Effects of Movement Distance, Duration, Velocity, and Type
on Action Prediction in 12-Month-Olds

Moritz M. Daum, Anja Gampe

University of Zurich, Switzerland

Caroline Wronski

University of Zurich, Switzerland

University of Applied Sciences, Potsdam, Germany

Manja Attig

Leibniz Institute for Educational Trajectories, Bamberg, Germany

**Manuscript accepted for publication in
INFANT BEHAVIOR AND DEVELOPMENT**

Correspondence concerning this article should be addressed to Moritz M. Daum,
University of Zurich, Department of Psychology, Binzmuehlestrasse 14, Box 21, CH-
8050 Zurich, Switzerland. Phone: +41 (0)44 635 74 86, E-mail:
daum@psychologie.uzh.ch.

Abstract

The goal of the present study was to test the influence of the spatial and temporal dynamics of observed manual actions on infants' action prediction. Twelve-month-old infants were presented with reach-and-transport actions performed by a human agent. Movement distance, duration, and—resulting from the two—movement velocity were systematically varied. Action prediction was measured via the latency of gaze arrival at target in relation to agent's hand. The results showed a general effect of all parameters on the infants' perception of goal-directed actions: Infants were more likely to predict the action goal the longer the movement distance was, the longer the movement duration was, and the slower the movement velocity was. In addition, they were more likely to predict the goal of a reaching than a transport action. The present findings extend previous findings by showing that infants are not only sensitive to differences in distances, durations, and velocities at early age but that these factors have a strong impact on the prediction of the goal of observed actions.

Keywords: action perception; stimulus properties; infancy; eye tracking; development

Word count: Abstract: 169

Main text: 5,890

Effects of Movement Distance, Duration, Velocity, and Type
on Action Prediction in 12-Month-Olds

1. Introduction

When performing as well as when observing goal-directed actions, human adults and infants shift their gaze to the goal of the action in advance of its completion (Falck-Ytter, Gredebäck, & von Hofsten, 2006; Flanagan & Johansson, 2003; Rosander & von Hofsten, 2011). A considerable number of developmental studies on action prediction have focused on the relation between action prediction and the ability to perform the respective action. This research has shown that the ability to predict an action goal is functionally related to the observer's competence to perform the same action. The better infants are in performing a respective action, the more likely they are to predict the goal of a similar observed action (e.g., Cannon, Woodward, Gredebäck, von Hofsten, & Turek, 2012; Gredebäck, Stasiewicz, Falck-Ytter, von Hofsten, & Rosander, 2009; Melzer, Prinz, & Daum, 2012). The basis for this functional relation is thought to be reflected by a process of direct matching (Green, Kochukhova, & Gredebäck, 2014) where observed actions are mapped onto one's own motor system in order to predict forthcoming consequences and goals of the action (e.g., Flanagan & Johansson, 2003). However, actions vary not only in their practicability and the observer's competence to perform them but also on their temporal and spatial dynamics; actions are executed over different distances and with different movement velocities. The goal of the current study was to investigate the influence of the spatial and temporal dynamics of observed manual actions on infants' action prediction.

So far, little attention has been devoted to aspects such as movement kinematics and stimulus properties when measuring online predictions. In one recent study,

Henrichs and colleagues (Henrichs, Elsner, Elsner, & Gredebäck, 2012) showed that the saliency of a goal object influences infants' action prediction: When observing goal-directed grasping actions, infants shifted their gaze significantly earlier to a salient compared to a less salient goal object. The present study addressed a yet different unexplored factor: the influence of spatial and temporal characteristics of the observed action–movement distance, movement duration, and movement velocity—on the observers' action prediction.

While little is known about the effects of spatial and temporal dynamics on the online prediction of action goals, more is known about infants' ability to discriminate temporal and spatial dynamics such as duration, distance and velocity. We will briefly review major findings of infants' discrimination of these three aspects. Already at a very early age, infants are sensitive to different durations of events (Brannon, Suanda, & Libertus, 2007; VanMarle & Wynn, 2006). These authors showed that already 6-month-olds discriminate brief durations, and that their discrimination function is characterized by Weber's Law: successful discrimination is determined by the proportionate difference rather than absolute difference between stimuli of different duration. The proportion of two stimulus magnitudes (e.g. duration) that are just noticeably discriminable is not fix over the course of development. In contrast, sensitivity for duration differences increases over the first year of life. While at the age of 6 months infants are sensitive to 1:2 ratios, this sensitivity increases to 2:3 ratios at the age of 10 months (Brannon et al., 2007). Accordingly, sensitivity to even subtle differences in durations increases as a function of age. This sensitivity is not stimulus specific. The temporal discrimination, for example, has been suggested to follow the same developmental progression as that of number discrimination in infancy (Lipton & Spelke, 2003).

Less work has focused on infants' discrimination of distances or sizes. One study has shown that 6-month-old infants discriminate different sizes at ratios between 1:2 to 1:4 but failed to discriminate a change at the ratio of 2:3 (Brannon, Lutz, & Cordes, 2006). These results suggest that, similar to the discrimination of durations, infants are sensitive to the proportionate difference rather than absolute difference between stimuli with respect to area discriminations in infancy as well.

Finally, objects exist in time and space and they often change their position in space. When an object moves from location A to location B, the ratio of the change of position over time determines its velocity of travel. Previous work has shown that already infants are sensitive to the fact that objects continuously exist in time and space (Spelke, Kestenbaum, Simons, & Wein, 1995) and that infants are able to individuate objects based on the velocity of motion (Wilcox & Schweinle, 2003). Evidence for the fact that infants are sensitive to velocity comes from findings demonstrating that 4- to 8-month-olds match auditory and visual information, but that this ability is disrupted when the velocity of object movement varies (Lewkowicz, 1992). More recent findings indicate that at 6 months, similar to the sensitivity to distance and duration, infants discriminate between velocity ratios of 1:2, and at 10 months, and even between velocity ratios of 2:3 (Möhring, Libertus, & Bertin, 2012). Although intriguing and fascinating, findings from older children suggest that the mechanisms underlying velocity discrimination continue to develop beyond the age 5, an aspect that has particularly been shown for the processing of slower velocities (Ahmed, Lewis, Ellemberg, & Maurer, 2005).

Taken together, the reviewed literature suggests that infants are in general sensitive to different aspects of dynamic events, such as distances, durations, and velocities. All the studies that have been referred to so far used looking-time paradigms

in which infants learned information about one physical aspect (distance, duration, or velocity) and their looking behavior to this learned stimulus was then compared when presented with a novel stimulus of different distance, duration, or velocity. However, everyday social interactions involve to a great extent the processing of events online, that is, while the event is about to unfold. In contrast to the measurement of infants' discrimination of different magnitudes, the online prediction of action goals is a rapid process that is highly constrained by the time and the information that is available (e.g., Gredebäck & Daum, 2015). Hence, the manipulation of the temporal as well as the spatial aspects of observed actions might substantially influence gaze behavior with respect to the action goals. First evidence for an effect of spatio-temporal properties on the prediction of moving physical objects comes from a set of studies by von Hofsten and colleagues in which the prediction of the reappearance of a briefly occluded moving object was measured. They showed, for example, that the prediction rate increased with increasing durations of occlusion, from 250 to 5,000 ms (Gredebäck, von Hofsten, & Boudreau, 2002). Similarly, at the age of 3 to 4 months already, gaze was shifted later to the reappearance location when the occluder was wide compared to when it was narrow and at the age of 5 months, infants were found to be sensitive to velocity change (Rosander & von Hofsten, 2004). In this age range, the tendency to make predictive gaze shifts largely depends on the duration of occlusion until the object reappears and that movement speed is represented even if the object is invisibly moving behind an occluder (von Hofsten, Kochukhova, & Rosander, 2007). Further evidence for the impact of action characteristics on the online action prediction comes from a study with 10- and 14-month old infants (Gredebäck et al., 2009). In this study, infants showed better goal prediction with respect to reaching than transport movements, which is indicative for the discrimination between different movement types. While infants start

to reach and grasp around the age of 3 to 4 months (e.g., Bertenthal & Clifton, 1998; von Hofsten & Lindhagen, 1979), it is some months later that they start to transport objects and release them at a certain location (Bruner, 1970; Elsner, Hauf, & Aschersleben, 2007; Falck-Ytter et al., 2006). Accordingly, infants have a longer experience in grasping than in transporting and releasing objects that is one possible explanation for their increase in predictions of grasping compared to transport actions.

The main question of the present study was whether spatio-temporal aspects such as movement distance, duration, velocity, and movement type have an impact on infants' online prediction of observed everyday actions. To answer this question, we conducted an eye-tracking study and measured the latency of infants' arrival of gaze at a goal location with respect to the arrival of the model's hand at the goal. We presented infants with repeated reach-and-transport actions: An adult human agent successively moved five objects into a container (see Figure 1). Because previous studies suggest that at the age of 12 months, infants are sensitive to all three parameters (size/distance: Brannon et al., 2006; velocity: Möhring et al., 2012; duration/time: VanMarle & Wynn, 2006) we tested infants at this particular age. Furthermore by the age of 12 months infants reliably predict the goals of observed manual actions with their gaze (Cannon et al., 2012; Falck-Ytter et al., 2006; Gampe, Keitel, & Daum, 2015; Melzer et al., 2012) a capacity that is increasing between 10 and 14 months of age for grasping and transport actions (Gredebäck et al., 2009). Two different movement distances between the object location and the goal container, as well as three different movement durations were chosen, resulting in four different movement velocities (not six as one might suppose, for an explanation, see Figure 2).

Given the above-mentioned sensitivity to all the manipulated parameters (movement type, distance, duration, and velocity), and the infants differential prediction

of grasp and transport actions, we expected infants' gaze behavior to be influenced by all parameters. The basic assumption is that lesser temporal constraints (i.e. more time to process the observed action) as well as greater experience with the action (grasp > transport) result in a greater likelihood of predictive gaze shifts: First, with respect to the parameter movement distance, we expected that the longer the distance, the more time is available to process the observed action (at least with equal velocities). Hence, the long movement distance is expected to result in higher prediction frequencies than the short movement distance. Second, with respect to movement duration, we expected that the more time it takes for an action to be executed, the more time is available to process the action and to generate predictions about potential action goals. Hence, we expect an increase of the frequency of predictive gaze shifts with increasing movement duration. Third, with respect to movement velocity we expected that slower movements are easier to process and result in an increase of the prediction frequency. We hypothesized that predictive gazes need a minimum time of processing to encode the action goal and simulate the movement. If the time is too short, no predictions will be possible. There is only limited evidence to state clear hypotheses about whether the processing time is absolute or relative to the observed actions. Adults disengage from an observed hand that is reaching for and manipulating an object, just after the hand starts to move (38 ms; Flanagan & Johansson, 2003). The only study that measured disengagement time in infants showed that 10-month-olds moved their gaze from a moving hand approx. 300 ms after the hand started to reach for a target object (Rosander & von Hofsten, 2011). If 300 ms would be a sufficient time to process and predict the observed actions, we would expect predictive gaze in all the presented conditions who involve a movement duration of at least 1 s. Finally, with respect to movement type, infants have been shown to be better in predicting reaching than

transport actions (Gredebäck et al., 2009), accordingly, we expected a main effect of movement type with infants being better to predict reaching than transport actions.

2. Method

2.1 Participants

The final sample consisted of 22 infants aged 12 months (12 girls, 10 boys; mean age: 12 months; 0 days, range: 11;15–12;20). Twelve additional infants (4 girls, 8 boys) were tested but not included in the final sample due to not providing enough data in all conditions (see Data Analysis for the description of the inclusion criteria). Contact information for the infants was obtained from public birth records. All infants were born full term (37–42 weeks gestation) and with normal birth weight ($> 2,500$ g). All parents gave informed consent before the study. The infants received a present at the end of the session of an approximate value of CHF 5,-. The study was approved by the local ethics committee and conducted in accordance with the Declaration of Helsinki.

2.2 Test Environment, Apparatus, Stimuli, and Design

The laboratory was unfurnished except for the test equipment. The infants were seated in a car safety seat (Maxi Cosi Cabrio), placed in front of the eye tracker. The stimuli were presented, and gaze was measured using a Tobii 1750 near infrared eye tracker (Tobii Technology AB, Danderyd, Sweden) with an infant add-on (precision: 1 deg, accuracy: 0.5° , sampling rate: 50 Hz) using the software Clearview (Version 2.7.1). A 9-point infant calibration was used. During calibration, a blue-and-white sphere expanded and contracted (extended diameter = 3.3 visual degrees) in synchrony with a sound. Screen size was 17 inch ($32.1 \times 24.4^\circ$), viewing distance approximately 60 cm.

The stimuli consisted of a simple reach-and-transport action (Falck-Ytter et al., 2006; Melzer et al., 2012) including two *movement types* successively being performed: A hand first grasped one of five LEGO® DUPLO® blocks (colored red, yellow, green,

orange, blue) and then transported it to and dropped it into a white container (Figure 1). One individual movement sequence (grasping of the block or transporting of the block) is further considered as one *action step*. The film started with the actor having the hand on top of the container, moving its hand in direction of the blocks, grasping block 1 (action step 1) and transporting it to the container (action step 2), after dropping it into the container, the hand directly moves back to the blocks in order to grasp block 2 (action step 3) etc. The size of the container was 20 x 20 x 15 cm (original size); 5.2 x 4.0° visual angle (horizontal x vertical size on screen) with an opening at the top. The two movement types were repeated for all five blocks. To make the stimulus presentation more appealing, grasping and releasing of the blocks was accompanied by a sound effect: a ping during the grasping and the typical sound of one LEGO® block falling onto a pile of others during the dropping of the LEGO® block into the container.

The *movement distance* between the blocks and the container was either short (7.8°) or long (15.6°) measured from the respective closest edges. *Movement durations* for the reach and grasp movements were varied in three steps (4 s, 2 s, 1 s); resulting in three different movement velocities for each movement distance, respectively. This variation of movement distance and movement duration resulted in a total of 6 conditions, see Figure 2. The order of presentation of the conditions was fully counterbalanced and infants were randomly assigned to one of the six possible orders. Each condition was presented four times. Different attention catchers were presented at the beginning of each trial. They consisted of colorful and bright looming pictures of different toys (horizontal and vertical dimensions: maximum 4.5°, minimum 2.3°) presented at the center of the monitor each in combination with a distinct attention-catching sound.

2.3 Procedure

The infants were tested in the laboratory at a time of day when they were likely to be alert and in a good mood. All infants were tested individually with one parent present. Each infant and their parents were first escorted to a reception room. For approximately 10 minutes, the infant was allowed to explore the room while the research assistant described the test procedure to the parents and one of the parents signed a consent form. Then, the infant and one parent were brought to the test room. The research assistant helped the parent to position the infant in the car seat. During stimulus presentation, the parent sat on a chair behind the infant. Parents were instructed not to interact with their children during testing. They were encouraged, however, to put both hands symmetrically close to the infant if it appeared necessary to comfort the infant. Once infant and parent seemed comfortable, the research assistant left the room and the stimulus presentation was started. The total length of stimulus presentation was approximately 10 minutes.

2.4 Data Analysis

To analyze the eye-movement data, the coordinates of the recorded gaze points from the right and left eye were averaged. If data from only one eye were available, this was used instead of the averaged data point. Two goal areas of interest (AOI) were defined, one for the container ($3.0^{\circ} \times 3.8^{\circ}$) and one for the blocks ($3.8^{\circ} \times 2.7^{\circ}$). The horizontal distance between the two AOIs was 8.5° (short distance) and 17.0° (long distance, measured from the closest horizontal edge), see Figure 1. For the grasping action, the container AOI was defined as starting AOI and the blocks as goal AOI, for the transporting action, the blocks were defined as starting AOI and the container as goal AOI. Between the container and the blocks, a movement AOI was defined. In order to control for random fixations at the goal AOI, only fixations at the goal AOI were

included that were preceded by a fixation (40 ms) in the starting or the movement AOI. In such cases, the difference (latency) was calculated between the point in time when the hand entered the block AOI (grasping movement) or the transported block entered the container AOI (transport movement) and the point in time of the observer's first fixation (40 ms) within that same AOI. This latency was categorized into two subgroups: A difference above zero indicated that the infants' gaze arrived at the AOI prior to the hand/block and was classified as *prediction*; a difference below zero indicated that gaze arrived at the AOI after the hand/object and was classified as *reaction*. *Prediction frequency* was calculated by dividing the number of predictions by the sum of all gaze shifts (predictions + reactions). The maximum number of observable action steps was 240 (5 objects x 2 movement types x 2 movement distances x 3 movement durations x 4 repetitions of each film). Infants who provided valid data, that is who had an looking time of above 40% of the respective action step length in at least 2 action steps for all of the 12 possible combinations of movement types, distances, and durations, were included in the data analysis. The analyses that are reported in the following are calculated on both the prediction frequencies as well as prediction latencies. Prediction frequencies are chosen when analyzing the effects of movement type, duration and distance and prediction latencies are chosen when analyzing whether gaze shifts were predictive or reactive in the different conditions.

Infants provided data from $M = 126$ action steps ($SD = 34.2$, $Min = 56$, $Max = 184$). Data was analysed in two different ways. First, we compared prediction frequencies of all trials. In this analysis, movement duration was 1 s, 2 s, or 4 s and the movement distance was either short or long. In a second step, we only analysed the specific conditions in which movement distance was long and short but the respective

movement velocities were equal (slow or fast). We will further explain reasons and details of this analysis in the respective section below.

3. Results

3.1 Analysis of Comparable Movement Durations

The results of the first analysis are depicted in Figure 3. We first conducted a 2 x 2 x 3 (Movement Type [grasp, transport] x Movement Distance [short, long] x Movement Duration [1 s, 2 s, 4 s]) ANOVA with prediction frequency as dependent variable, and movement type, movement distance, and movement duration as within-subjects variables. This analysis revealed a main effect of movement type, $F(1, 21) = 52.53, p < .001, \eta^2 = .71$. Prediction frequency was greater in grasp ($M = .49, SE = .02$) than transport ($M = .26, SE = .02$) movements. We further found a main effect of movement duration, $F(1, 20) = 75.46, p < .001, \eta^2 = .88$; prediction frequency was greater the longer the movement duration for each action step was. Finally, the movement-type x movement-duration interaction was significant, $F(2, 20) = 17.71, p < .001, \eta^2 = .64$; the effect of movement duration was larger during the observation of grasping movements than transport movements. No other main effects or interactions were significant, all $ps > .252$.

To sum up, when movement distance and duration were used as a constant independent within-subjects variable, only movement type and movement duration but not movement distance had an effect on infants' gaze latencies during the observation of goal-directed grasping and transport movements. However, the combination of distance and duration results in four different velocities and the three different levels of the factor movement duration do not result in comparable levels of the factor movement velocity (see Figure 2). For this reason, we added a second analysis where we used

comparable movement velocities (at the cost of different movement durations) as within-subjects variable instead of movement duration.

3.2 Analysis of Comparable Movement Velocity

As becomes evident in Figure 2, the combination of movement distances and durations resulted in four different velocities of which not all were comparable between the two distances. This aspect might have blurred a potentially existing effect of distance on the latency of the gaze latencies in the previous analysis. To account for this, we reanalyzed the data with movement velocity instead of duration as a potentially influencing parameter on infants' prediction frequency. Movement velocity was equal in the following two distance-duration combinations (see Figure 2): The movement velocity was equally *slow* in the condition with short movement distance and movement duration of 2 s (short - 2 s) and the condition with long movement distance and movement duration of 4 s (long - 4 s). Movement velocity was equally *fast* in the condition with short movement distance and movement duration of 1 s (short - 1 s) and with long movement distance and movement duration of 2 s (long - 2 s). With these combinations, we conducted a 2 x 2 x 2 (Movement Type [grasp, transport] x Movement Distance [short, long] x Movement Velocity [slow, fast]) ANOVA with prediction frequency as dependent variable, and movement type, movement distance, and movement velocity as within-subjects variables. The results are depicted in Figure 4. This analysis revealed a main effect of movement type, $F(1, 21) = 39.34, p < .001, \eta^2 = .65$, with prediction frequency being higher for the observed grasping ($M = .49, SE = .03$) than transport ($M = .28, SE = .02$) movements. We further found a main effect of movement velocity, $F(1, 21) = 38.87, p < .001, \eta^2 = .65$; the faster the action was performed the smaller was the prediction frequency (fast: $M = .25, SE = .03$, slow: $M = .52, SE = .03$), which is comparable to the effect of movement duration reported in the

analysis with comparable movement duration. In contrast to this analysis reported above, here, a main effect of distance occurred, $F(1, 21) = 19.09, p < .001, \eta^2 = .48$. Prediction rate was greater with increased movement distance (long: $M = .50, SE = .04$, short: $M = .27, SE = .03$). This distance effect was modulated by movement type: an interaction between movement velocity and movement type, $F(1, 21) = 9.02, p = .007, \eta^2 = .30$; showed that the effect of velocity was stronger in the grasping than the transport movements. No further interaction was significant, all $ps > .22$.

3.3 Predictability of the actions

To evaluate to which extent the gaze shifts were actually predictive, we calculated t -tests against zero for the gaze latencies for each combination of movement type, distance, and duration, using Bonferroni corrections for multiple comparisons ($n = 12$ comparisons; adjusted alpha level $p = .0042$). The respective results including means and SD s are depicted in Table 1. These results showed that all actions with the longest movement durations (4 s) resulted in predictive gaze shifts. All movements with the shortest durations (1 s) resulted in reactive gaze shifts. Medium duration movements (2 s) resulted in a differentiated pattern. Grasping actions with short distance were predicted by the infants, grasping with long distance and transporting with short distance were not different from zero and transporting with long distance were reactive.

4. Discussion

The main aim of the present study was to test the influence of the spatial and temporal dynamics of observed actions on infants' action prediction. To this end, we manipulated movement distance, duration, and velocity of a reach-and-transport action and measured the latency of 12-month-old infants' gaze shifts towards the action goals. The results showed a general effect of all parameters on the infants' perception of goal-directed actions. Infants predicted more action steps the longer the movement duration

was, the longer the movement distance was, and the slower the movement velocity was. In addition, prediction frequency differed between the two presented action types with infants being more likely to predict grasping than transport actions. In the following, we will discuss these effects and implications for future research.

With respect to the effects of movement distance, duration and velocity, the present results support previous findings indicating that infants are sensitive to differences in distances, durations, and velocities (e.g., Brannon et al., 2006; Möhring et al., 2012; VanMarle & Wynn, 2006) in the sense that different levels in all parameters result in differences in the prediction of action goals. In addition, the present results extend previous findings demonstrating that the kinematic information of an ongoing dynamic event have a substantial impact on infants' online action prediction.

The present study extends previous findings on the effect of spatio-temporal properties on the prediction of the reappearance of briefly occluded moving objects. Similar to what has been reported from occlusion studies, the present findings indicate an effect of movement distance (e.g., Rosander & von Hofsten, 2004), duration (e.g., Gredebäck et al., 2002), and velocity (e.g., von Hofsten et al., 2007) not only play a role during the prediction of the reappearance of a moving and partly occluded physical object but also for prediction of action goals where the same spatio-temporal aspects are manipulated. During the observation of both kinds of events, the future state of the observed event has to be predicted and both functional as well as spatio-temporal and kinematic aspects are influencing this prediction.

The fact that, at first glance, all parameters resulted in similar effects on the prediction frequency might suggest that there is no obvious hierarchy between the parameters. However, it is necessary mentioning that the distance effect only appeared when action velocities were comparable for both distances. In this case, actions

performed over the long movement distance resulted in higher prediction frequencies compared to the short distance when the movement velocity was the same. However, different velocities over equal distances result in different movement durations. Hence, it is difficult to completely disentangle duration and velocity. This confound, together with the fact that the first analysis did not reveal a distance effect, in particular with regard to effect sizes, suggests that duration had the strongest influence on action prediction in the present paradigm. The interaction between distance and movement type suggests, however, that duration is a strong, but not the only parameter affecting online action prediction and that distance at least moderates the effect of duration.

Previous research indicates infants' sensitivity to magnitude discrimination is related to the proportional rather than the absolute difference (e.g., Brannon et al., 2007). It is not easy to apply this finding to the present results because in the current study, we did not measure magnitude sensitivity but impact of different variations of spatial and temporal magnitudes on the prediction of action goals. However, in the present study we varied the different levels of movement duration (1 s, 2 s, 4 s) in a way that the increase could be perceived as being non-linear with respect to the absolute values (1 s vs. 2 s) but also as being linear with respect to the proportional values (1:2, respectively). The reported increase of prediction frequencies (see Figure 1, left panel) follows a linear trajectory and suggests a linear rather than a non-linear influence of movement duration on prediction frequency. Accordingly, this suggests that similar to magnitude discrimination, the influence of movement duration is related to the relative proportions rather than the absolute differences between the different movement durations, which is reminiscent to what has been formulated as Weber's law.

The present results showed that infants were more likely to predict the action goal of grasping than transport movements. This replicates what has previously been

reported (e.g., Gredebäck et al., 2009) with respect to reaching and transport actions in particular. This reflects the fact that the simple grasping of an object is usually developed earlier than the transporting of an object into a container. Already newborns aim their extended arm movements towards interesting objects (von Hofsten, 1982). Intentional and successful grasping emerges only a few months later, at the age of 3–4 months (von Hofsten & Lindhagen, 1979). Dropping objects into buckets starts again a few months later between 9 and 12 months of age (Bruner, 1970; Elsner et al., 2007; Falck-Ytter et al., 2006).

The differential functional dependency between performance and prediction of grasping and transport movements is in line with a number of previous findings that suggest that action prediction is related to the infants' performance of the same actions. For example, infants' contralateral grasping is related to their prediction of contralateral grasping movements (Melzer et al., 2012), their increased experience in performing grasp-and-transport actions results in a similar increase of their prediction of the same actions (Cannon et al., 2012), and toddlers' skills to solve a puzzle is correlated with their prediction of observed puzzle-solving actions (Gredebäck & Kochukhova, 2010). In our data, the interaction effect between movement type and movement duration extends these previous studies. Movement duration had a bigger effect on the prediction of actions that infants start to perform earlier in life (like grasping actions) than on actions they begin to perform later in development (like transport actions), which would be in line with embodied accounts of cognitive development.

The greater likelihood of predictive gaze shifts in grasp compared to transport actions is subject to alternative explanations as well. First, the effect can be driven by the fact that during the transport movement, the actor's hand holds a colorful block that might attract the infants' attention more strongly than the empty hand during the

grasping movement. Object saliency has been reported to affect action prediction (Henrichs et al., 2012). In the present study, the saliency of the block in the hand might have resulted in infants' gaze sticking longer to the transporting than the grasping hand before disengaging from the hand and shifting to the container. The current findings of lower prediction frequency might thus reflect something like 'sticky fixations' to the salient block in the moving hand (e.g., Hood & Atkinson, 1993) rather than on differences in motor development. A second aspect that might have influenced infants' gaze behavior is the use of different acoustic signals at the end of the transport and the grasping movement. It might have been the case, that one signal might have been more attractive for the infants (and hence, have increased the saliency of the goal object) resulting in a greater likelihood of action prediction in one compared to the other movement type, independent of the motor representation of the movement. Both concerns are valid and need to be addressed in future research. However, it is worth mentioning that the saliency of the stimuli was identical for all conditions in the present paradigm. Accordingly, while differences in saliency might account for the main effect of movement type, they cannot account for the reported effects of movement distance, duration, and velocity.

The most important aspect that the present results add to the literature is that not only functional, but also more low-level properties have a significant impact on infants' action predictions. In the same way as the saliency of a goal objects affects latency and frequency of action predictions (Henrichs et al., 2012), the present results show that differences in spatio-temporal action kinematics such as movement distance, duration, and velocity influence infants' action prediction as well. In fact, the results of the present study suggests that parameters such as movement distance, duration, and velocity need to be considered very carefully in research on action prediction because

already small variations of these parameters can have a great impact on the prediction frequency and the outcome of different studies focusing on action prediction might not only be related to the infants' skills of performing the presented actions but might also differ with respect to the particular movement kinematics applied. The present results only represent a first step into the direction of exploring the development of the influence of the action kinematics on action prediction. Recent results suggest that the development of velocity-based predictions of action goals corresponds to the development of the velocity the infants' action performance (Stapel, Hunnius, & Bekkering, 2015). This suggests that the closer the velocity of the observed action is to the velocity of the action performed by an individual child, the better he or she will be in predicting the action goal. From adult research it is known that action prediction is sensitive to temporal modifications of observed actions (e.g., Graf et al., 2007). Further research is needed to explore a) the extent to which this is similarly the case in infancy and b) the developmental trajectory of the optimal timing of actions to anticipate and how this is functionally related to the development of the performance of the same actions. Research on the relation between action prediction and action experience suggests that with increasing age, children become faster in their performance of grasping and transport actions (Ambrosini et al., 2013; Gampe et al., 2015; Gredebäck & Kochukhova, 2010; Gredebäck et al., 2009; Melzer et al., 2012). Accordingly, this fact suggests an age-related increase of predictions for same velocity stimuli. Future research is needed to see if older toddlers might already succeed in the faster velocities of this study and to investigate whether infants did not perceive the fastest movements as natural and because of that not being able to predict. Taken together, future studies should interpret their data very cautiously when drawing conclusions about prediction abilities since those do not only depend on the developing motor abilities but also on the

spatio-temporal aspects of observed actions including distance, duration, and velocity, with duration and distance being particularly relevant for the respective age group tested. This finding might shed more light on reported inability to predict action goals at a certain age that might primarily be caused by an inappropriate choice of the temporal and spatial action dynamics.

To conclude, previous research reports that infants in general start to predict the goal of observed actions between the age of 6 and 12 months. The present research adds the evidence that at the age of 12 months, the prediction of the goal of an observed action is strongly influenced by the dynamics of the action, that is, the time it takes the action to unfold, the distance of the action and the velocity with which the action is performed.

5. References

1. Ahmed, I. J., Lewis, T. L., Ellemberg, D., & Maurer, D. (2005). Discrimination of speed in 5-year-olds and adults: are children up to speed? *Vision Research*, 45(16), 2129–35. <http://doi.org/10.1016/j.visres.2005.01.036>
2. Ambrosini, E., Reddy, V., de Looper, A., Costantini, M., Lopez, B., & Sinigaglia, C. (2013). Looking ahead: Anticipatory gaze and motor ability in infancy. *PLoS ONE*, 8(7), e67916. <http://doi.org/10.1371/journal.pone.0067916>
3. Bertenthal, B. I., & Clifton, R. K. (1998). Perception and action. In D. Kuhn & R. S. Siegler (Eds.), *Handbook of child psychology: Vol. 2. Cognition, perception, and language* (5th ed., pp. 51–102). New York: John Wiley & Sons.
4. Brannon, E. M., Lutz, D., & Cordes, S. (2006). The development of area discrimination and its implications for number representation in infancy. *Developmental Science*, 9(6), F59–64. <http://doi.org/10.1111/j.1467-7687.2006.00530.x>
5. Brannon, E. M., Suanda, S., & Libertus, K. (2007). Temporal discrimination increases in precision over development and parallels the development of numerosity discrimination. *Developmental Science*, 10(6), 770–7. <http://doi.org/10.1111/j.1467-7687.2007.00635.x>
6. Bruner, J. S. (1970). *The growth and structure of skill*. (K. J. Connolly, Ed.) *Mechanisms of Motor Skill Development* (pp. 63–94). London: Academic Press.
7. Cannon, E. N., Woodward, A. L., Gredebäck, G., von Hofsten, C., & Turek, C. (2012). Action production influences 12-month-old infants' attention to others' actions. *Developmental Science*, 15(1), 35–42. <http://doi.org/10.1111/j.1467-7687.2011.01095.x>

8. Elsner, B., Hauf, P., & Aschersleben, G. (2007). Imitating step by step: A detailed analysis of 9- to 15-month-olds' reproduction of a three-step action sequence. *Infant Behavior & Development, 30*, 325–335.
9. Falck-Ytter, T., Gredebäck, G., & von Hofsten, C. (2006). Infants predict other people's action goals. *Nature Neuroscience, 9*(7), 878–879.
<http://doi.org/10.1038/nn1729>
10. Flanagan, J. R., & Johansson, R. S. (2003). Action plans used in action observation. *Nature, 424*, 769–771.
11. Gampe, A., Keitel, A., & Daum, M. M. (2015). Intra-individual variability and continuity of action and perception measures in infants. *Frontiers in Psychology: Developmental Psychology, 6*(00327).
<http://doi.org/10.3389/fpsyg.2015.00327>
12. Graf, M., Reitzner, B., Corves, C., Casile, A., Giese, M. A., & Prinz, W. (2007). Predicting point-light actions in real-time. *NeuroImage, 36*, T22–T32.
13. Gredebäck, G., & Daum, M. M. (2015). The microstructure of action perception in infancy: Decomposing the temporal structure of social information processing. *Child Development Perspectives, 9*(2), 79–83. <http://doi.org/10.1111/cdep.12109>
14. Gredebäck, G., & Kochukhova, O. (2010). Goal anticipation during action observation is influenced by synonymous action capabilities, a puzzling developmental study. *Experimental Brain Research, 202*(2), 493–497.
<http://doi.org/DOI 10.1007/s00221-009-2138-1>
15. Gredebäck, G., Stasiewicz, D., Falck-Ytter, T., von Hofsten, C., & Rosander, K. (2009). Action type and goal type modulate goal-directed gaze shifts in 14-month-old infants. *Developmental Psychology, 45*(4), 1190–1194.
<http://doi.org/10.1037/a0015667>

16. Gredebäck, G., von Hofsten, C., & Boudreau, J. P. (2002). Infants' visual tracking of continuous circular motion under conditions of occlusion and non-occlusion. *Infant Behavior & Development*, 25(2), 161–182. [http://doi.org/10.1016/S0163-6383\(02\)00119-4](http://doi.org/10.1016/S0163-6383(02)00119-4)
17. Green, D., Kochukhova, O., & Gredebäck, G. (2014). Extrapolation and direct matching mediate anticipation in infancy. *Infant Behavior & Development*, 37(1), 111–8. <http://doi.org/10.1016/j.infbeh.2013.12.002>
18. Henrichs, I., Elsner, C., Elsner, B., & Gredebäck, G. (2012). Goal salience affects infants' goal-directed gaze shifts. *Frontiers in Psychology*, 3, 391. <http://doi.org/10.3389/fpsyg.2012.00391>
19. Hood, B. M., & Atkinson, J. (1993). Disengaging visual attention in the infant and adult. *Infant Behavior & Development*, 16(4), 405–422. [http://doi.org/10.1016/0163-6383\(93\)80001-O](http://doi.org/10.1016/0163-6383(93)80001-O)
20. Lewkowicz, D. J. (1992). Infants' response to temporally based intersensory equivalence: The effect of synchronous sounds on visual preferences for moving stimuli. *Infant Behavior and Development*, 15(3), 297–324. [http://doi.org/10.1016/0163-6383\(92\)80002-C](http://doi.org/10.1016/0163-6383(92)80002-C)
21. Lipton, J. S., & Spelke, E. S. (2003). Origins of number sense: Large-number discrimination in human infants. *Psychological Science*, 14(5), 396–401. <http://doi.org/10.1111/1467-9280.01453>
22. Melzer, A., Prinz, W., & Daum, M. M. (2012). Production and observation of contralateral reaching: A close link by 12 months of age. *Infant Behavior & Development*, 35(3), 570–579. <http://doi.org/10.1016/j.infbeh.2012.05.003>

23. Möhring, W., Libertus, M. E., & Bertin, E. (2012). Speed discrimination in 6- and 10-month-old infants follows Weber's law. *Journal of Experimental Child Psychology, 111*(3), 405–418. <http://doi.org/10.1016/j.jecp.2011.11.002>
24. Rosander, K., & von Hofsten, C. (2004). Infants' emerging ability to represent occluded object motion. *Cognition, 91*(1), 1–22. [http://doi.org/10.1016/S0010-0277\(03\)00166-5](http://doi.org/10.1016/S0010-0277(03)00166-5)
25. Rosander, K., & von Hofsten, C. (2011). Predictive gaze shifts elicited during observed and performed actions in 10-month-old infants and adults. *Neuropsychologia, 49*(10), 2911–2917.
26. Spelke, E. S., Kestenbaum, R., Simons, D. J., & Wein, D. (1995). Spatiotemporal continuity, smoothness of motion and object identity in infancy. *British Journal of Developmental Psychology, 13*(2), 113–142. <http://doi.org/10.1111/j.2044-835X.1995.tb00669.x>
27. Stapel, J. C., Hunnius, S., & Bekkering, H. (2015). Fifteen-Month-Old Infants Use Velocity to Predict Others' Action Targets. *Cognition, 6*, 1092. <http://doi.org/10.3389/fpsyg.2015.01092>
28. VanMarle, K., & Wynn, K. (2006). Six-month-old infants use analog magnitudes to represent duration. *Developmental Science, 9*(5), F41–9. <http://doi.org/10.1111/j.1467-7687.2006.00508.x>
20. von Hofsten, C. (1982). Eye-hand coordination in newborns. *Developmental Psychology, 18*(3), 450–461.
30. von Hofsten, C., Kochukhova, O., & Rosander, K. (2007). Predictive tracking over occlusions by 4-month-old infants. *Developmental Science, 10*(5), 625–640. <http://doi.org/10.1111/j.1467-7687.2007.00604.x>

31. von Hofsten, C., & Lindhagen, K. (1979). Observations on the development of reaching for moving objects. *Journal of Experimental Child Psychology*, 28(1), 158–173. [http://doi.org/10.1016/0022-0965\(79\)90109-7](http://doi.org/10.1016/0022-0965(79)90109-7)
32. Wilcox, T., & Schweinle, A. (2003). Infants' use of speed information to individuate objects in occlusion events. *Infant Behavior and Development*, 26(2), 253–282. [http://doi.org/10.1016/S0163-6383\(03\)00021-3](http://doi.org/10.1016/S0163-6383(03)00021-3)

Table 1:

Comparisons of Mean Latencies Against Zero. Significant Predictions Are Depicted in Bold. Similar Shades of Grey Indicate the Comparable Movement Velocities, Respectively, See Figure 2.

Movement			Latency				CI [95%]	
Type	Distance	Duration	<i>M</i>	<i>SD</i>	<i>t</i> ⁺	<i>p</i> -value	Lower	Upper
Grasp	Short	4 s	927.72	279.66	15.55	< .001	803.73	1051.72
		2 s	142.28	173.94	3.837	0.001	65.16	219.40
		1 s	-223.38	147.81	-6.92	< .001	-290.66	-156.09
	Long	4 s	734.68	431.82	7.98	< .001	543.22	926.14
		2 s	110.68	199.79	2.47	0.023	17.18	204.19
		1 s	-235.07	148.04	-7.27	< .001	-302.46	-167.68
Transport	Short	4 s	251.07	421.79	2.72	0.013	59.073	443.07
		2 s	-117.95	198.05	-2.72	0.013	-208.10	-27.80
		1 s	-330.54	146.15	-10.60	< .001	-395.34	-265.75
	Long	4 s	470.49	626.18	3.44	0.003	185.46	755.53
		2 s	-221.55	181.33	-5.59	< .001	-304.09	-139.01
		1 s	-385.11	153.17	-10.95	< .001	-458.94	-311.28

Note. ⁺*DF* = 20, Bonferroni-adjusted Alpha level: *p* = .0042.

Table 2:

Mean Prediction Frequencies for Movement Type, Distance, Duration and Velocity.

Similar Shades of Grey Indicate the Comparable Movement Velocities, Respectively,

See Figure 2.

Movement				<u>Latency</u>	
Type	Distance	Duration	Velocity	<i>M</i>	<i>SD</i>
Grasp	Short	4 s	slowest	0.848	0.115
		2 s	slow	0.553	0.256
		1 s	fast	0.156	0.236
	Long	4 s	slow	0.778	0.247
		2 s	fast	0.477	0.301
		1 s	fastest	0.145	0.178
Transport	Short	4 s	slowest	0.391	0.285
		2 s	slow	0.256	0.216
		1 s	fast	0.102	0.172
	Long	4 s	slow	0.483	0.262
		2 s	fast	0.268	0.265
		1 s	fastest	0.078	0.184

A)

B)

Figure 1. Stimulus setup: A) Depiction of the two movement types: the grasping movement (left to middle picture) and the transporting movement (middle to right picture); B) Data analysis details including goal areas of interest for short (left) and long (right) movement distances between the initial location of the LEGO® blocks and the container into which the blocks were moved.

Figure 2. Combinations of movement distance and duration and—resulting—movement velocity (increasing from the slowest (dark grey = $15.6^{\circ}/s$) to the fastest (white = $1.95^{\circ}/s$). Please note that movement velocity was equally *slow* (medium grey = $3.9^{\circ}/s$) in the conditions where the short distance was combined with a movement duration of 2 seconds and the long distance with a movement duration of 4 seconds. The movement velocity was equally *fast* (light grey = $7.8^{\circ}/s$) in the conditions where the short movement distance was combined with a movement duration of 1 second and the long movement distance with a movement duration of 2 seconds (light grey).

Figure 3. Results of the overall analysis: Prediction frequencies with respect to movement type and distance (left), movement type and duration (middle), and movement distance and duration.

Figure 4. Results of the analysis with comparable movement velocities: Prediction frequencies with respect to movement type and distance (left), movement type and velocity (middle), and movement velocity and distance.

6. Highlights

- We measured the influence of the spatio-temporal aspects of observed actions on action prediction.
- Twelve-month-olds saw manual actions with different movement distances and durations.
- We found that movement duration, distance, velocity and type influenced action prediction.