The relationship between gaze shifts elicited during observed and performed actions in infants and adults

Kerstin Rosander and Claes von Hofsten
Dep of Psychology, Uppsala University

Key words: infants, prediction, motor development, perception-action, eye movements

Abstract

We asked whether other people's actions are understood by projecting them onto one's own action programs and whether this mode of control is functioning in infants? Adults' and infants' gaze and hand movements were measured in two live situations. The task was either to move an object between two places in the visual field, or to observe the corresponding action performed by another person. When performing the action, infants and adults behaved strikingly similar. They initiated the hand and gaze movements simultaneously and gaze arrived at the goal ahead of the hand. When observing such actions, the initiation of the gaze shifts was delayed relative to the observed movement in both infants and adults but gaze still arrived at the goal ahead of the hand. The infants' gaze shifts, however, were more delayed at the start, less proactive at the goal, and showed kinematic variability indicating that this mode of functioning is somewhat unstable in 10-month-old infants. In summary, the results showed that both adults and infants perceive the goal of the action and move gaze there ahead of time, but they did not support the idea of a strict matching of the kinematics between the eye movements carried out when performing and observing actions.

Introduction

It has been suggested that observed actions performed by other people are understood through a matching process whereby they are mapped onto one's own motor representation of that action (Flanagan & Johansson, 2003, Rizzolatti, Fadiga, Gallese,1996). Flanagan & Johansson (2003) showed that subjects who observed someone moving objects from one place to another, moved their eyes predictively to the goal of the displacement. The purpose of such predictive eye movements when the displacement action is performed by the subject him/herself is to guide the hand to the goal. There is no such direct rationale for the proactive gaze shifts performed during action observation. If, however, actions are understood by projecting them onto one's own action system as stated by the Mirror Neuron System (MNS) Hypothesis (Rizzolatti et al, 1996), the proactive gaze shifts performed during action performance should be produced during action observation as well. Because the eyes are free to move when observing such actions, the direct matching hypothesis predicts that subjects should produce eye movements similar to those produced when they perform the tasks.
This hypothesis raises question about the nature of this matching process. To what degree does the matching include the kinematic properties of the movement? One possibility is that the gaze shift performed when another person is observed to perform a goal directed movement is precisely matched to the gaze shift when the subject him/herself performs the movement. Another possibility is that only the general properties of the movement are matched, like the starting and/or the arrival times of the observed movement and the accompanied gaze shifts. Flanagan and Johansson (2003) demonstrated that one's own action of moving an object from one place to another in the visual field was highly similar to the observed action. The gaze predicted the start as well as the goal, of the hand movement. This close matching between the kinematics and the timing of eye movements performed and observed was interpreted as driven by a mechanism that projects other people's actions onto one's own motor programs.

The questions raised in the present study concern how infants and adults move an object to a visual goal and how they go about observing another person performing the same action. Do infants shift gaze to the goal ahead of the hand when performing a manual action as adults have been reported to do (Flanagan & Johansson, 2003)? This question has, to our knowledge, not been studied in infants before. It seems reasonable that infants shift gaze to the goal ahead of time if they are to guide the object displacement there, but it is not known how much. Neither is it known whether they begin to shift gaze to the goal before the hand begins to move or whether gaze just catches up. These facts are important when considering how infants move their eyes when they observe other people who move objects to a goal. If, infants understand other people's actions by projecting them onto their own action system, the proactive gaze shifts performed during action performance should also be produced during action observation. The purpose of the present study was to investigate these relationships by measuring the timing of gaze and hand movements when subjects move an object from one place to another and when they observed some one else performing the same action. This makes it possible to determine, not only whether infants proactively move gaze to the goal of an observed action, but also how well this action matches the timing of the gaze movement when the child performs the action him or herself.

Falck-Ytter et al (2006) found that 12-month-old infants but not 6-month-olds predicted the goal of an observed goal directed manual action by moving gaze there ahead of time. The gaze of the12-month-olds, however, did not move to the goal as proactively as adults. On the average gaze arrived at the goal 170 ms ahead of the hand while the corresponding time for the adults was 350 ms. However, it is not known how well this proactive behavior matches the timing of gaze shift when the child performs the displacement action him or herself.

If observed actions are mapped onto motor representations of those actions (Rizzolatti & Craighero 2004), this mirroring should also be reflected in the neural expressions associated with the actions. For instance, it has been found that a specific frequency interval in the EEG spectrum, the mu rhythm, is enhanced during rest and desynchronized during action performance. The same desynchronization appears when adults observe actions (Gastaut and Bert, 1954) and, recently, Southgate et al (2009) showed similar results in 9-month-olds both when they observed and reached for a goal. The mu-rhythm was more desynchronized when these infants observed a goal-directed reaching movement than when they observed a non-goal-directed movement. Nyström, Ljunghammar, Rosander & von Hofsten (2009) also found this effect in a group of 8-month-old infants observing a goal-directed action.
The assumption of the MNS hypothesis is, that in order to match an observed goal-directed action to ones own motor program, the subject must have developed /established those motor programs (ahead of time). The reason why displacement movements are not mirrored at that age, might be that infants do not yet engage in moving the objects they reach for to specific external goals. At 9-10 months of age, however, they do this consistently (Claxton et al, 2003). Therefore, we focused on this age for the present study. When an object is moved to a new position this must be represented. The ability to represent a goal is essential for pointing, and infants start pointing to a goal at 10.5 to 11 months of age. (Butterworth and Grover, 1990).. Furthermore, at this age infants perform gaze following, such that they look at a goal that a person points at. In the present study, ten-month-old infants and adults were studied in a live situation when looking at an adult person who grasped and moved an object to a goal, and when performing the actions themselves.

Methods:
Subjects: Fourteen 10-11-month-old infants participated in the study. Two additional infants who took part in the experiment did not displace the object consistently as demonstrated but brought the objects to the mouth or dropped them on the floor. The final group consisted of 5 girls and 9 boys. All families obtained a gift certificate of 10 € for their participation. The experiment was in accordance with the Helsinki declaration of 1994, and was approved by the local ethics committee at Uppsala University. The parents signed a consent form before the experiment started. The 9 adults were 20-26 years old (6 females, 3 males). They were informed, and signed a written consent form as well.

Apparatus:

Set up and procedure:
Infants: The subjects were placed in a high chair with a table attached to it, facing Experimenter 1 (see Figure 1). The parent sat behind the subject. Experimenter 2 applied two electrooculogram (EOG) sensors at the outer canthi, with the ground on the forehead, and put a hat onto the head of the infant with the preamplifier of the EOG attached and two reflective markers for the Qualisys motion analysis system. Furthermore, a reflective marker was attached to the back of each hand of the subject and Experimenter 1. The Qualisys cameras and a web-camera (Logitech) were placed in the ceiling above and in front of the infant. The experiment started with a calibration procedure for the EOG in which Experimenter 1 grasped

an attractive object positioned 20 cm in front of the infant and moved it horizontally back and forth in the frontoparallel plane. The next condition was to demonstrate the transport of the object from start to goal. The object was a small boll that could be fitted into a cylinder (the goal), made of Plexiglas (diameter 5 cm, height 16 cm). After that condition, the subject wanted to move the object self. Importantly, no indications where the goal was situated were provided by Experimenter 1 when the infants tried themselves. The distance between the start and goal was either 37 or 18 cm (estimated visual angles: 50 or 25 deg.). These conditions were randomly presented according to the mood of the infant. Experimenter 2 started the trials when the subject seemed ready to perform or attend to the performance of Experimenter 1. Every trial was 12 s and data was sampled at 120 Hz. The web camera registered the scene while data was collected with the synchronized EOG and Qualisys systems.

Adults: The subject participated in 2 blocks of 6 trials, one block where they performed the action themselves and one where they observed the experimenter performing the action. Before the first trial an EOG calibration procedure was performed. For the performance trials, the instruction was: “just grasp and move the object similarly to when you work in the kitchen”. The subjects used their preferred hand when moving the object. In 3 of performance trials the subjects grasped the object on the left side and transported it to the right, and in the other 3 trials they grasped it on the right and transported it to the left. The transport distance was 50 cm (estimated visual angle 60 degrees). For the observation trials the instruction was: “look at the action of experimenter”. The experimenter then demonstrated 3 trials where an object was moved from the same right position to the same left used in the self-performing or vice versa. For each second subject the experiment started with the 6 observation trials, followed by the 6 performing ones, and so on.

Data analysis: All hand- and head data were transferred to xyz coordinates with the Qualisys software and the EOG voltage to x-coordinates. The data files were transferred to Matlab and Fystat (Umeå University) programs. Gaze was then calculated as the vector sum of head and eye movements as described in earlier studies (von Hofsten & Rosander, 1997; Rosander & von Hofsten, 2002), thus obtaining gaze in rotation angles and angular velocity.
The velocities of the hands in their 3-D trajectories were then calculated. Data for gaze and hand velocities were inspected visually and the onset (after grasping) and end of the action were determined from the calculated velocities (thresholds……respectively).The hand movements were considered to have started when the velocitiy was greater than xxx mm/s and to have ended at the goal when the velocity once again was below that value. The gaze shift was considered to have started when gaze velocity was greater than xxx deg/s and to have arrived at the goal when the velocity was once again. The time difference, DHG, between hand and gaze was used as a measure of prediction: if the difference was positive, the gaze was ahead of the hand. DHG was determined at the start and the goal. Furthermore, the kinematic parameters movement time (MT) and percentage peak velocity (PPV) of the hand were determined. The eye movements were primarily saccadic. The number of saccades in a gaze shift, and whether they were performed before or after the PPV of the hand was analyzed. Finally, the MT of gaze was estimated.

The statistics was performed in SPSS. The main purpose was to compare the DHG at start and goal in the observing and performing conditions for both adults and infants. As the distributions of DHG data was found to be skewed, non-parametric tests were used. For the two independent distributions of adults and infants, the Hann Whitney was applied, and for the within-subject tests of start and goal the Wilcoxon (related distributions) was applied. Skewness, means, medians of the DHG distributions are given in Table 1.

Results

General: The infants enthusiastically performed the task of grasping the object, and moving it into the cylinder (Figure 1). They often performed other actions : they took the object to the mouth and then moved it to the goal, they switched hand during the transport, they showed the object to the experimenter or mother, or they threw it on the floor. All such trials were excluded. On the average, 10-50% of the recorded movements from each subject could be analyzed. No systematic difference was seen between the long and short displacement distances, and therefore the results were pooled. No difference in DHG was observed in the adult group between the left-right or the right-left actions, and therefore these groups were pooled as well.

Action and action observation:

In Figure 2 individual adult means of DHG for the observation and the performance conditions are shown at the start and goal and in Figure 3 the corresponding individual infant means are shown.. When the subjects performed the actions themselves, the DHG for the infants and adults were quite similar at the start (Mann-Whitney, U= 114.35, P=0.7). At the goal, all the individual mean DHG were positive but the adults' gaze arrived significantly earlier than the infants' (U= 875.5, P=0.023). In the action observation condition significant differences were seen both at start and goal between the adults and the infants (U= 444.5, P=0 and U= 408, P=0 at start and goal respectively). The adults had lower DHG at start, and higher at the goal as compared to the infants. At the onset the DHG is significantly negative (P), indicating that the observed hand starts earlier than the gaze.

There were correlations between DHG at start and goal in the performance condition for both adults (pearson 0.54/p=0.0/N=46, Spearman, Kendall) and infants (pearson 0.61/P=0.0/N=52). For the observation condition, a significant correlation between DHG at start and goal was seen only in adults (0.338/P=0.013/N=53).

A linear regression analysis with the DHG (goal) as dependant and DHG (start) as independent gave significant regression for both infants and adults in the performance condition. The characteristics were 0.76 (adults) and 0.75 (infants) for the slopes, with the intercepts 0.48 and 0.35 s respectively. The regression correlations were 0.54 and 0.61. For the observation trials the regression was significant only for the adult group: 0.53 (slope) , 0.430 (intercept) and 0.34 (correlation coefficient).

Kinematic parameters of the action movements:

Table 2 shows MT and PPV of performance and observation movements in both groups. The PPV(performance?) is higher in the infants, 54 %, as compared to the adults 45 %. The MT of the hand and gaze is significantly higher in the observation trials than in the performance trials. The velocity peak appears in the middle part of the movement. The DHG was calculated as the difference (hand (peak)-gaze (peak)), to demonstrate how the gaze had advanced relative to the hand. The mean DHGs at start, peak-region, and goal are shoen in figure 4, and the relative number of trials with positive DHG.in figure 5.

Saccades during hand movements:

The gaze shifts were primarily saccadic. In a large proportion of the trials the subject shifted gaze to the goal in just one saccade. This was more common in the performance condition, in 71% and 63% of the trials by the adults and infants respectively. In the observation condition the corresponding proportions were 56% (adults) and 32 % (infants) Table 3

On every action trial the adults produced the first saccade before the hand PPV. For the infants, the corresponding figure was 86%. When subjects observed the displacement movements the saccades appeared later. In that condition the adults and the infants produced the first saccade before PPV in 67% and 34% of the trials, respectively. When adults acted, the percentage trials with only one saccade produced before PPV was 69 % (thus only 2 % less than the total number of trials with one saccade). The corresponding figure for the infants was 51 %. When the gaze shift was accomplished in only one saccade during observation, it was produced later during the displacement, in 33% (adults) and 7 % (infants) before PPV . The increase in % trials with positive DHG between start and peak region correlates (visa) with the % first saccade. (visa om good prediction high number saccades before the peak)

Discussion

Three. main results have implications both for the planning of actions and for how other people's actions are understood by 10-month-old infants and adults. First, the results reveal that manual actions are very well coordinated with looking in both infants and adults. Secondly, when the infants and the adults observed another person moving an object to a goal, they reliably shifted their gaze to the goal ahead of the observed hand. Thirdly, the onset of the gaze shifts was delayed relative to the observed hand in both infants and adults.

Goal prediction of observed and performed actions: When performing manual actions, the gaze shifts accompanying them start at about the same time as the hand itself and arrive at the goal ahead of the hand. This was valid for both infants and adults. The only difference between these two age groups is in terms of the arrival time and the variability between trials. The adult's gaze arrived consistently earlier to the goal than the infants' and the infants also showed more variability than the adults between trials. This suggests that the programming of manual displacement movements and the gaze shifts are essentially accomplished ahead of the start in both infants and adults. As can be seen in Table 3, the adults, in almost three quarters of the trials, shifted gaze to the goal in a single saccade while the infants did so in almost two thirds of the trials. This suggests that the difference between infants and adults is primarily a question how automatic the programming is. (test if diff. 75%and 60%) ta upp regressionen-likheter adults,infants ta upp relation goal dhg saccade

During observation, both infants and adults reliably shifted their gaze to the goal of the movement ahead of the observed hand. This is remarkable because the predictive eye movements do not have an obvious function in this situation. However, if the observed actions are projected onto one's own motor programs, as predicted by the MNS hypothesis (Rizzolatti et al, 1996), predictive eye movements are expected. This is in accordance with the present results. The adults had a gaze advantage of 306 ms and the infants an advantage of 105 ms. Earlier studies support this result. Flanagan & Johansson (2003) found a gaze advantage of 150 ms, Falck-Ytter et al. (2006) 350 ms, and Verrel et al. (2007) 460 ms. Although the object was transported over different distance in these studies (15° of visual angle in Flanagan et al.(2003), 22° in Falck-Ytter et al. (2006), 80° in Verrel et al. (2007), and 50° in the present study) there is no obvious relationship between distance and the size of the gaze advantage. The smaller gaze advantage for the infants rather indicate that the coordinative structures linking one's own gaze behavior to the observed actions of other people is not firmly established in this group of subjects. (no regression correlation).This is also indicated by the pattern of saccades for this group of subjects. In only a third of the trials, the gaze shifts of the infants in this condition were accomplished in a single saccade in contrast to the performance condition.

Another factor that might influence the size of the DHG is familiarity. Falck-Ytter et al. (2006) (and Johanson et al) used a repetitive task with no previous experience with the specific movements observed. The model moved an object from one position to another and then returned to the first position to grasp a second object to be moved etc. In that experiment, the 12-month-old subjects showed no gaze advantage on the first trial but an advantage of overat least 334 ms on the second one. The corresponding numbers for the adults were 250 and 465 ms respectively. In the present experiment there was no simple repetition of trials. The model moved the either right to left or vice versa (adults) and the distance was either 18 or 37 cm (infants).

Onset of gaze for observed actions:The third set of results that stands out is related to the onset of the gaze shifts associated with observed actions. They were delayed in both infants and adults although the delay was much greater for the infants (see Table 1). While the first saccade was launched before the peak velocity of the hand in all of the adult and in nearly all of the infant performance trials, the same figures for the action observation trials were much lower (2/3 o the adult trials and 1/3 of the infant trials). It can be noted that in very few of the infant trials, the gaze shift was accomplished in only one saccade that was launched before the peak velocity of the observed hand (1 out of 13). The consistently found delay in the onset of gaze shifts associated with an observed action is most probably related to the perception of its goal. Not until a small part of the hand movement is completed it is evident where the hand is heading. The delay is less likely accounted for in terms of a reaction-time. The observed displacement action is not unexpected. It is part of a somewhat larger action sequence that also includes the approach of the hand to the object. Furthermore, the final goal of the action (inserting the ball in the tube) was hardly unknown to the subjects. Both infants and adults had observed the action at the beginning of the experiment and, at least, the infants had earlier performed the action themselves. Thus, from a cognitive point of view, there is no reason why the onset of the gaze shifts should be delayed. If, however, other people's actions are projected onto one's motor programs, it is expected that a fraction of the action needs to be observed before the motor program is activated. It is clear from Fogassi et al. (2005) that the mirror neurons for grasping in the inferior parietal lobe of rhesus monkeys did not begin to fire at the onset of the observed movement but only after a short delay when the hand is on its way to the object to be grasped.

Matching observed and performed actions: What does it mean that an observed action is projected onto one's own motor program of that action? A strict interpretation of this hypothesis would assume that the performed eye movements in the action observation condition would match the eye movements in the action performance condition. However, as Table X shows, there are more saccades in the action observation condition. Another expectation is that some of the kinematics should be preserved between the action performance and the action observation conditions, that is, if the gaze shift in the action observation condition starts later, gaze should arrive at the goal later. This holds for the adults but not for the infants. In adults, the DHG at start is related to the DHG at goal in a similar way for the performance and the observation conditions (see Fig X). For the infants, however, while there is a significant correlation between the DHG at start and goal for the performance condition, there is no such correlation for the observation condition. Thus, the results do not support a strict interpretation of the MNS hypothesis in terms of matching of the kinematics between the observed and the performed eye movements. It seems that the MNS is more geared to the goal of an observed action than to its kinematics. For DHG,the similarity in performance between infants and adults is significantly better than between the observed actions. This result indicate that the own motor action develops ahead of the ability to predict a similar observed action.

The MNS hypothesis states that other people's actions are projected onto existing motor programs. This implies that an action performed by another subject cannot be understood before it is mastered. The displacement action studied here is a recent acquisition for the infants studied. It parallels the acquisition of understanding pointing and gaze following. Both these skills emerge at around 9 to 10 months of age the same age as children's understanding of manual displacement actions.(ja men vad är relevansen-nog att kunna representera ett mål? The ability to interpret an intended, observed action, as its goal, is considered as a cornerstone in the matching of observed to own action.) Falck-Ytter et al. (2006) found that 6-month-old infants showed a consistent lag when tracking manual displacement movements, and at this age infants do not grasp objects to move them to goals ,except for the mouth Other demonstrated actions, however, may be better known to infants earlier in life and thus elicit predictive gaze shifts. Kochukhova et al. (2009) showed that observation of eating actions elicited predictive gaze shifts to the mouth in 6-month-old infants

Van Elk et al. (2008) investigated the effect of natural motor experience on motor resonance during action observation in 14- to 16-month-old infants. They found stronger mu- and beta-desynchronizations for observation of videos of crawling compared to walking infants and the size of the effect was strongly related to the infant's own crawling experience. Furthermore, Sommerville et al (2005) found that action experience altered 3-month-olds perception of other people's actions, so that they are better than without experience. The conclusion from these studies support that the MNS utilizes a "library" of actions (Gallese) ,and these are gradually established during development. It is concluded that the present study also support that during development, an action is learnt by the individual before other peoples actions can be matched with one´s own. Then, an observed goal-directed motor action is understood from one's own mastered goal directed predictive action. From the presented data it is evident that at 10 months of age the ability to transport objects to a goal is similar to that in adults. When the ability appears in development, it is adult like.

Acknowledgement:

This project was supported by the EU integrated project FP6-004370 (Robotcub). We thank Therese Ljunghammar and Dorota Stasiewicz for help with conducting the experiments, and Terje Falck-Ytter for comments on the manuscript.

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Table 1. Skewness, means and medians of the DHG in adults and infants at the start and

	Adults observe	Adults perform	Infants observe	Infants perform
skewness	0.091 (0.327)	-1.304(0.350)	0.056 (0.414)	0.706 (0.330)
mean	-232.1 (137.4)	9.8 (140.8)	-376.1(206.3)	30.4(267.5)
median	-247.0	32.0	-362.0	-23.0

At the goal

skewness	0.752 (0.327)	-0.292 (0.350)	0.057 (0.414)	0.357 (0.330)
mean	306.2 (216.8)	491.5 (197.7)	104.8 (170.6)	374.7 (326.8)
median	254.0	509.5	95.0	362.0

Table 2: Average MT and PPV for hand and gaze in the performance condition.

	MThand	MTgaze	PPVhand	PPVgaze	
Adults	788	302	45	41	
Infants	784	376	54	41	

Table 3

	Adult performs	**Adult observes**	**Infant performs**	**Infant observes**
Number of trials	49	43	59	41
First saccade before PPV	100%	67%	86%	34%
1 saccade	71.4%	55.8%	62.7%	32%
1 saccade and before PPV	69.3%	32.6%	50.8%	7.3%

Figure captions

Figure 1. example of registered gaze and hand movements when a 10-month-old is performing (a) and observing the experimenter's hand (b). Velocity as a function of time (blue= hand, red =gaze).

Figure 2. Performing and observing: Means of DHG in each subject (adults) at the start and the goal (red = observing and blue = performing)

Figure 3: ..in infants

Figure 4. Average DHG at start, peak region, and goal in infants and adults (red= adults, blue=infants) for the observation and performance conditions.

Figure 5. Relative number of trials where the DHG >0 at the start, peak region, and goal.

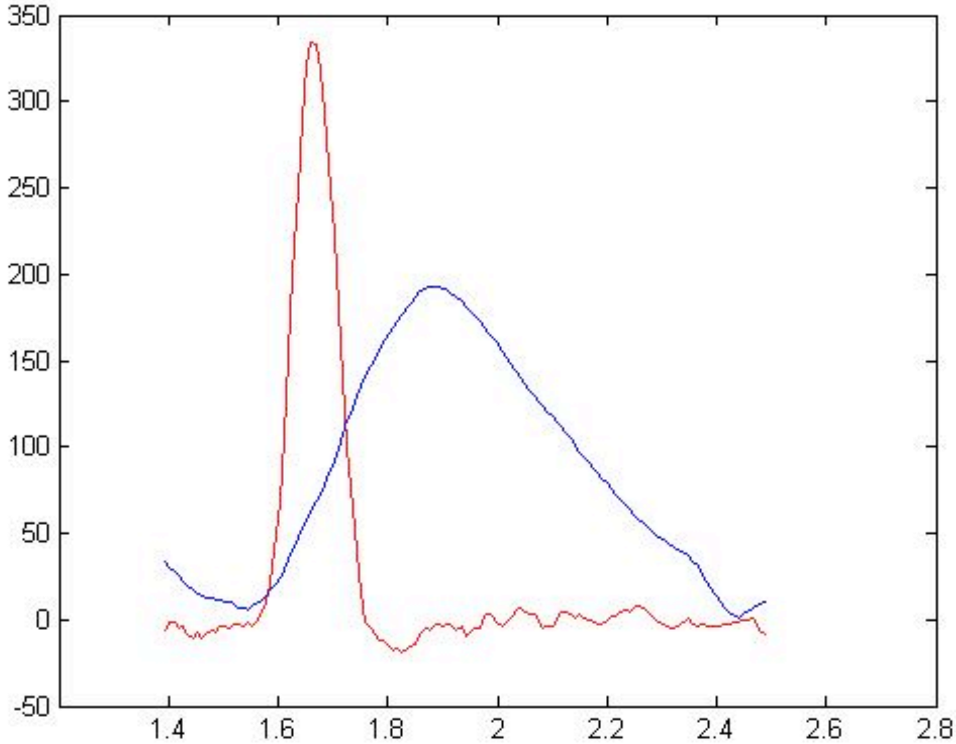
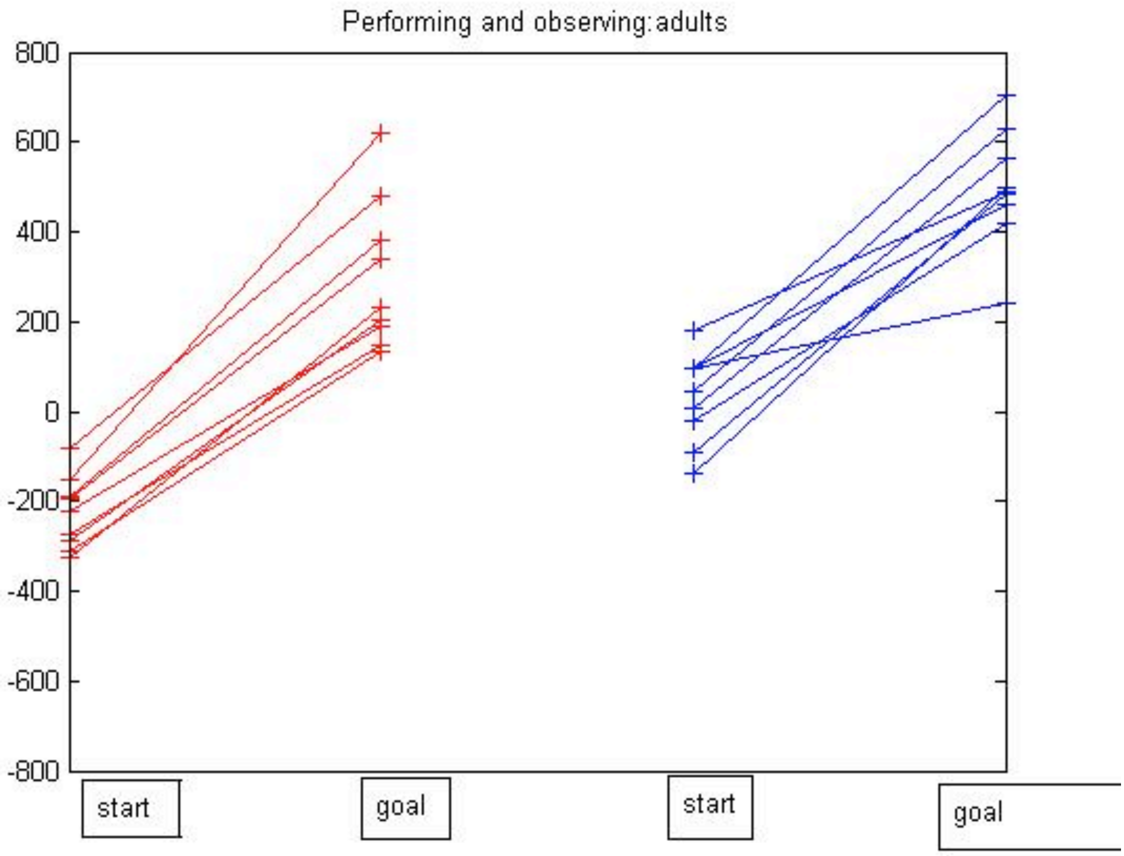
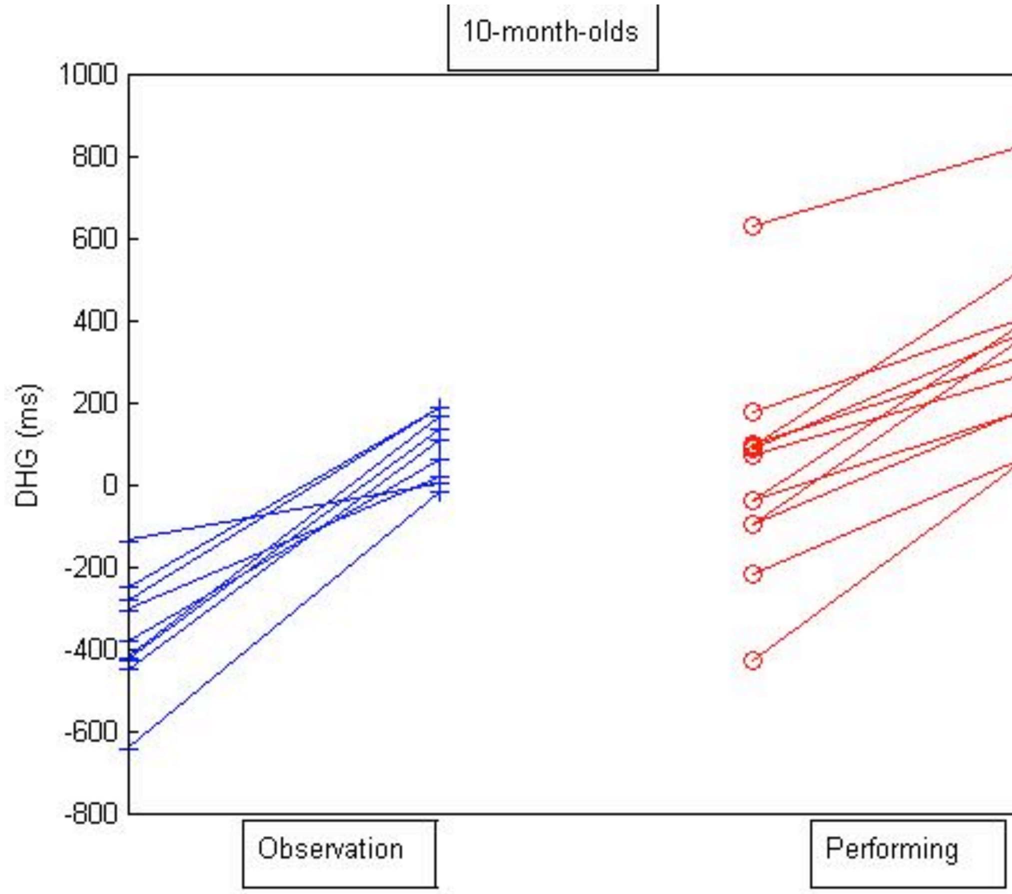
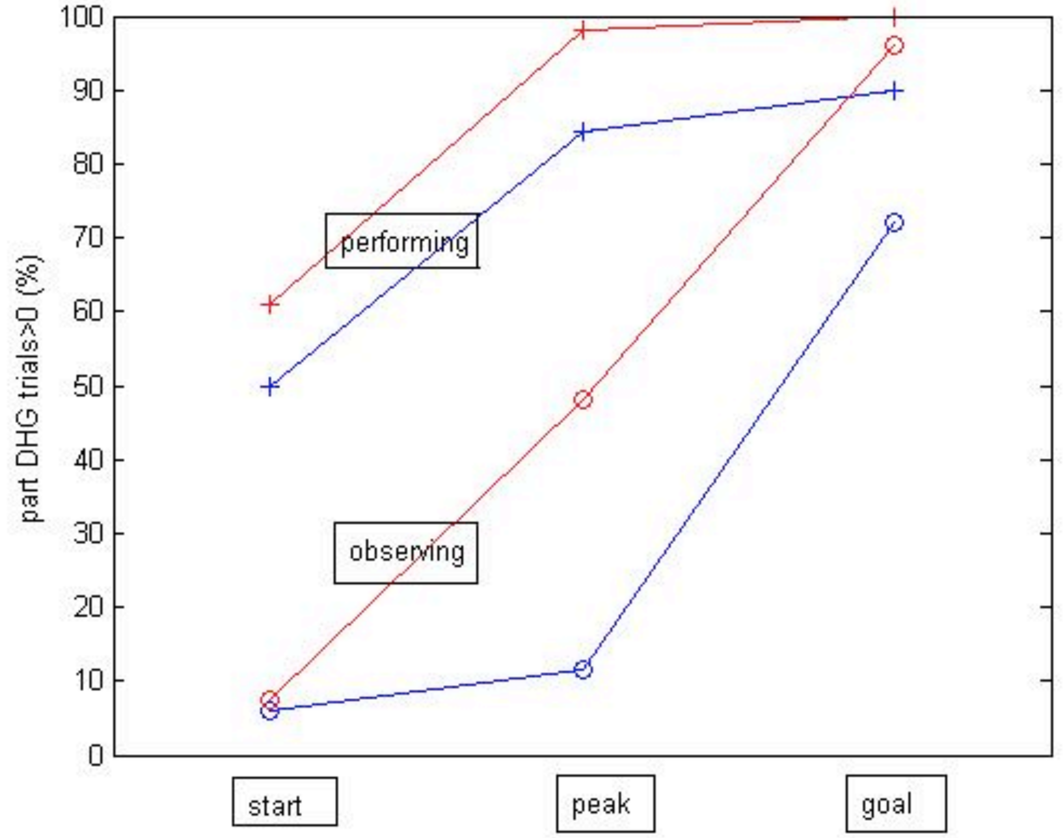


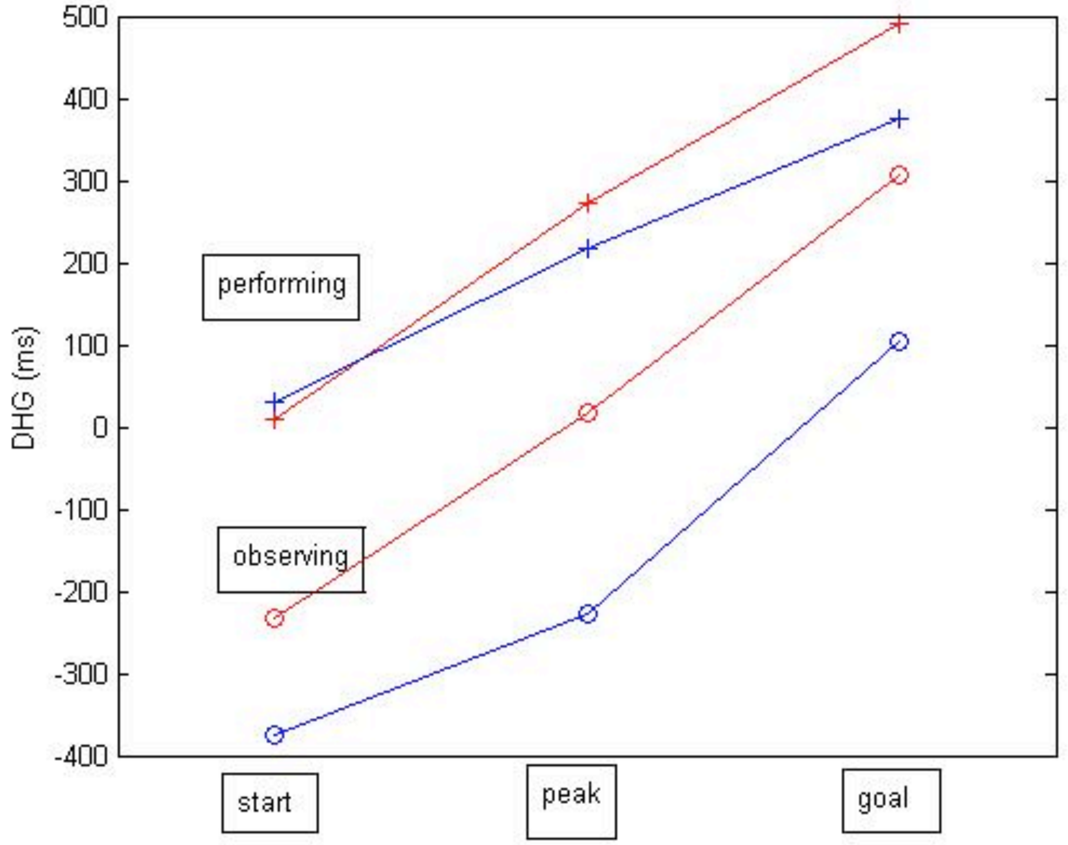
Figure 1 a.


Performing and observing:adults
800
600
400
200
0
-200
-400
-600
-800
start
goal
start
goal


10-month-olds
DHG (ms)
1000
800
600
400
200
0
-200
-400
-600
-800
Observation
Performing



100
90
80
70
60
50
40
30
20
10
0
part DHG trials>0 (%)
performing
observing
start
peak
goal



500
400
300
200
100
0
-100
-200
-300
-400
DHG (ms)
performing
observing
start
peak
goal