Science

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Reduced prospective motor control in 10-month-olds at risk for autism spectrum disorder

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Keywords: prospective motor control, autism spectrum disorder, siblings, motor development.
Abstract

Motor impairments are not a part of the diagnostic criteria for autism spectrum disorder (ASD), but are overrepresented in the ASD population. Deficits in prospective motor control have been demonstrated in adults and older children with ASD, but have never before been examined in infants at familial risk for the disorder. We assessed the ability to prospectively control reach-to-grasp actions in 10-month-old siblings of children with ASD (high-risk group, n=29, 13 female), as well as in a low-risk control group (n=16, 8 female). The task was to catch a ball rolling on a curvilinear path off an inclined surface. The low-risk group performed predictive reaches when catching the ball, whereas the high-risk group started their movements reactively. The high-risk group started their reaches significantly later than the low-risk group (p=.03). These results indicate impaired prospective motor control in infants susceptible for ASD.
Autism spectrum disorders (ASD) are a group of heterogeneous and common neurodevelopmental disorders (prevalence of around 1%; Centers for Disease Control and Prevention [CDC], 2014) characterized by early emerging impairments in social interaction and communication, as well as restrictive and repetitive behaviors (Diagnostic and Statistical Manual of Mental Disorders–5th Edition [DSM-5], American Psychiatric Association [APA], 2013). Previous work has shown that children who go on to receive an ASD diagnosis express impairments in a range of abilities already during the first year of life, including problems with attention, unusual temperament characteristics and diminished social motivation (Jones, Gliga, Bedford, Charman, & Johnson, 2014). The risk for ASD in infant siblings of children with ASD is more than ten-fold compared to the risk in the general population (Constantino, Zhang, Frazier, Abbacchi, & Law, 2010; Sandin et al., 2014). The high familial risk makes longitudinal studies of infant siblings a feasible strategy in the search for early ASD markers (for a review, see Jones et al., 2014).

Motor impairments are not part of the diagnostic criteria of ASD (American Psychiatric Association, 2013), and are typically not considered a core feature of the disorder. However, it is well established that motor problems are common within this population (e.g. Jansiewicz et al., 2006; Lai, Lombardo, & Baron-Cohen, 2014; Minshew, Sung, Jones, & Furman, 2004). In particular, studies on adults have shown that individuals with ASD often display longer reaction times before starting a reaching movement than typically developing (TD) controls (Glazebrook, Elliott, & Szatmari, 2008). Other motor deficits in ASD include atypical basic movement kinematics (Cook, Blakemore, & Press, 2013) and longer movement times (Stoit, van Schie, Slaats-Willemse, & Buitelaar, 2013).

Individuals with ASD demonstrate specific problems with prospective control of actions (i.e. the ability to plan actions towards future events or consider future task demands). In a series of studies, individuals with ASD have demonstrated reactive rather than
prospective changes in muscle activity during load-lifting tasks (David et al., 2009; Schmitz, Martineau, Barthélémy, & Assaiante, 2003), and reduced ability to prospectively plan their own actions with respect to future goals (Cattaneo et al., 2007; Hughes, 1996). Prospective control is crucial in the mastery of actions (von Hofsten, 2004). It is particularly needed for actions on moving objects, which need to be future oriented in order to overcome the internal processing lag of the motor system (estimated to be around 250-400 ms; Berthier & Robin, 1998; von Hofsten, Vishton, Spelke, Feng, & Rosander, 1998). If one is unable to compensate for this lag (via prospective control), then timing will be reactive, which will result in unsuccessful reaches, deteriorated motor ability and problems interacting with both physical objects and socially with others (Cattaneo et al., 2007; Schmitz et al., 2003; von Hofsten & Rosander, 2012).

Data from retrospective home videos (Ozonoff et al., 2008; Teitelbaum, Teitelbaum, Nye, Fryman, & Maurer, 1998) indicate early motor abnormalities in infants later diagnosed with ASD. However, the unsystematic nature of these data limits the conclusions that can be drawn. Longitudinal work on high-risk (HR) siblings, where motor development has been assessed with standardized tests (Mullen Scales of Early Learning [MSEL]; Mullen, 1995), have consistently demonstrated lower scores on both the gross (GM) and fine motor (FM) scales in 6-14 month old HR infants who went on to receive an ASD diagnosis (Landa & Garrett-Mayer, 2006; Libertus, Sheperd, Ross and Landa, 2014; Ozonoff et al., 2010). In addition, Flanagan, Landa, Bhat and Bauman (2012) examined postural control during a pull-to-sit task in 6-month-olds at familial risk for ASD. Ninety percent of the infants who went on to get an ASD diagnosis showed head lag while being pulled to sit at 6 months, which is very unusual at this age (Bly, 1994). This work shows that motor impairments are common and variable in ASD. However, the precise nature of motor deficits in young children with the disorder (or in infants at risk for ASD) remains largely unknown. The reason for this is partly...
that previous studies have focused more on gross motor problems (e.g. assessed via home videos) or otherwise used measures uninformative with regards to the specific mechanisms underlying the motor problems reported in these populations (e.g. MSEL).

Based on the ASD literature reviewed above (Cattaneo et al., 2007; David et al., 2009; Hughes, 1996; Schmitz et al., 2003) it can be expected that problems with prospective control may be particularly pronounced in children with ASD. Some has suggested that early disturbances in these processes could compromise how children explore new objects or engage socially, as well as being related to the higher frequency of stereotyped and repetitive behavior seen in ASD (Loh et al., 2007; Thelen, 1996). In other words, early emerging problems with prospective motor control could be one mediating factor connected to both the social communication as well as the restrictive and repetitive behaviors domain (American Psychiatric Association, 2013).

The aim of the present study is to assess the ability of infants at risk for ASD to prospectively control their own reach-to-grasp actions. The performance of the HR group was compared to performance of a group of low-risk (LR) infants. Given that 1) prospective control is an essential component of all goal-directed actions and thus a foundation for typical development (von Hofsten, 2004), 2) it is clearly disrupted in ASD (Glazebrook et al., 2006, 2008; Schmitz et al., 2003) and 3) up to 50% of the HR infants will receive an ASD diagnosis or develop significant ASD-related problems (Ozonoff et al., 2014), we expected that compared to the LR group, the HR group would show reduced prospective control while catching a moving object. Ten-month-old infants were presented with a task requiring them to reach and grasp a ball rolling on a curvilinear path off an inclined tabletop. Similar tasks have previously been used to assess prospective control in typically developing infants (Hespos, Gredebäck, von Hofsten, & Spelke, 2009; Spelke & von Hofsten, 2001; von Hofsten, 1980)
but it has never been used to assess motor performance in children with ASD or infants at elevated risk for autism.

Method

Participants

In total, 45 10-month-old infants were included in the final sample. The HR group consisted of 29 infants (13 female), and the LR group consisted of 16 infants (8 female). One HR infant (female) did not perform any trials and was excluded before data analysis. The groups were comparable in terms of chronological as well as mental age, and socioeconomic background (see Table 1). Participants were part of an ongoing longitudinal study that follows infants from 10 to 36 months of age. Here, data from the 10-month assessment are reported. Infants in the HR group were recruited through the project’s web site, advertisements and clinical units. LR infants were recruited from vital birth records. Both groups were primarily from the greater Stockholm area, Sweden. Each infant in the HR group had at least one older sibling with a community diagnosis of ASD. Current regional guidelines recommend first choice standardized diagnostic instruments when diagnosing ASD, and in our project, we were able to confirm the use of the Autism Diagnostic Observation Schedule (ADOS) or the Autism Diagnostic Interview-Revised (ADI-R) in 70 to 75% of all cases through inspection of obtained medical records. Four infants in the HR group were half siblings to the child with ASD. LR infants had no relatives (up to the second degree) with ASD. To match the HR group, we required that all LR siblings also had at least one typically developing older sibling. One LR infant only had an older half sibling. All infants included in the sample were born full-term (>36 weeks), and did not have any known or suspected medical or developmental concerns (including visual/auditory impairments). The MSEL (Mullen, 1995) was conducted with each infant by an experienced licensed psychologist to assess the infants’ developmental
level. Table 1 shows the results on each used subscale in the two groups. More than 90% of infants in both groups had parents who were born in Sweden.

Apparatus and procedure

We assessed whether and when the infants caught a ball that rolled toward them on a curvilinear path off an inclined tabletop. Each infant was seated in a stable infant chair at a quadratic table (60*60 cm). The parent was seated right behind the infant. The experimenter was seated on the other side of the table across from the infant. This positioning allowed for interaction between the experimenter and the infant, and also for the experimenter to start the rolling motion of the ball toward the infant.

Two toy rails were mounted on the tabletop as tracks, both from the left and right, for the ball to roll against (see Figure 1A). The ball’s diameter was 4 cm. The starting location of the ball (left or right side) was counterbalanced across trials. Two different inclination degrees were used, resulting in two different rolling speeds. The experiment always started with the slower rolling speed, at which the tabletop was inclined 2.8 degrees from the horizontal plane, resulting in a rolling speed of approximately 2.6 cm/sec when the ball entered reaching space, the area where the ball was within approximate reach for the infant, i.e. within the infants’ arm length; see Figure 1A (Hespos et al., 2009; Spelke & von Hofsten, 2001). In the condition with the higher speed, the tabletop was inclined 4.1 degrees, resulting in a rolling speed of approximately 3.6 cm/sec. After a series of warm-up trials, where the infant became accustomed to the task, at least four trials with the slower rolling speed were presented, followed by at least four trials with the higher rolling speed. At the start of each trial, when the infant was attentive, the experimenter let go of the ball at the edge of the tabletop on her side, and the ball started rolling toward the infant. The release of the ball was not accompanied by any type of social cue (e.g. vocalizing, facial expression change).
The infant could watch the ball roll for approximately three seconds before the ball passed the rails and entered the reaching space. The infant was free to initiate the reaching movement at any point. The trial was over when the infant either caught the ball or when it rolled off the table. Neither the experimenter nor the parent stopped the ball from rolling off the table. On average, each infant attempted 11.6 trials (range: 5-18 trials), regardless of whether the ball was caught or not. If the infant did not move his/her hands in the direction of the ball at any time during the trial, this was regarded as a “no attempt” trial. In total, each session lasted approximately 10 minutes. A video camera (Sony Handycam HD) was mounted above the table, recording a full view of the experimental setup, as well as the infant and the experimenter. A motion-capture system (Qualisys Motion Capture System, Göteborg, Sweden) recorded the infant’s movements. This system will be used for other questions than the one being addressed here; motion tracking data from this system will not be reported in this article.

Data analysis and statistics

In this study, prospective motor control was measured via reach latency, namely the time when the hand started to move relative to when the ball entered reaching space (Figure 1A). Trained observers (blind to group membership) registered the time from video recordings when the rolling ball passed the end of the tracks, and entered reaching space. We measured when the infants started to move her/his arm and when the hand first made contact with the object (or came within 2 cm from the ball, here defined as catching the ball; see procedure in Hespos et al., 2009). If the reaching movement was initiated before the ball entered reaching space the reach was considered predictive. If the reaching movement was initiated after the ball entered reaching space this was considered a reactive reach. In this context (like prior work using the same procedure on typically developing infants; Hespos et al., 2009; Spelke &
von Hofsten, 2001) predictive reaches were considered to reflect prospective motor control. In order to control for other aspects of the reaching action we also analyzed movement duration (defined as the time between reach initiation and ball contact).

Frame-by-frame software (Mangold International INTERACT, Arnstof, Germany) was used for the coding. Inter-rater reliability was assessed on 12 (26%) randomly selected participants, and concordance was very high (ball entering reaching space: \( r > .99 \), reach initiation: \( r > .99 \), contact time \( r > .99 \)).

Analyses of the data distributions confirmed normality and homogeneity of variance (unless otherwise stated). Independent \( t \)-tests with risk status (HR vs. LR) as the between-subjects factor was used, and single sample \( t \)-tests to measure whether average reach latency differed significantly from zero, with significant negative difference from zero meaning predictive reaches. Two-tailed probabilities (\( \alpha = 0.05 \)) were used. There were no group differences in terms of performance at each rolling speed or concerning starting location (left or right side), thus, in all analyses data were collapsed across rolling speed and starting location. Two infants in the HR group and one infant in the LR group did not perform any trial at the higher rolling speed. Preliminary analyses revealed no group differences concerning reach latency when the ball was not caught, thus, this variable was not analyzed further.

**Results**

Infants in the HR and LR groups attempted to reach for the ball equally often (HR \( M = 11.9 \) trials, \( SD = 3.1 \); LR \( M = 11.1 \) trials, \( SD = 2.4 \)), \( t(43) = .939, p = .353, d = .29 \), and they were equally likely to catch the ball (HR \( M = 85\% \), \( SD = 18\% \); LR \( M = 86\% \), \( SD = 15\% \)), \( t(43) = .103, p = .919, d = .03 \).
In the trials where the ball was caught, the mean reach latency was -201 ms ($SD=187$ ms) in the LR group and -13 ms ($SD=356$ ms) in the HR group. The reach latencies in the two groups differed significantly from each other, $t(40)=2.25$, $p=.030$, $d=.71$ (equal variances not assumed, adjusted p-value is reported). A single sample $t$-test showed that reach latency for the LR group significantly differed from zero, $t(14)=4.16$, $p=.001$, $d=2.22$, whereas the same test for the HR group did not differ from zero ($p>.5$; see Figure 1B). That is, infants in the LR group started moving their arm predictively, 201 ms before the ball entered their reaching space, whereas infants in the HR group initiated their reach just as (-13 ms) the ball entered the same space.

We found no group differences in movement duration, (LR $M=1.05$ sec, $SD=.16$, HR $M=.97$ sec, $SD=.22$), $t(40)=1.18$, $p=.245$, $d=.37$ and also no significant correlation between reach latency during catches and performance on the FM scale of the MSEL ($r=.099$, $p=.534$). The same was true for the other subscales as well (all $p$’s>.05).

**Discussion**

The aim of the present study was to assess the ability of infants at risk for ASD to prospectively control reach-to-grasp actions. This study confirms that infants expected to develop typically (the low-risk group) reach for moving objects in a predictive manner. Such prospective motor control plays a critical role for infants’ ability to act effectively on objects in the world (von Hofsten, 2004). Against this background, it is striking that infants at high-risk for ASD performed reactive reaches, not initiating their movements toward the object before it had entered their reaching space. Previous research has shown poorer prospective motor control in adults and older children with ASD (David et al., 2009; Schmitz et al., 2003). The current study adds to this picture by showing that such problems are present within the first year in infants susceptible for ASD.
It is important to note that the design of this study does not allow for conclusions that these findings are specific to ASD. This would require the inclusion of other types of risk groups as controls, and that one conducted a comprehensive neuropsychiatric diagnostic assessment at an age when eventual diagnoses could be posed. Nevertheless, as described in the introduction, one could expect poor prospective control to be specifically related to later ASD diagnosis. This scenario would be in line with the view that impairments in prospective control mechanisms cause a problematic developmental cascade, affecting areas beyond motor functioning, including the social as well as the repetitive behaviors and interests domain (Wolpert, Doya, & Kawato, 2003; Cattaneo et al., 2007; Loh et al., 2007; Thelen, 1996). The current study motivates more study into prospective motor control in infants at risk for developmental disorders.

We found no significant correlation between reach latency and performance on the fine motor scale of the MSEL and also no group differences on this measure. The lack of correlation between reach latency and the fine motor scale is likely due to the fact that most of the items in the MSEL fine motor scale require handling of static objects, and in cases like these, timing of movements will not be crucial. When measuring prospective control during reaching we are tapping into the microstructure of motor performance, a level of detail not assessed by established developmental tests. Previous longitudinal studies focusing on standardized test items (such as the MSEL), have identified group differences (Landa & Garrett-Mayer, 2006; Ozonoff et al., 2010) with consistently lower scores in the HR samples, but it is difficult to point to specific motor functions based only on such measures. Further, in these studies, group differences have been proven difficult to show before twelve months of age (but see Leonard et al., 2014; Libertus et al., 2014), and it might be that the infants in this sample are too young for such group differences to be detected.
In the current study infants in the HR group were equally interested in the task and attempted as many trials as the infants in the LR group. Thus, it does not seem like the later movement initiation in the HR group is due to attentional or motivational differences. Also, the two groups were equally successful at catching the ball, suggesting that the late movement initiation did not result in a (detectable) difference in performance. The movement duration in the two groups was comparable, rendering no support for the view that the successful reaches were due to the infants’ compensation of the late start of the movement. The comparable movement durations also indicate that action execution is intact in infants at risk for ASD, and thus, the reason for the later reach initiations is unlikely to be due to badly timed muscular forces. Also, the effect cannot be explained by general developmental delay in the HR group, considering that there were no group differences on any subscales of the MSEL (see Table 1). Finally, given that most siblings in the HR group are not expected to develop ASD or other related atypicalities (Ozonoff et al., 2014), it is not surprising that a number of infants in this group showed a performance comparable to that of the LR group.

The study sample included four half siblings in the HR group. Even though the risk is lower for half siblings to receive an ASD diagnosis (Sandin et al., 2014), it is substantially elevated compared to LR controls, and the nature of the risk in half siblings is not expected to be qualitatively different than for full siblings (Gaugler et al., 2014). Consequently, we chose to include half siblings in the HR group in this study.

It is also important to note that although we observed a significant difference between the two groups, the LR group was substantially smaller than the HR group. While not ideal in the current context (comparing groups on the basis of risk status), it is typical for longitudinal studies of this kind to recruit more HR infants than LR infants (e.g. Zwaigenbaum et al., 2005). One reason for this is that the outcome data will allow multiple
categories within the HR group, each of which are expected to approximately match the size of the LR group.

Future research in this area should clarify if the early motor impairments seen in ASD and in siblings of children with ASD are uniquely linked to ASD, or if they are linked to developmental disorders frequently co-occurring with ASD, such as ADHD, motor coordination disorder or intellectual disability (Izawa et al., 2012; Johnson, Gliga, Jones, & Charman, 2014). These questions will be partly answered by following up the current sample, which is likely to include children with a range of different outcomes (Ozonoff et al., 2014). Nevertheless, the inclusion of just one type of risk group (siblings of children with ASD) will limit the conclusions. Ideally, in order to address the specificity question, one should assess different risk groups, and conduct a comprehensive and unbiased follow-up assessment of categorical as well as dimensional outcomes.

Motor skill is built on a range of sub-competencies (Gowen & Hamilton, 2013; Wolpert & Ghahramani, 2000). Nevertheless, when motor issues are discussed in relation to the early development of ASD, such distinctions are frequently ignored. Thus, another important direction for future research is to dismantle the various sub-compartments of ‘motor skill’ in order to see which are, and which are not, related to a particular developmental disorder. This entails moving beyond standardized scales of motor function. Rather, what seems to be needed are new experimental paradigms that taps into specific (sub-)functions, and which are suited for infants and young children (such paradigms already exist for older populations; see e.g. Izawa et al., 2012; Stoit et al., 2013), as well as more fine-grained ways of assessing motor execution. With regards to the latter, we are analyzing the data from the current study collected through a motion tracking system. This will provide kinematic description of the movement with high spatiotemporal resolution and allow us to examine,
among other things, whether and how the reduced prospective motor control reported here affects the kinematic profile of the subsequent movement.

Finally, it would be important to broaden the study of motor development in relation to ASD to include qualitatively different types of actions. For example, concerning motor execution, infants frequently bang objects repeatedly towards surfaces – a behavior that could be conceived as a basic, early emerging percussive behavior (Kahrs, Jung, & Lockman, 2014), but which also has a clear repetitive aspect. From this perspective, studying the relation between early repetitive banging and later ASD outcomes would be an interesting question to address in future research.

Author contributions
T.L.E. and G.G. designed the study with contributions from T.F-Y. and S.B. The EASE Team performed data collection. T.L.E. analyzed the data and drafted the paper with contributions from G.G. and T.F-Y. All authors revised the paper critically and approved the final version.

Acknowledgements
We would especially like to thank families participating with their infants in this study. Thank you also to Maria Axnér for help with data collection and coding, to members of the Uppsala Child- and Babylab for valuable comments on an earlier version of this paper, and to Torkel Carlsson. This research was supported by the Swedish Research Council in partnership with FAS, FORMAS, and VINNOVA (Cross-disciplinary research program concerning children’s and young people’s mental health; [259-2012-24]); in addition to The Bank of Sweden Tercentenary Foundation [P12-0270:1]; the Swedish Research Council [523-2009-7054]; and ERC-StG [CACTUS 312292].
References


### Table 1.

*Characteristics of high risk (HR) and low risk (LR) study groups, final samples (Mean/SD)*

<table>
<thead>
<tr>
<th>Measure</th>
<th>HR</th>
<th>LR</th>
<th>Pairwise comparison (p value&lt;sup&gt;1&lt;/sup&gt;)</th>
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<td>Age (months)</td>
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<td>10.25/.45</td>
<td>.517</td>
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<tr>
<td>MSEL&lt;sup&gt;2&lt;/sup&gt; Total score</td>
<td>99/14</td>
<td>99/14</td>
<td>.953</td>
</tr>
<tr>
<td>MSEL VR&lt;sup&gt;3&lt;/sup&gt;</td>
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<td>.313</td>
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<tr>
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<td>56/11</td>
<td>.906</td>
</tr>
<tr>
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<td>45/11</td>
<td>44/12</td>
<td>.767</td>
</tr>
<tr>
<td>MSEL EL&lt;sup&gt;6&lt;/sup&gt;</td>
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<td>.496</td>
</tr>
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</table>

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<sup>1</sup>Independent samples t-test; <sup>2</sup>Mullen Scales of Early Learning; <sup>3</sup>Visual Reception subscale; <sup>4</sup>Fine Motor subscale; <sup>5</sup>Receptive Language subscale; <sup>6</sup>Expressive Language subscale; <sup>7</sup>Socio Economic Status, calculated on the basis of parental education and income (equal weighting), expressed as a z score.
Figure 1A. Illustration of the catching task, with a superimposed representative ball trajectory in 2D. Y-axis shows Y coordinates in mm. 0 mm on the Y-axis marks the first point in space where the ball can be reached (positive values indicates the ball is outside reaching space). Red ball indicates approximate movement initiation in the HR group, and blue ball represent the LR group. Arrow indicates movement direction.
Figure 1B. Mean reach latency in sec for the two groups. Error bars represent 95% confidence intervals. Circles represent individual data points. *p < .05 (independent t-test), **p < .01 (single sample t-test).