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Abstract

When do infants start to understand that they can grasp an object by its handle when the interesting part is out of reach? Whereas it is known from preferential looking tasks that already at three months of age infants show surprise when all parts of an object do not move together, little is known about when infants are able to use such knowledge in an active grasp situation. To answer this question we presented six, eight, and 10 month-old infants in a cross-sectional and a longitudinal study with a white cardboard handle within reach and a bright ball at the end of the handle and out of reach. A trick condition, where the handle and the ball seem attached but were not, was added to get an indication of the infant's expectation by observing a possible surprise reaction.

Results show that 6-month-olds' most frequent first behaviors consisted in pointing toward the ball without grasping the handle, or grasping the handle without looking at the ball until it moved. In addition, they often did not look surprised in the trick condition. Eight- and 10-month-olds most often grasped the handle while looking at the ball, and showed clear surprise in the trick condition. This was interpreted as showing that around eight or 10 months, infants take a significant step in understanding the cohesiveness of composite objects during grasping.

Keywords: Infant, development, composite object, grasping, cohesiveness

1. Introduction

Grasping composite objects is an everyday experience, as, for instance, when grasping a cup by its handle. A particular case is when the salient and desired part of a composite object, for example the food part of a lollipop, is too far away to be grasped directly: in that case, we take for granted that we can retrieve the desired part by using the part of the object which is within reach, often a handle. This is because we know that all parts of a composite object move together. But this principle, which seems totally obvious to adults, may not be so obvious to infants. The literature on this question does not provide very much information.

Thus, while a large amount of work has been done on how grasping emerges and becomes adapted to the shape of an object around 5 months (Hofsten, 1984, 1986; Mathew & Cook, 1990; Thelen, 1992; Thelen, Corbetta, & Spencer, 1996), much less is known about infants' understanding of composite objects. Some work related to this question has been done using the technique of visual habituation (e.g. Cheries, Mitroff, Wynn, & Scholl, 2008; Spelke & Van de Walle, 1993; see the review by Spelke & Kinzler, 2007). This work has shown that infants are sensitive quite early to the physical laws that govern objects and in particular that infants possess the notion of the cohesiveness of a rigid object (an object must maintain a single bounded contour over time). For instance, three-month-old infants show surprise when all parts of an object do not move together (Spelke & Van de Walle, 1993).

However, a problem with such visual habituation studies is that the results do not necessarily generalize to tasks where actual physical actions are involved: a substantial discrepancy has been observed between the age at which infants display perceptual knowledge and the age at which infants are able to use this knowledge for action. For instance, visual habituation studies show that the principle of solidity (an object cannot move through a solid barrier) seems to be understood at three months (Spelke, Breilinger, Macomber, &

Jacobson, 1992), but two-year-olds still open the door beyond an obstructing panel to reach for a rolling ball that disappeared behind an occluder, giving the impression that they do not expect that the high panel visible above the occluder will prevent the ball from rolling (Berthier, DeBlois, Poirier, Novak, & Clifton, 2000). Thus, in the case of a composite object, though it is known that infants already show surprise at three months of age when all parts of an object do not move together (Spelke & Van de Walle, 1993), one can wonder at what age they are actually able to manually grasp a composite object by one part in order to retrieve a different, more interesting, part. This is the question asked in the present study.

A clue towards an answer to this question might be found in the classic means-end studies involving cloth-pulling, string pulling, cane pulling, etc. first explored by Richardson (1932), Piaget (1963), Uzgiris & Hunt (1975), Bates et al. (1980) or Willatts (1984). These studies show that around 9-10 months, infants have sufficient understanding to be able to pull a string in order to retrieve an out-of-reach toy. Using the string-pulling paradigm, other studies have aimed at understanding action representations with respect to an ultimate goal and their relation to the ability to produce similar sequences (Sommerville & Woodward, 2005). For instance, Sommerville and Woodward showed that 10-month-olds can identify the goal of string-pulling when they watched an actor doing it, but only if they could themselves "planfully solve a similar sequence" (Sommerville & Woodward, 2005, p.1; see also McCarty, Clifton, & Collard, 2001; McCarty, Clifton, & Collard, 1999). But these tasks could be understood as means-end problem-solving tasks involving not one composite object but rather two distinct objects with one desired object and another object which is a means to retrieve it. Conceptually therefore, it seems reasonable to think that such means-end tasks might constitute a more complex problem to the child than the simple task of exploiting an object's rigidity to bring closer an unattainable part of the object. Indeed, children are exposed to the coherent motion of solid objects from birth on, and it seems plausible that their early accession to the notion of “object” precisely requires them to understand that parts of an object all move together. The intutition would thus be that such very basic understanding, which underlies the notion of object, has a different status and might develop differently from the conceptually more complex ability to solve means-end tasks like the string pulling task. Our purpose here was therefore to contribute to the understanding of the development of this cohesiveness or composite object notion.

To this end, we performed a cross-sectional and a longitudinal study. We presented 6- to 10-month-old infants with a brightly decorated ball attached to the end of a featureless white cardboard handle (see Figure 1). Pilot experiments previously performed in a day-care nursery had confirmed that such a featureless handle was much less desirable than the ball, since when handle and ball were placed in front of children, after looking at both, they invariably chose to play with the ball. We used two types of handle, a straight handle and an L-shaped handle. Our intuition was that the L-shaped handle, being more unusual in shape, and providing a less direct connection from the handle to the ball, might tax the infant’s comprehension to a greater extent. The object was presented so that the handle was within reach, but the ball was out of reach. We observed to what extent infants simply begged for the ball and ignored the handle, or to what extent they realized that grasping the handle would allow retrieval of the ball. Investigating the infant’s visual understanding of object structure in grasp planning by observing looking and manual behavior before grasping has previously been used, for instance to check the infant’s anticipation of the solid versus flexible quality of the object (Barrett, Traupman, & Needham, 2008), or its understanding of “connectedness” (Rat-Fischer, O’Regan, & Fagard. 2014). We added an additional ‘invisible disconnection’ condition to help disambiguate the results. We assumed that this trick condition would elicit surprise only when the baby understood the notion of cohesiveness. Differently decorated balls were used to minimize the transfer between conditions. In a second longitudinal study we followed ten infants from 6 through 8 and 10 months of age using the same protocol.

2. Study 1

2.1. Methods

2.1.1. Participants

A total of 38 full-term infants, twenty-six boys and twelve girls, participated in the study. All infants did the whole session without fussing and were kept in the study. They were divided into three age groups: there were sixteen infants between 6 and 6,5 months of age (mean = 6.2), eleven between 8 and 8,5 months of age (mean = 8.4), and eleven between 10 and 10,5 months of age (mean = 10.3). These age groups were chosen to be compatible with what is known about the emergence of grasping (Hofsten & Ronnqvist, 1988) and means-end behavior (Willatts, 1984). Infants' parents were contacted by mail and recruited from a local list of families. Prior parental consent was granted before observing the infants.

2.1.2. Procedure

In all conditions the ball was presented out of reach and the handle was presented within reach. In the "composite object" condition (C1), the bright ball was attached to the end of the handle. In the "invisible disconnection" condition (C2), the ball was placed next to the handle so that it looked like it was attached to the handle, but actually was not.

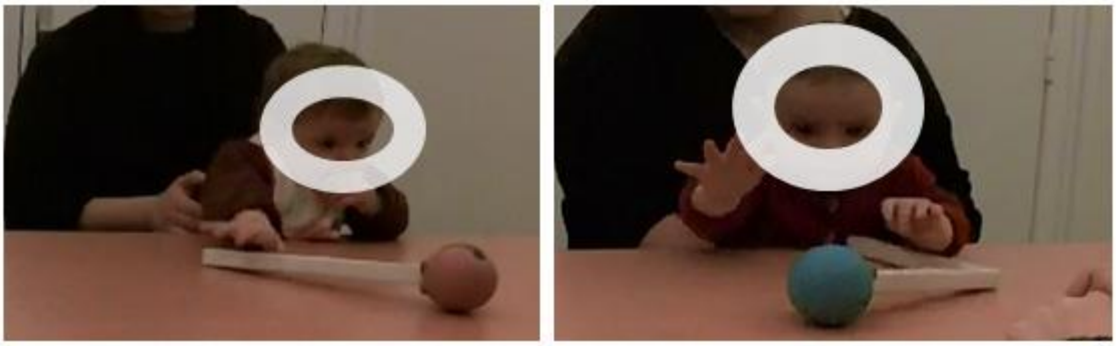

Figure 1: a/ Straight object, handle to the right (Infants grasps the handle while looking at the ball, level 3); b/ L-shaped object, handle to the left (Infant points to the ball, level 1)

Analysis of the video recordings allowed us to code which part of the object -- the ball or the handle -- the infant was looking at while grasping. To facilitate coding, objects were presented obliquely with the handle on one side and the ball on the other. All infants received four trials, two in the composite object condition (one with the straight object and one with the L-shaped object), and two corresponding trials in the invisible disconnection condition. For half of the infants the straight object was presented with the handle to their left (ball to the right) and the L-shaped object with the handle to their right (ball to the left), and for half of the infants this was reversed. The experimenter first placed the objects behind an occluder, and the trial began when the occluder was removed. Because we wanted to know the infant's expectation after simply viewing the object, that is, before manually interacting with the object, we could only present each configuration (Straight and L-shaped) once. The order of presentation of the two objects was counterbalanced. The "invisible disconnection" condition (C2) was always presented after the normal, "composite" condition (C1) so that it would not contaminate the composite condition.

2.1.3. Data analysis

All trials were videotaped. Although detailed analyses of individual reaching and grasping would provide a rich source of data, the essential question posed in our study could be answered by simply assigning performance to three levels of competence. The levels were assigned by checking whether infants' behavior met certain criteria within a trial. The criteria were different for the composite object condition (C1) and invisible disconnection condition (C2), but in both cases they were designed to assess the degree to which the infant understood the link between the handle and the ball.

In the composite object condition (C1), the main criteria used to define the different levels were the relation between what the child does and where it looks:

> Level 1: The child demonstrates no understanding of the link between handle and ball. This level is coded if one of the following behaviors is recorded: Child points only toward ball but does not grasp handle; Grasps handle after pointing to ball but without looking at ball anymore; Grasps handle without looking at ball at all; Ball's movement immediately triggers eyes' movement toward it; Looks at ball but does not grasp the handle.
>
> Level 2: Transitional. We attributed this level if criteria for neither Level 1 nor Level 3 were present. An example would be if the child begs repeatedly for the ball before grasping the handle, or if the child grasps the handle after touching it by chance. Though defined by negation of levels 1 and 3, we assume that level 2 corresponds to the existence of real transitional mechanisms coming into play.
>
> Level 3: The child clearly understands the link between handle and ball. This level is coded if one of the following behaviors is recorded: Grasps handle directly while looking at ball; Stretches second hand toward ball while pulling handle.

In the invisible disconnection condition (C2), the criteria used to distinguish the levels of comprehension involved the degree of surprise manifested by the child:

Level 1: The child demonstrates no understanding of the link between handle and ball. This level is coded if one of the following behaviors is recorded: Shows no surprise that the ball doesn't come; Does not look at the ball when it moves the handle.

Level 2: Transitional, neither clearly Level 1 nor Level 3.

Level 3: The child clearly understands the link between handle and ball. This level is coded if one of the following behaviors is recorded: Shows surprise that the ball doesn't come; Stops or changes the grasping movement after seeing that the ball doesn't come; Alternates looking between ball, handle and experimenter; opens mouth; Opens eyes wide.

For both conditions, we checked the number of trials during which the infants looked at the experimenter immediately before, during or immediately after pulling the handle (none of the infants looked at their parents at that stage of the action).

Inter-rater agreement, based on two independent judges scoring 25% of the sample averaged 89% agreement for level at C1 and 90% agreement for level at C2, 95% agreement for gaze at C1 and C2.

2.1.4. Statistical analyses

The raw data were the level of performance reached by the infant in each condition. We calculated an ANOVA on this level of performance (1 to 3). We first checked whether there was an effect of position of the handle, and of order of presentation for each of the two conditions separately. When there was no effect, we did not include these variables the main ANOVAs. We did that because of the small number of subjects, so as not to lose too many cells. Thus, for the composite condition, we calculated the ANOVA on the level of performance with age and object as independent variables, and for the disconnection condition, we calculated the ANOVA on the level of performance with age, object, and order as independent variables.

2.2. Results

2.2.1. Composite object condition (C1)

In condition C1 the ball is connected to the handle. We expected the infants to behave differently depending on their understanding of the notion of composite object. If they understood the notion (Level 3), they should grasp the handle first and look at the ball while pulling the handle. They might also stretch the other hand toward the ball while pulling the handle. If they did not understand the notion (Level 1), infants should first point toward the ball, and then, failing to obtain it, grasp the handle for itself without looking at the ball.

Since half of the infants started with the straight object, and half started with the L-shaped object, we first checked whether the order of presentation influenced the level of performance. For this we calculated an ANOVA on the level of performance with Order of presentation (x 2) and Object (x 2) to see if the performance differed significantly if they were presented first or second, and if this was the same independently of object. There was no significant main effect for order ($p=.67$), no main effect for object ($p=.67$, see Table 1) and no significant interaction ($p=.47$). We also checked whether the position of the handle made a difference for the results, and whether this was the same for both objects. The ANOVA on the level of performance with Position (x 2, to the left vs. to the right) and Object (x 2) as independent variables showed no effect for position of the handle ($p = .53$), no effect for the object ($p = .29$) and no significant interaction ($p = .84$). Thus, for the results on the age effect, we will consider neither order nor position of the handle.

6 mo		8 mo		10 mo	
1.3 (.12)		2.2 (.15)		2.6 (.18)	
Straight	L-shaped	Straight	L-shaped	Straight	L-shaped
1.4 (.8)	1.1 (.34)	2.1 (.9)	2.4 (.8)	2.8 (.5)	2.4 (.7)

Table 1: Mean level (SD inside brackets) at C1 as a function of age and object

As seen in Figure 2, the most frequently coded level at 6 months was Level 1, whereas at 8 and more so at 10 months, the most frequently coded level was Level 3.

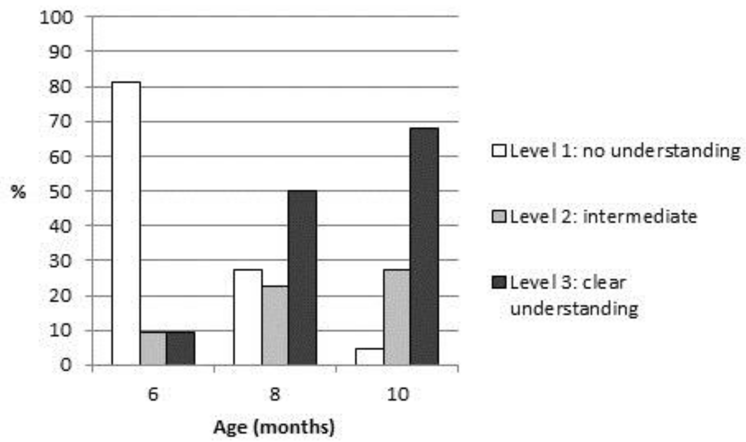

Figure 2: Frequency of each level of performance in each age group at C1 (both objects pooled) at the cross-sectional study

To check whether the performance changed significantly with age and differed according to the object, we calculated an ANOVA on the level of performance (1 to 3) taking Age (x 3, 6, 8, 10), and Object (x 2, Straight, L-shaped) as independent variables. The results show a significant main effect for age, $F(2,70) = 16$, $p < .000001$. A LSD post-hoc test shows that the effect is due to the difference between the 6-month-olds and the two other age groups ($p < .00001$ for both). Thus, eight- and 10-month-olds showed a significantly better level of performance than 6-month-olds. The difference between 8- and 10-month-olds did not reach significance (p = .08). As already mentioned, there was no significant effect for object. There was no age x object interaction (see Table 1).

Finer analysis of the data is presented in Table 2. The 6-month-olds' most frequent first behaviors consisted in grasping the handle without looking at the ball or pointing toward the ball, whereas the 10-month-olds' most frequent first behavior consisted in grasping the handle while looking at the ball (and sometimes stretching the other hand toward the ball). More generally, pointing first toward the ball decreases from 6 to 10 months whereas pulling the handle while looking at the ball increases during the same age period.

	6 mo	**8 mo**	**10 mo**
Pulls handle while looking at handle	14/32 (43.7%)	3/22 (13.6%)	3/22 (13.6%)
Points hand toward ball	11/32 (34.4%)	4/22 (18.2%)	1/22 (4.5%)
Clasps hands on table while looking at ball	1/32 (3.1%)	0/22 (0%)	0/22 (0%)
Pulls handle while looking at ball	6/32 (18.7%)	15/22 (68.2%)	18/22 (81.8%)

Table 2: First behavior at C1 as a function of age (number of infants)

Thus, 8- and 10-month-olds grasp the handle more while looking at the ball than 6-month-olds.

2.2.2. Invisible disconnection condition (C2)

In this condition, the ball and the handle appeared connected. However, in fact they were only placed one against the other but not attached, so that when the infant pulled the handle, the ball did not come along. We assumed that if the infants expected that grasping the handle would allow retrieving the ball, they would grasp the handle and then look surprised that the ball does not come along. We expected the infants to show surprise by stopping their grasping movement after seeing that the ball does not come along, by looking alternately between ball and handle after grasping the handle, and even by looking at the experimenter or/and opening the mouth (Level 3). The case corresponding to lack of surprise would be if the infant did not look at the ball after grasping the handle (Level 1).

We expected to find an order effect in this condition, at least for the infants who were surprised not to see the ball coming along with the handle. We expected that they would show less surprise at the second presentation than at the first one, and so we expected that Level 1 would be obtained more often at the second trial than at the first trial. We first checked that this was the case by calculating an ANOVA on the level of performance with Order of presentation (x 2) and Object (x 2) to see if the performance differed significantly between the two trials if they were presented first or second, and if this was true independently of object. There was a significant main effect for order, $F(1,72) = 9.4$, $p < .01$, no main effect for object ($p = .42$) and no significant interaction ($p = .24$). Significantly fewer infants showed surprise (Level 3) for the object presented second (see Figure 3). We also checked whether the position of the handle made a difference in the results, and whether this was the same for both objects. The ANOVA on the level of performance with Position (x 2, to the left vs. to the right) and Object (x 2) as independent variables showed no effect for position of the handle ($p = .67$), no effect for the object ($p = .95$) and no object x position interaction ($p = .06$). Thus, for the results on the age effect, we will consider order but not position of the handle.

To check whether the level changes with age at Condition 2, and differs according to the object and to the order, we calculated an ANOVA on the level of performance (1 and 3) with Age (x 3, 6, 8, 10), Object (x 2, Straight, L-shaped), and Order (x 2, First vs. Second) as independent variables. The results show a significant main effect for age, $F(2,64) = 8.5$, $p < .001$. A LSD post-hoc test shows that the effect is due to the difference between the 6-month-olds and the 8-month-olds ($p < .02$) and between the 6-month-olds and the 10-month-olds ($p < .0001$). The difference between 8- and 10-month-olds did not reach significance ($p = .08$). As can be seen in Figure 3, the level of performance increases with age, which means that the older infants are more surprised than the younger ones. As previously mentioned, there was no main effect for object but a significant main effect for order, $F(1,64)=11.4$, $p<.01$. None of the interactions was significant.

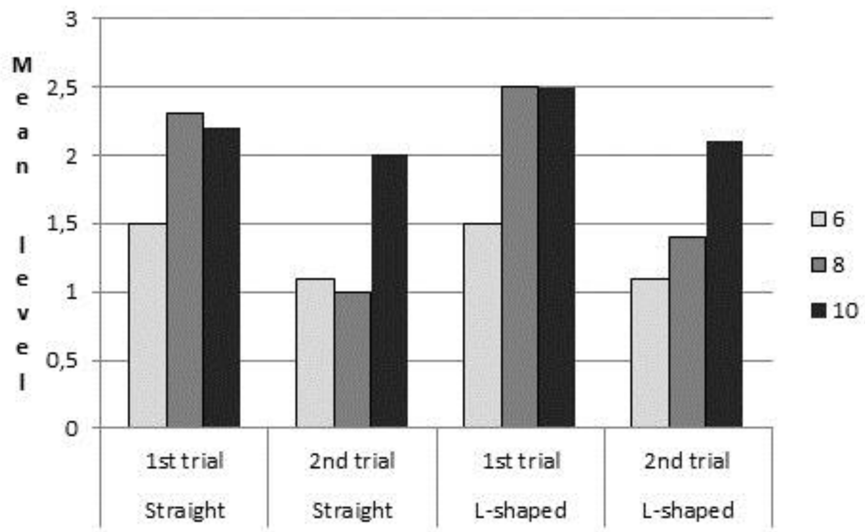

Figure 3: Mean level at C2 as a function of Age, Object, and Trial at the cross-sectional study (the lowest the level, the less surprised infants are)

2.2.3. Comparison between classifications in C1 and C2

We expected that the infants who seemed unaware of the notion of composite object in C1 would show less surprise in C2 than the infants who gave the impression of understanding that they could retrieve the ball by grasping the handle in C1. We also expected the correlation to be higher at the first trial than at the second trial. To check this hypothesis, we calculated the correlation between the levels of performance in C1 and C2 for each trial separately. There was a positive and significant correlation between the levels of performance in C1 and C2 for the first trial, $r = 0.42$, $n = 38$, $p = .008$, and a positive but non-significant correlation between the levels of performance in C1 and C2 for the second trial, r = 0.15, n = 38, p = .37.

2.2.4. Analysis of the gaze toward the experimenter

We checked the number of trials during which the infants looked at the experimenter immediately before, during or immediately after pulling the handle. In C1, infants did not look very often at the experimenter (see Figure 4). At 6 months, four infants looked at the experimenter at one trial, and one looked at both trials (thus 18.7% of all trials were accompanied by gaze toward the experimenter); at 8 months, one infant looked at the experimenter at one trial and one infant looked at the experimenter at both trials (16.6% of all trials were accompanied by gaze toward the experimenter); at 10 months, one infant looked at the experimenter at one trial and three infants looked at the experimenter at both trials (31.8% of all trials were accompanied by gaze toward the experimenter). Most gazes toward the experimenter occurred while pulling or moving the handle, three occurred before action, and three occurred after pointing toward the ball.

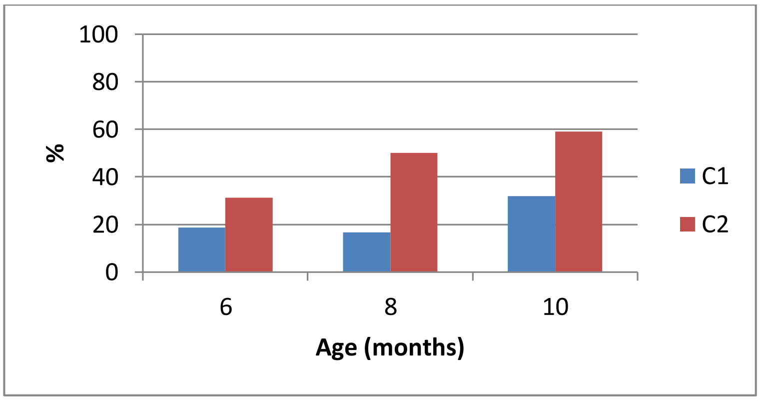

Figure 4: Percentage of trials with gaze toward the experimenter as a function of age and condition

In C2, infants looked at the experimenter much more than in C1 (see Figure 4): at 6 months, 10 infants looked at the experimenter at one trial and none at both trials (thus 31.2%

of all trials were accompanied by gaze toward the experimenter); at 8 months, five infants looked at the experimenter at one trial and three infants looked at the experimenter at both trials (50% of all trials were accompanied by gaze toward the experimenter); at 10 months, five infants looked at the experimenter at one trial and four infants looked at the experimenter at both trials (59.1% of all trials were accompanied by gaze toward the experimenter).

Most gazes toward the experimenter occurred after pulling the handle and looking at the ball not coming along (55.9%). The other occurrences were gazes while pulling the handle (26.5%), before action (8.8%), or while pulling or moving the handle (8.8%). Interestingly, the distribution of these occurrences varies considerably with age. The gazes toward the experimenter which may be considered as a sort of questioning of the situation (i.e. after pulling the handle and looking at the ball not coming along) represent 9.4% of all trials at 6 months (30% of all gazes), 27.3% of all trials at 8 months (54.5% of all gazes), and 54.5% of all trials at 10 months (92.3% of all gazes; see Figure 5). An ANOVA on the number of gazes toward the experimenter as a function of condition and age showed a significant effect for condition ($F(1,10) = 8.03$, $p = .018$) but no effect for age. A post-hoc LSD test indicates that the difference is not significant at 6 months ($p = .26$) but is significant at 8 months ($p = .006$) and at 10 months ($p = .03$).

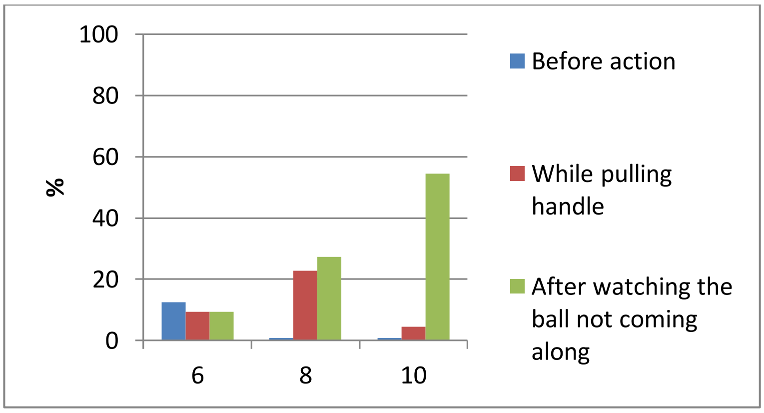

Fig 5: Percentage of trials with look at the experimenter as a function of age and time of gaze

Thus, although gaze toward the experimenter was only one of the criteria used to code the behavior at C2 as reflecting surprise that the object does not come along with the handle, the frequency of this looking behavior reflects well this increase of expectation with age.

2.3. Conclusion from study 1

In this study, in which infants were presented with a composite object made of an attractive ball at the end of a plain handle, we observed a significant change of performance between 6 and 8 months. Whereas 6-month-olds often behaved as if they did not expect the handle and the ball to be connected, most 8- and 10-month-olds' behavior indicated that they knew from visual inspection that the ball would come along with the handle. This was confirmed when we presented the infants with the trick, invisible disconnection condition, where handle and ball seemed connected but were only touching. In this condition the 8- and 10-month-olds looked more surprised that the ball did not come along with the handle than the 6-month-olds. In addition, infants who seemed not to understand the connection between the handle and the ball in the normal condition were also those who were not surprised that the ball did not come along with the handle in the trick condition.

3. Study 2

3.1. Methods

3.1.1. Participants

Study 2 was a longitudinal study conducted with the same material as in the first study. Ten children were followed longitudinally and tested at 6, 8 and 10 months. The procedure was the same as for the cross-sectional study: All infants received four trials, two in the composite object condition (one with the straight object and one with the L-shaped object), and similarly two trials in the invisible condition. Since in the cross-sectional study there was no difference found for order of presentation and for position of the handle in the first study, all ten infants started with the straight object, and for both objects the handle was presented to the right of the infant.

For the analyses, the videos were coded by two coders, one who was common to both studies (JF), until 100% agreement was reached, after which one coder (MP) coded the rest of them. About 30% of the videos were coded by both reviewers.

Results

3.2.1. Composite object condition (C1)

In condition C1 the ball is connected to the handle. As one can see in Figure 6, the most frequently coded level at 6 months was Level 1, whereas at 8 and even at 10 months, Level 1 was the least frequently coded.

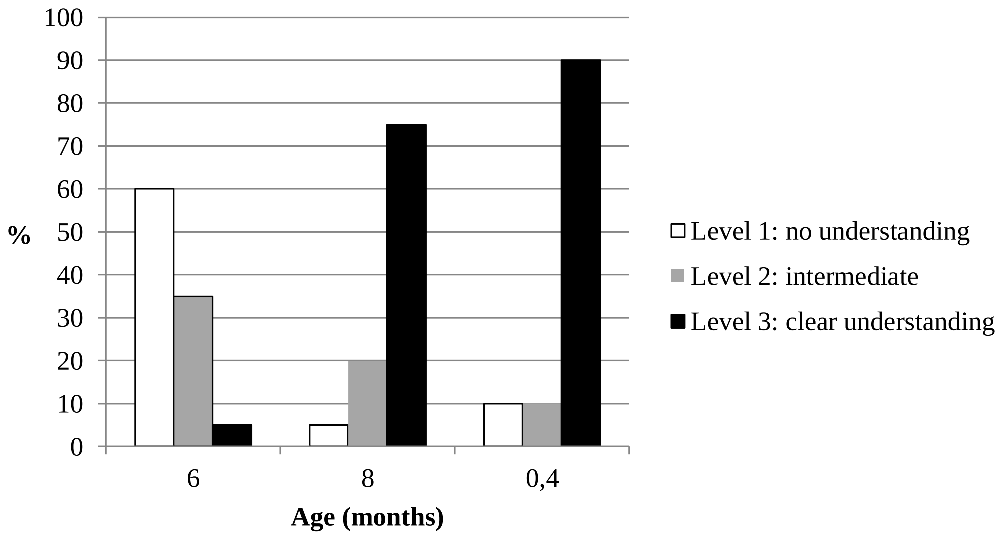

Figure 6: Frequency of each level of performance at each age at C1 (both objects pooled) at the longitudinal study

To check whether the performance changed significantly with age and differed according to the object, we calculated an ANOVA for repeated measures on the level of performance (1 to 3) taking Age (x 3, 6, 8, 10), and Object (x 2, Straight, L-shaped) as independent variables. The results show a significant main effect for Age ($F(2,18) = 47.97$, $p < .000001$). A LSD post-hoc test shows that the effect is due to the difference between 6 months and the two other ages ($p < .00001$ for both). Thus, infants showed a significantly better level of performance at eight than at 6 months, but they did not change significantly between 8 and 10 month ($p = .23$). There was no significant effect for Object. There was no Age x Object interaction (see Table 1).

3.2.2. Invisible disconnection condition (C2)

In this condition, the ball and the handle appeared connected. However, in fact they were only placed one against the other but not attached, so that when the infant pulled the handle, the ball did not come along.

We expected to find an order effect in this condition. We expected that infants would show less surprise at the second presentation than at the first one, and so, that Level 1 would be obtained more often at the second trial than at the first trial. But since in this second study the straight object was always given first, order effect is confounded with object effect. To check whether the level changes with age at Condition 2, and differs according to the object / order, we calculated an ANOVA for repeated measures on the level of performance (1 and 3) with Age (x 3, 6, 8, 10), Object/Order (x 2, Straight, L-shaped) as independent variables. The results show a significant main effect for age, $F(2,16) = 41.7$, $p < .000001$. A LSD post-hoc test shows that the effect is due to the difference between all three ages ($p < .0001$ for all comparisons). As can be seen in Figure 7, the level of performance increases with age, which means that as they grew older, infants were more surprised than before. There was no main effect for Object/Order and no significant interaction with Age.

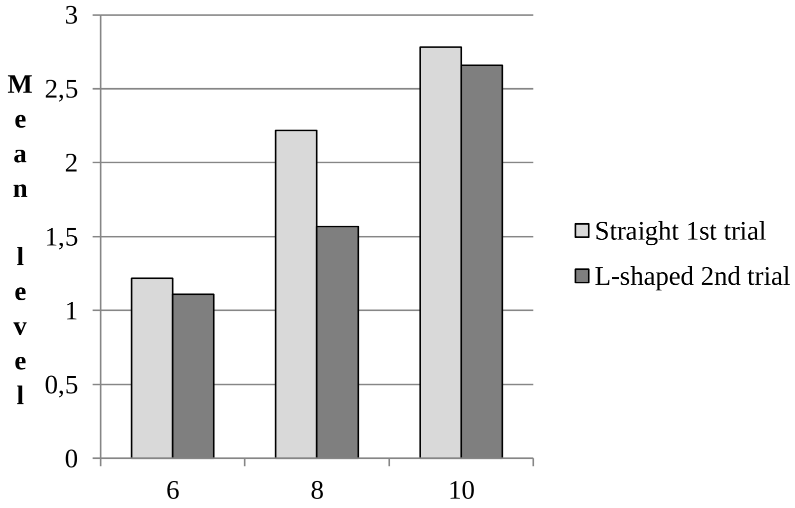

Figure 7: Mean level at C2 as a function of Age and Object / Trial at the longitudinal study (the lower the level, the less surprised infants are)

3.2.3. Comparison between classifications in C1 and C2

We expected that infants who seemed unaware of the notion of composite object in C1 would show less surprise in C2 than those who seemed to understand that they could retrieve the ball by grasping the handle in C1. To check this hypothesis, we calculated the correlation between the levels of performance in C1 and C2 for each age separately. There was a positive and significant correlation between the levels of performance in C1 and C2 at six months (r = .64), a positive but not-significant correlation at eight months (r = 0.46), and a positive and significant correlation at 10 months (r = .93).

3.2.4. Comparison with the results of the cross-sectional study

Since the longitudinal study was performed in a different laboratory[1], we checked whether the results of the two studies were coherent. We compared the level of performance at C1 and at C2, for each age separately. At C1, an ANOVA on the summed scores for the two objects (maximum = 6) as a function of Group (x 2, cross-sectional and longitudinal) showed no effect of Group at six months ($p = .94$), at eight months ($p = .36$) and at 10 months ($p = .31$). At C2, the ANOVA also showed no significant effect for Group ($p = .26$, 14, and .13, at 6, 8, and 10 months respectively.

3.3. Conclusion from study 2

The longitudinal study gave results comparable to those of the first study. Whereas at six months, infants often behaved as if they did not expect the handle and the ball to be connected, at 8 and 10-months most of them behaved as if they knew from visual inspection that the ball would come along with the handle. This was confirmed when we presented the infants with the trick, invisible disconnection condition, where handle and ball seemed connected but were only touching. In this condition infants looked more surprised that the ball did not come along with the handle as they grew older. In addition, the less infants seemed to understand the connection between the handle and the ball in the normal condition, the less they seemed surprised that the ball did not come along with the handle in the trick condition.

4. Final discussion

The question asked in this study was: At what age do infants understand that all parts of a composite object move together in an active reach and grasp situation? To reach this stage, infants must be able to take into account the notion of cohesiveness, i.e. the fact that

[1] The cross sectional study was performed at the Laboratoire Psychologie de la Perception in Paris. The longitudinal study was performed in the Faculty of Education and Rehabilitation Sciences in Zagreb.

when one part of a solid object moves, the whole object will also move. Such knowledge has been observed in infants as young as 3-month-old in purely visual studies (e.g. Spelke & Van de Walle, 1993), but has, it seems, never been studied in an active condition, where the infant must use knowledge of cohesiveness to actively retrieve part of an interesting composite object. Furthermore, in other tasks it is known that there may be large differences in the age when a child demonstrably has visual expectations and the age when it is able to actively accomplish a task (Spelke et al., 1992; Berthier et al., 2000).

In two studies, one cross-sectional and the other longitudinal, infants were presented with a composite object made of an attractive ball at the end of a plain handle. We estimated the infant's visual anticipation of the composite object's cohesiveness through looking and manual behavior before grasping, which is a variable previously used for evaluating infants' understanding of object properties (e.g. Barrett, Traupman, & Needham, 2008; Rat-Fischer, O'Reagan, and Fagard, 2014; Ambrosini, Reddy, de Looper, et al., 2013).

We observed a significant change of performance between 6 and 8 months. Whereas 6-month-olds often behaved as if they did not expect the handle and the ball to be connected, most 8- and 10-month-olds' behavior indicated that they knew from visual inspection that the ball would come along with the handle. This was confirmed when we presented the infants with the trick, invisible disconnection condition, where handle and ball seemed connected but were only touching. In this condition older infants looked more surprised that the ball did not come along with the handle than the younger ones. In addition, infants who seemed not to understand the connection between the handle and the ball in the normal condition were also those who were not surprised that the ball did not come along with the handle in the trick condition. This demonstrates that the invisible disconnection condition is a good control for testing understanding of the cohesiveness of the object. The results obtained on 38 infants in a cross-sectional study were replicated in a longitudinal study in which 10 infants were tested at 6, 8 and 10 months.

Thus it seems that infants learn to use the notion of cohesiveness for grasping between six and eight months of age. One could ask, if infants have passive knowledge of cohesiveness already at three months, why our 6-month-old infants in the invisible disconnection condition give the impression of not expecting all parts of an object to move together when they grasp the object themselves?

There may be several reasons why six-month-olds do not look at the ball while grasping the handle, other than not anticipating that grasping the end of the handle may make the interesting part to come along. One reason that we can eliminate is that they did not notice the ball. The ball is very bright and all infants looked at the ball first. Alternately, infants could think the handle was more interesting and therefore captured their attention. Our choice of a very neutral white handle and a very bright attractive ball makes this interpretation unlikely. Note that we had checked before starting the longitudinal study that when handle and ball were placed in front of children, they invariably chose to play with the ball.

One explanation may be that passively looking at a display does not engage as much attention as when action is required. At six months reaching and grasping is a recently acquired skill which requires a lot of attention from the infant. Paying attention to a barely controlled movement, as when action is required, may be enough for the infant to forget what it has previously learned about object properties. This interpretation meets the interpretation often given to explain that infants seem to understand an object concept much earlier when they have to response visually (Spelke & Van de Walle, 1993) than when they have to response manually (Berthier et al., 2000).

The progress between 6 and 8 months may be due, not only to the fact that their grasping skill has matured (Hofsten, 1984; Thelen, 1992), but also to the fact that as their grasping skill develops, infants are given increasingly diversified sets of toys. Many of these toys are composite objects, like rattles, which look like the objects presented here. Infants thus acquire personal experience of grasping one part of an object and seeing the whole object coming along. Stressing the role of action in discovering object affordances and physical laws supports the approach, initiated by Piaget (1963), which is part of the ecological point of view defended by researchers as Gibson (1988) and Lockman (2000). In this view, acting on objects allows the infant to discover their affordances and the physical laws regulating the physical world. It would be interesting to see how 6-month-old or younger infants would behave if they were provided with simulated reaching experiences. These experiences have been shown to encourage reaching behaviors and facilitate action perception (Libertus & Needham, 2010; Skerry, Carey, & Spelke, 2013; Sommerville, Woodward, & Needham, 2005). One could argue, for instance, that when a 3-month-old shows surprise when all parts of an object do not move together (Spelke & Van de Walle, 1993), the infant does not have complete knowledge about the cohesiveness property: pure perceptual detection of irregularity could be involved. Only after themselves acting on composite objects would infants truly understand the notion of cohesiveness applied to real objects.

Finally, an additional factor is the fact that as they become increasingly able to sit and look at the world around them, infants have many opportunities to watch people grasp objects by one part and to observe that the whole object follows (Rochat & Coubet, 1995).

In conclusion, infants involved in an active reaching and grasping situation appear to take into account the fact that all parts of composite objects move together starting between six and eight months of age. It is also around this age that infants are surprised when all parts of a composite object don’t move together when they grasp the object by one part. Our findings provide another demonstration of the difference between passive, purely visual knowledge, and knowledge that can be put to use in an active situation. Here, despite passive knowledge of cohesiveness as observed at three months by, e.g., Spelke & Van de Walle (1993), infants only succeed in the active task between 6 and 8 months.

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Captions

Table 1: Mean level (SD inside brackets) at C1 as a function of age and object

Table 2: First behavior at C1 as a function of age (number of infants)

Figure 1: a/ Straight object, handle to the right (Infants grasps the handle while looking at the ball, level 3); b/ L-shaped object, handle to the left (Infant points to the ball, level 1)

Figure 2: Frequency of each level of performance in each age group at C1 (both objects pooled) at the cross-sectional study

Figure 3: Mean level at C2 as a function of Age, Object, and Trial at the cross-sectional study (the lowest the level, the less surprised infants are)

Figure 4: Percentage of trials with gaze toward the experimenter as a function of age and condition

Figure 5: Percentage of trials with look at the experimenter as a function of age and time of gaze

Figure 6: Frequency of each level of performance at each age at C1 (both objects pooled) at the longitudinal study

Figure 7: Mean level at C2 as a function of Age and Object / Trial at the longitudinal study (the lowest the level, the less surprised infants are)