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ORIGINAL ARTICLE

Petra Hauf · Birgit Elsner · Gisa Aschersleben

The role of action effects in infants' action control

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Abstract In adults, the selection and the planning of actions are influenced by the anticipation of desired action effects. However, the role of action effects for action control in infants is still an unresolved issue. One important prerequisite for infants' action control is that infants are able to relate certain movements to certain effects. To test this assumption, it was investigated how infants' action control is affected by action effects. By applying an imitation paradigm, we studied 12- and 18-month-old infants who first observed an adult experimenter demonstrating a three-step action sequence on a toy bear. In three experimental groups, the second action step, the third action step, or no action step elicited an arbitrary sound as an additional acoustic action effect. It was coded how often each of the target actions was performed by the infant in a subsequent 90-s test phase. As predicted, the frequency of the infant's target action varied depending on which action step elicited the action effect. In both age groups, the target action that was combined with an acoustical effect was not only produced more often but also occurred with lower latency and was in most cases the first target action shown by the infants. These results are interpreted as evidence of the important role of action effects in infants' action control.

Introduction

The role of action effects for action control has been studied for a long time. The idea that adults control their movements by the anticipation of desired effects was already held by psychologists in the 19th century (e.g., James, 1890/1981). Their introspective analyses led them to assume that intentional action requires a goal, i.e., some anticipatory representation of the expected action effects. In the last two decades, these ideas have been revitalized in experimental work on action control, and several approaches agree that the anticipation of action goals plays an important role in the planning, the programming, and the execution of movements (e.g., Jeannerod, 1994; Prinz, 1997; Rosenbaum & Krist, 1996).

Recently, the importance of action goals for action selection and action planning was accented in a theoretical framework called the theory of event coding (Hommel, Müsseler, Aschersleben, & Prinz, 2001). The primary assumption of this approach, which is based on the common coding approach by Prinz (1990, 1997), is that action and perception share common representational resources. Whereas separate coding accounts need to postulate transformations to explain how coordination between the action system and the perceptual system is achieved, the common coding account tells a much simpler story. Event representations that are common to perception and action make transformations between perceptual and motoric information unnecessary. The common coding approach emphasizes the role of action effects, i.e., it is assumed that actions are represented and controlled by their anticipated action effects (the action-effect principle; Prinz, 1997). Empirical support for such an approach comes from rather different domains, for example, from studies on the timing of movements (e.g., Aschersleben & Prinz, 1995; Aschersleben, Stenneken, Cole, & Prinz, 2002; Drewing & Aschersleben, 2003), on compatibility effects (e.g., Elsner & Hommel, 2001; Hommel, 1996; Kunde, 2001; Müsseler & Wühr, 2002), on sequence learning (Zießler & Nattkemper, 2002), and on action perception (Knoblich & Flach, 2001; for an overview see Hommel et al., 2001). Overall, there is ample evidence that action goals are coded in terms of anticipated action effects and

P. Hauf (✉) · B. Elsner · G. Aschersleben
Max Planck Institute for Psychological Research,
Amalienstrasse 33, 80799 Munich, Germany
E-mail: hauf@psy.mpg.de
Tel.: +49-89-38602260

B. Elsner
Psychological Institute, University of Heidelberg,
Heidelberg, Germany

that action effects play an important role both in action acquisition and in action control. While the relevance of action effects has been extensively investigated in adults, the question of whether this principle applies to infants' action perception and production as well, has only recently become a topic of research.

In contrast, there is ample evidence that infants learn contingencies between self-performed movements and the environmental events that follow these movements (for a review, see, Rovee-Collier, 1987). For example, 2- to 5-month-old infants learn the relations between leg kicks and the contingent movements of a mobile (e.g., Rovee & Rovee, 1969; Rovee-Collier & Shyi, 1993). In these studies, infants lie in a crib with a ribbon running between their ankle and an overhead mobile. Within a few minutes, infants recognize the contingency between their foot kicks and the movement of the mobile—their rate of kicking increases dramatically. In further studies, infants learned the relations between leg kicks and the sounds of a rattle (Rochat & Morgan, 1998), or to turn their heads in anticipation of a bottle (Papousek, 1967). Even newborns learn to suck in a certain frequency in order to hear a particular (i.e., their mother's) voice (DeCasper & Fifer, 1980). The main characteristic of this instrumental learning is that the production of the movement is influenced by an interesting event that follows it. Overall, most studies in infant research that are related to the role of action effects are concerned with infants' capacity to learn about contingencies between movements and their consequences. However, almost nothing is known about the role of action effects in an infant's control of actions when the infant already knows about these action-effect relations.

A precondition for the study of action control in infants is that the infants have to be able to differentiate means (movements) from ends (action effects, goals) in their own behavior as well as in the actions performed by other persons. The ability to use a towel as a supporter to obtain an object, or to remove an obstacle to reach an object, has been interpreted as a sign of understanding the differentiation of means and ends (Piaget, 1952; Uzgiris & Hunt, 1975; Willats, 1999). At 9 months, infants differentiate goals from behavioral means in their own actions, and then they start to understand others as intentional agents with goals, attention, and decision-making powers (Csibra, Gergely, Biro, Koos, & Brockbank, 1999; Leslie, 1984). Recent evidence suggests that understanding of goal-directedness already emerges at 6 months and, more importantly in the present context, that action effects play an important role. Jovanovic and colleagues (Jovanovic, 2002; Jovanovic et al., 2003) demonstrated the crucial role of action effects for infants' interpretation of the goal-directedness of other persons' actions. Their habituation study was based on findings by Woodward (1998, 1999), who showed that 6-month-olds do understand grasping an object as a goal-directed action, but do not do so for lowering the back of the hand on an object. Jovanovic et al. (2003) replicated this study with 6-month-olds but added a salient effect to the action shown. As a consequence of this modification, the 6-month-old infants did interpret the back-of-the-hand movement as goal directed, whereas they did not do so in the original study by Woodward (1999). This indicates that even 6-month-old infants use object-directed action effects to specify action goals, and hence action effects are in this sense important for action understanding.

The purpose of the present study was to demonstrate that infants control actions by anticipating their effects when they know about specific action-effect relations. To study the role of action effects in situations in which infants already know about these contingencies, it is important to make sure that several preconditions are fulfilled before the infants are tested. Firstly, the infants have to be able to perform the target actions, i.e., the actions must already be part of their action repertoire. Secondly, as the aim of the present experiment is not to study the acquisition of action-effect contingencies, infants have to be informed about the fact that specific actions lead to interesting effects. A possible way to achieve this is by demonstrating these action-effect relations to the infants prior to a test phase in which the infant itself has the possibility to perform the same actions. One widely used method to investigate action control and action understanding in infants is the imitation paradigm, in which an adult experimenter demonstrates one or several actions on specific objects while the infant watches. Afterwards, the objects are handed over to the child and whether he or she performs the target actions he or she has seen is analyzed. This paradigm has been mainly used to study observational learning, i.e., research has primarily focused on the questions at which particular age children start to acquire behavior by means of imitation, and for how long they remember modeled actions (for a recent overview, see Meltzoff, 2002). One basic result is that, usually, imitation behavior starts around 9 months (e.g., Meltzoff, 1988; Tomasello, 1999). In the present study, the imitation paradigm was applied as an experimental method to inform infants about possible actions and their effects.

An experimenter demonstrated a three-step action sequence to the infants. The second and the third step of that sequence could be performed independently of each other, i.e., they were not causally related. Either the second or the third action step (target action) was followed by a salient action effect. It was manipulated between subjects which step produced an interesting effect (two "effect" groups). Moreover, there was a third group ("no-effect" group), in which none of the modeled action steps produced an effect. If, as expected, action effects play an important role in infants' action control, the behavior in the three groups should differ. The existence of salient action effects should allow the infants in the two effect groups to infer a goal in the model's actions. As a consequence of the action-effect manipulation, we expect that the infants in the effect groups should infer different goals from the model's actions depending on which step was followed by the action effect. The action step that was followed by an effect should be shown more often than the action step that did not produce a salient effect. In addition, if the observation of an action effect during the demonstration phase already leads to the anticipation of this desired action effect, the corresponding action step should be produced with lower latency. Moreover, the order of the target actions should differ in the two effect groups: The action step that was followed by the interesting effect should be shown first. To trace developmental changes within the 2nd year of life, we performed two experiments on different age groups (12- and 18-month-old infants).

Experiment 1

Method

Participants

The final sample consisted of 36 (19 males, 17 females) healthy, full-term 12-month-old infants (mean age: 11 months and 29 days, range: 11 months and 21 days to 12 months and 19 days), who were recruited from public birth records and by word of mouth. All infants scored within their age range in selected tasks of the Bayley Scales of Infant Development (BSID-II, Bayley 1993). Fifteen additional 12-month-olds (8 males, 7 females) were tested but were not included in the final sample because of general inactivity (n = 10), refusal to remain seated (n = 3), or maternal interference (n = 2).

Test environment, apparatus and stimuli

The test room was unfurnished except for the test equipment. The parent and experimenter faced each other across a small (0.8 × 0.8 m) table, with infants on their parents' laps. A camera to the left of the experimenter was focused to include the infant's torso, head, and most of the tabletop. A second camera to the right of the infant and parent was focused to include the hands of the experimenter and the infant, and most of the tabletop as seen from the infant's side of the table.

The objects used during the experiment were a brown teddy bear (height 22 cm), a wooden barrier (length 50 cm, height 11 cm) and two identical looking cylinders (height 5 cm, diameter 5 cm) covered with brown and white felt. One cylinder made a sound when shaken but the other did not. The loudspeaker of a tape recorder was installed behind the wooden barrier, and the experimenter could start the tape recorder with a foot key under the table. During the whole session the bear sat at the barrier. At the beginning of the session one cylinder was positioned on the barrier in front of the bear (see Fig. 1).

Procedure

Infants were tested in our lab at a time of day when they were likely to be alert and playful. Each participant and parent was escorted to a reception room. For approximately 10 min the infant was allowed to explore the room, while the experimenter described the test procedure to the parent. Next, the infant and parent were brought to the test room and the infant was given approximately 2 more minutes to acclimate to that environment. Once the infant seemed comfortable, the experiment began. The experiment consisted of one session that was divided into a demonstration phase and a test phase.

Demonstration phase A three-step-action sequence was demonstrated to each infant. The experimenter took the cylinder off the barrier (1st step), shook it three times (2nd step), and put it back onto the barrier in front of the bear (3rd step). Then, this action sequence was repeated two more times. This stimulus presentation period lasted for 30 s. Each infant was randomly assigned to one of the three groups according to whether he or she was to partake in the "shaking with effect" (n = 12), "returning with effect" (n = 12), or "no effect" (n = 12) demonstration. The three experimental groups differed in the presentation of the acoustical effect:

1. In the "shaking with effect" group, shaking the cylinder produced a snaring sound by means of a mechanism hidden inside the cylinder. When the cylinder was returned to the bear, no sound was heard.
2. In the "returning with effect" group, shaking the cylinder did not produce any sound, but the sound was presented when the cylinder was returned to the bear and replaced on the barrier. The sound was identical to the one presented in the "shaking with effect" group, but it was recorded on tape, and the experimenter started the tape with the foot key under the table as soon as the cylinder reached the barrier in front of the bear. Thus, both effect groups saw the same actions and heard the same sound effect, but in one group the effect appeared after shaking, and in the other group, it appeared after returning.
3. The infants in the "no effect" group saw the action sequence without any acoustical effect.

Test phase The test phase followed immediately after the demonstration phase, and the test procedure was similar for all groups. The experimenter put the test objects within reach of the infant. A 90-s response period was timed, starting when the objects were within the infant's reach. The sound effects were presented in the same way as in the preceding demonstration phase. In the "shaking with effect" group, the cylinder made the sound when the infant shook it; in the "returning with effect" group, the experimenter pressed the foot key to start the tape whenever the infant returned the cylinder onto the barrier in front of the bear; and in the "no effect" group no sound effect occurred at any time.

Data analysis

Each videotaped test phase was scored by an observer, who was blind to the infants' group assignment. In addition, 25% of the test phases were coded by a second independent observer. Interobserver reliability will be given for each experiment separately.

Imitation score and latency to first touch To control if the infants in the three experimental groups were equally able to perform the action sequence, an imitation score was calculated by scoring the presence or absence of the three steps of the demonstrated action sequence (1st step: taking the cylinder; 2nd step: shaking the cylinder; 3rd step: returning the cylinder to the barrier in front of the

Fig. 1 Objects used in the experiments: A brown teddy bear sitting at a wooden barrier with one of the two identical looking cylinders covered with brown-white felt in front of it

bear) with 1 or 0 respectively, and summing the scores for each infant (range = 0–3). Moreover, with the second control variable, the latency to the first touch, we checked whether the experimental set-up was equally interesting for infants in all groups—no matter whether an acoustical effect was presented or not. The latency to the first touch was scored as the time interval that passed between the moment when the objects were within the infant's reach and the moment when the infant touched one of the objects for the first time.

Latency to the first occurrence of the target actions and their order We analyzed two variables to investigate whether the infants' actions were affected by the observed action effects, namely the latency to the first occurrence of the target actions (shaking and returning) shown by the infant, and the order of the target actions. The latencies indicate when, during the 90-s test phase, the infants showed each of the target actions shaking and returning for the first time. If a target action was not performed during the test phase, the value of this variable was set to 90 s because this was the maximum latency that was possible. Most of the latency distributions were rather asymmetrical, therefore, median (Md) latencies and the quartiles (25% and 75% of the distribution) were calculated. In addition to the latencies, the order of the target actions shown by the infant was scored, i.e., for each infant we determined whether shaking was performed before returning or vice versa.

Frequency of target actions To test the prediction that the presentation of an interesting acoustical action effect has a differential impact on the behavior of the infants, the frequencies of the two target actions:

1. Shaking the cylinder
2. Returning the cylinder and replacing it on top of the barrier in front of the bearwere analyzed additionally, i.e., it was coded how often each infant produced each of the two target actions during the 90-s test phase.

Results and discussion

Interobserver reliability was $r = .96$ for the target action shaking and $r = .94$ for returning. The mean imitation scores were 2.6 (SE = .16) for the "shaking with effect" group, 2.4 (SE = .16) for the "returning with effect" group, and 2.0 (SE = .31) for the "no effect" group indicating that infants in all three groups were able to perform the demonstrated actions. A one-way analysis of variance (ANOVA) with the between-subjects factor group revealed no differences between groups ($p > .15$). In more detail, 94% of the 12-month-old infants took the cylinder, 72% of the infants showed the target action shaking, 67% showed the target action returning, and 42% of the infants even performed both target actions (shaking and returning). The latency to the first touch was very low in all experimental groups ("shaking with effect" group: M = 5.2 s, SE = 2.21; "returning with effect" group: M = 4.9 s, SE = 1.97; "no effect" group: M = 7.9 s, SE = 3.61), and did not differ between groups ($p > .20$). The results obtained in these control variables indicate that the presented objects and the applied experimental procedure can be considered suitable for the age group investigated, and that group differences in further analyses were actually caused by the action-effect manipulation.

Latency to the first occurrence of the target action

The median and the quartiles of the latencies to the first occurrence of the target actions shaking and returning in the three experimental groups are shown in Fig. 2. The latency to the first shaking was shorter in the "shaking with effect" group (Md = 18.0 s) than in the "returning with effect" group (Md = 41.0 s) and in the "no effect" group (Md = 60.5 s; Fig. 2a). This pattern of results was confirmed by separate Mann-Whitney U tests indicating a significantly shorter latency to the target action shaking in the "shaking with effect" group (mean rank = 8.92) than in the "returning with effect" group (mean rank = 16.08; U = 29, $p < .006$; one-tailed). The latency to the first shaking was also shorter in the "shaking with effect" group (mean rank = 9.08) than in the "no effect" group (mean rank = 15.92; U = 31,

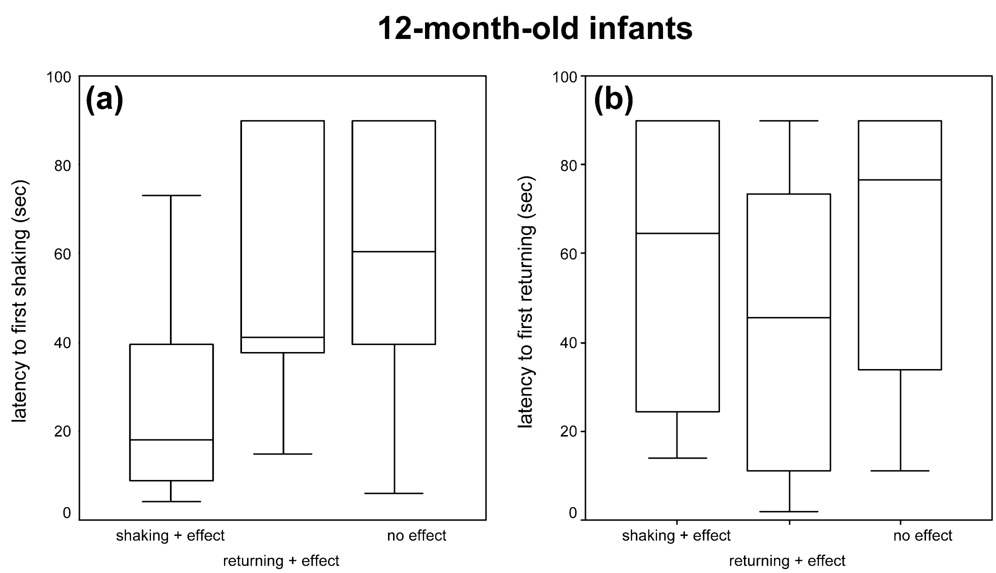

Fig. 2 Latency to the first occurrence of **a** the target action shaking and **b** the target action returning in the three experimental groups: "shaking with effect", "returning with effect", and "no effect" (12-month-old infants, Experiment 1). Each box plot shows the median (*middle line across the box*), the 1st and 3rd quartiles (25% and 75% of the distribution, *lower and upper sides of the box* respectively) and the range (*ends of the line segments*)

$p < .009$; one-tailed). The application of one-tailed tests is justified by the existence of a clear prediction concerning the direction of the difference. Moreover, as expected the latency to the first shaking did not differ between the "returning with effect" group and the "no effect" group ($p > .20$).

The latency to the first returning reveals a similar pattern of results, at least qualitatively. The infants in the "returning with effect" group (Md = 45.5 s) returned the cylinder faster than those in the two other groups ("shaking with effect": Md = 64.5 s; "no effect": Md = 76.5 s; Fig. 3b). The Mann-Whitney U test, however, indicated only a significant difference between the "returning with effect" group (mean rank = 10.13) and the "no effect" group (mean rank = 14.88; U = 44, $p < .05$; one-tailed), but not for the difference between the "returning with effect" group (mean rank = 11.08) and the "shaking with effect" group (mean rank = 13.92; U = 55, $p = .17$; one-tailed). As expected, the latency to the first returning did not differ between the "shaking with effect" group and the "no effect" group ($p > .20$).

Order of the target actions

Beyond this, the order of the target actions indicates which of the two target actions shaking and returning was shown first by each infant. In the "no effect" group, there was no difference between the number of infants showing each of the target actions first (5 infants shook first, 5 infants returned first, and 2 infants did neither but played with the cylinder in another way). In the two effect groups, however, the number of infants showing shaking before returning or returning before shaking differed (Table 1). Nine out of 12 infants in the "shaking with effect" group shook the cylinder first and only then returned it. In the "returning with effect" group 7 out of 12 infants returned the cylinder before shaking it. This pattern of results was confirmed by a 2 × 2 χ^2-test revealing a significant interaction between the order of target actions and the effect groups, $\chi^2(1, N = 24) = 2.73$, $p = .049$ (one-tailed). Thus, the results indicate that the action step that has been followed by an acoustical effect in the demonstration phase is also the first target action performed by the infants during the test phase.

The latency to the first occurrence of the target actions and their order clearly indicate that the infants' actions were affected by the observed action effects. As the action effects were present not only in the demonstration phase but in the test phase as well, the frequency of the target actions during the 90-s test phase were also analyzed.

Frequency of target actions

The mean frequencies of the target actions shaking and returning in the three groups are shown in Fig. 3. Infants in the "shaking with effect" group shook the cylinder more often than both the infants in the "returning with effect" group and those in the "no effect" group, which did not differ (see Fig. 3a). A corresponding χ^2-test revealed a significant difference between groups, $\chi^2(2, N = 167) = 133.74$, $p < .001$. Separate χ^2-tests indicated a significantly higher frequency of the target action shaking in the "shaking with effect" group than in the "returning with effect" group, $\chi^2(1, N = 150) = 69.36$, $p < .001$, or in the "no effect" group, $\chi^2(1, N = 143) = 83.08$, $p < .001$, whereas the frequency of shaking did not differ between the "returning with effect" and the "no effect" group ($p > .20$).

A similar pattern of results was obtained for the frequency of the target action returning. Infants in the "returning with effect" group returned the cylinder more often to the barrier in front of the bear than the infants in the two other groups, which again did not differ

Table 1 Number of 12-month-old infants performing the target action shaking before returning or returning before shaking in the two effect groups

	Shaking before returning	Returning before shaking	Total
"Shaking with effect" group	9	3	12
"Returning with effect" group	5	7	12
Total	14	10	24

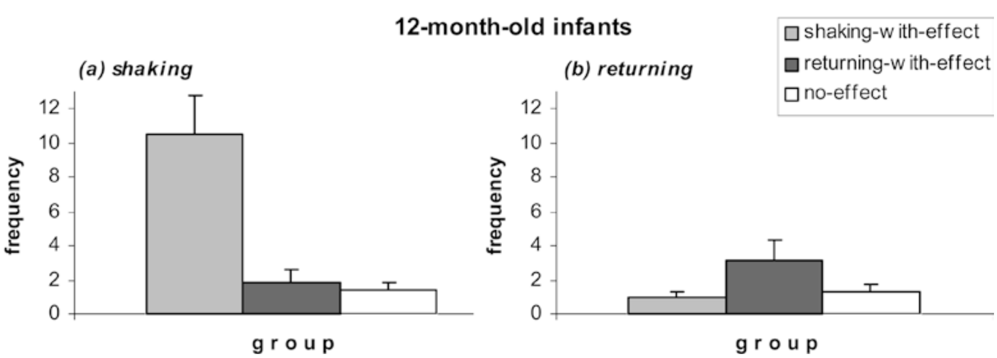

Fig. 3 The mean frequency of **a** the target action shaking and **b** the target action returning in the three experimental groups (12-month-old infants, Experiment 1)

(Fig. 3b). A corresponding χ^2-test yielded a significant difference between groups, χ^2 (2, N = 72) = 27.75, p < .001. This result was confirmed by separate χ^2-tests indicating a significantly higher frequency of the target action returning in the "returning with effect" group than in the "shaking with effect" group, χ^2(1, N = 57) = 19.16, p < .001, or in the "no effect" group, χ^2(1, N = 60) = 15.00, p < .001. The frequency of returning did not differ between the "shaking with effect" group and the "no effect" group (p > .20). At the age of 12 months, the target actions performed by the infants already seemed to be strongly influenced by the effects that follow that action. Target actions that produced an interesting acoustical effect were exhibited significantly more often than target actions without that effect.

Overall, infants aged 12 months not only produced those target actions that were followed by an interesting effect more often but these actions were also performed with a lower latency. Moreover, the action step that had been followed by an effect was shown before the other target action that did not produce an effect. On the basis of both the latency to the first target actions and their order we can reject the alternative explanation that infants learned about the action effect contingencies only in the test phase, in which the effects were also present. Such an account would not be able to explain why the target actions that the infants expect to produce the interesting effect are performed faster and before the other target action. As long as the infant has not performed the corresponding target action at least once, he or she would not know whether it still produces the effect in the test phase. The results indicate that the infant expects that the effect will follow one target action whereas it will not follow the other and therefore uses the effect anticipation for selecting action steps. From this general pattern of results we can conclude that the selection of target actions in 12-month-old infants is strongly influenced by the action effects anticipated by the infants. To further investigate the development of the infants' ability to anticipate action effects and to use knowledge about action effects for their action selection, we conducted a second experiment with 18-month-old infants.

Experiment 2

Method

Participants

The participants were 36 (20 males, 16 females) healthy, full-term 18-month-old infants (mean age = 18 months 3 days, range: 17 months and 17 days to 18 months and 19 days), who were recruited from public birth records and by word of mouth. Sixteen additional 18-month-olds (8 males, 8 females) were tested but were not included in the final sample because of general inactivity (n = 10), refusal to remain seated (n = 4), or maternal interference (n = 2). All infants were normally developed (tested by the Bayley Scales of Infant Development; BSID-II, Bayley 1993).

Test environment, apparatus, stimuli, and procedure

The test environment, apparatus, stimuli, and procedure were identical to those in Experiment 1. Each experimental group consisted of 12 infants.

Results and discussion

Interobserver reliability was r = .96 for the target action shaking and r = .96 for returning. As in Experiment 1, the mean imitation scores did not differ between the experimental groups ("shaking with effect" group: M = 2.8, SE = .12; "returning with effect" group: M = 2.5, SE = .16; "no effect" group: M = 2.6, SE = .2; F(2, 33) = 1.24, p > .20). All 18-month-old infants took the cylinder, 78% of the infants showed the target action shaking, 86% showed the target action returning, and 67% of the infants even performed both target actions (shaking and returning) at least once. To examine age-related differences in the imitation score, the results of Experiments 1 and 2 were analyzed in a 2 × 3 ANOVA with the between-subjects factors age and experimental group. Only the main effect of age was significant, F(1, 66) = 4.05, p < .024, while the other factors failed to reach significance (p > .20). Although the 12-month-olds already performed at least two out of three action steps (M = 2.3, SE = .13), the average imitation score was even higher in the 18-month-olds (M = 2.6, SE = .09).

As in the 12-month-old infants, the latency to the first touch of the objects did not differ between the experimental groups. A one-way ANOVA revealed no significant main effect of group (p > .20). The latencies were again rather low ("shaking with effect" group: M = 5.9 s, SE = 3.88; "returning with effect" group: M = 1.8 s, SE = .71; "no effect" group: M = 5.3 s, SE = 2.70). Thus, the applied experimental procedure was as well suited to the 18-month-olds as it was to the 12-month-old infants.

Latency to the first occurrence of the target action

Again, we analyzed the latency to the first occurrence of the target actions (shaking and returning) and their order. As shown in Fig. 4a the latency to the first shaking was shorter in the "shaking with effect" group than in the "returning with effect" group and in the "no effect" group, which did again not differ ("shaking with effect" group: Md = 9.0 s; "returning with effect" group: Md = 39.5 s; "no effect" group: Md = 39.5 s). Although the latency to the first shaking was numerically lower in the "shaking with effect" group (mean rank = 11.79) than in the "returning with effect" group (mean rank = 13.21), the Mann-Whitney U test revealed no significant difference between these groups (U = 64; p > .20; one-tailed). Similarly, the test of the difference between the "shaking with effect" group (mean rank = 10.38) and the "no effect" group (mean rank = 14.63) only confirmed a trend (U = 47; p = .07; one-tailed). As expected, the latency to the first shaking did not differ between the ‘‘returning with effect’’ group and the ‘‘no effect’’ group (p > .20).

Concerning the latency to the first returning, the infants in the ‘‘returning with effect’’ group returned the cylinder faster than in the two other groups (‘‘returning with effect’’ group: Md = 10.0 s; ‘‘shaking with effect’’ group: Md = 33.5 s; ‘‘no effect’’ group: Md = 23.5 s; Fig. 5b). This pattern of results was partly confirmed by the Mann-Whitney U test revealing a significant difference between the ‘‘returning with effect’’ group (mean rank = 8.83) and the ‘‘shaking with effect’’ group (mean rank = 16.17; U = 28, p = .005; one-tailed). However, there was only a trend in the comparison of the ‘‘returning with effect’’ group (mean rank = 10.38) and the ‘‘no effect’’ group (mean rank = 14.63; U = 47; p = .07; one-tailed). As expected, the latency to the first returning did not differ between the ‘‘shaking with effect’’ group and the ‘‘no effect’’ group (p > .20).

Although—due to large variability in the data—not every single expected comparison reaches significance, the general pattern of results in the latencies to the first target actions corresponds to the predictions. Moreover, this is supported by the huge differences in variability. The interquartile range of the latency to first shaking in the ‘‘shaking with effect’’ group (31 s) only amounts to about one-third of the interquartile ranges in the two other groups (89 s in the ‘‘returning with effect group’’ and 82 s in the ‘‘no effect group’’). This effect was even stronger for the latency to first returning (interquartile ranges: in the ‘‘returning with effect’’ group it was 9 s compared with 39 s in the ‘‘shaking with effect’’ group and 51 s in the ‘‘no effect’’ group; see Fig. 4). Overall, the target action, which the infant expected to produce an interesting effect, was not only shown faster on average but also within a smaller time range. For example, 75% of the infants in the ‘‘returning with effect’’ group showed the first returning within the first 18 s whereas in the other two groups, 75% of the infants returned within the first 60 s.

Order of the target actions

Additionally, the order of the first occurrence of the two target actions shaking and returning was analyzed. In the ‘‘no effect’’ group, the number of infants showing each of the target actions first was almost identical (5 infants shook first, 6 infants returned first, and 1 infant

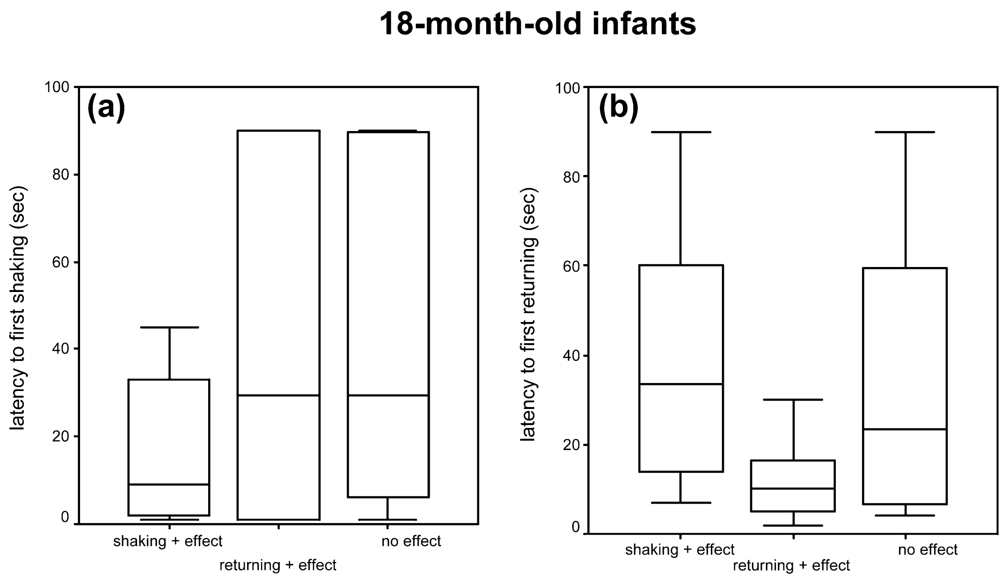

Fig. 4 Latency to the first occurrence of **a** the target action shaking and **b** the target action returning in the three experimental groups (18-month-old infants, Experiment 2). Each box plot shows the median (*middle line across the box*), the 1st and 3rd quartiles (25% and 75% of the distribution, *lower and upper sides of the box* respectively) and the range (*ends of the line segments*)

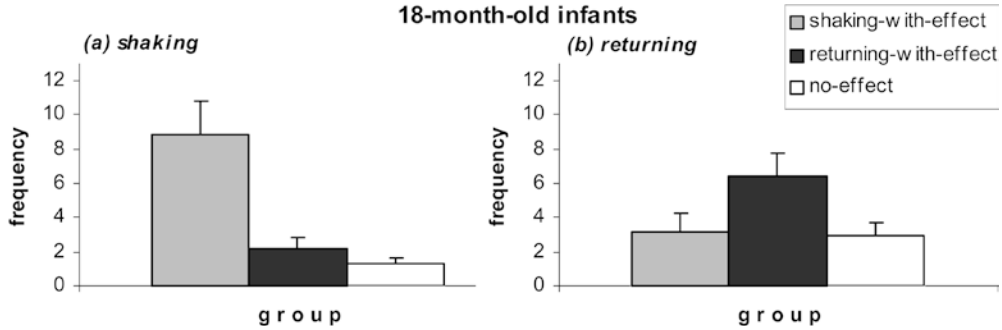

Fig. 5 The mean frequency of **a** the target action shaking and **b** the target action returning in the three experimental groups (18-month-old infants, Experiment 2)

did neither, but played with the cylinder in another way). In the two effect groups, however, the number of infants showing shaking before returning or returning before shaking differed (Table 2). In the "shaking with effect" group, 11 out of 12 infants shook first and only then returned the cylinder. In the "returning with effect" group 7 out of 12 infants returned the cylinder first before performing the target action shaking. A 2×2 χ^2-test yielded a significant interaction between the order of target actions and the experimental groups, $\chi^2(1, N = 24) = 6.75$, $p = .005$ (one-tailed), i.e., the action step that was followed by an acoustical effect in the demonstration phase was the first target action performed by most of the 18-month-old infants.

Frequency of target actions

The analysis of the frequencies of the target actions performed shows the expected pattern of results (Fig. 5). The 18-month-olds in the "shaking with effect" group shook the cylinder more often than the infants in both the "returning with effect" group and the "no effect" group, which did not differ (Fig. 5a). A corresponding χ^2-test revealed a significant difference between groups, $\chi^2(2, N = 148) = 98.28$, $p < .001$. Separate χ^2-tests indicated a significantly higher frequency of the target action shaking in the "shaking with effect" group than in the "returning with effect" group, $\chi^2(1, N = 131) = 50.08$, $p < .001$, and in the "no effect" group, $\chi^2(1, N = 123) = 64.40$, $p < .001$, whereas the frequency of shaking did not differ between the "returning with effect" and the "no effect" group ($p > .20$).

A similar pattern of results was obtained for the frequency of the target action returning. The 18-month-olds in the "returning with effect" group returned the cylinder to the barrier more often than the infants in the two other groups, which again did not differ (Fig. 5b). A χ^2-test on the frequency of the target action returning yielded a significant difference between groups, $\chi^2(2, N = 152) = 22.16$, $p < .001$. This result was confirmed by separate χ^2-tests indicating a significantly higher frequency of returning in the "returning with effect" group than in the "shaking with effect" group, $\chi^2(1, N = 116) = 13.79$, $p < .001$, and in the "no effect" group, $\chi^2(1, N = 114) = 15.47$, $p < .001$, whereas the frequency of returning did not differ between the "shaking with effect" group and the "no effect" group ($p > .20$). The results of the present experiment show that 18-month-old infants' behavior varied due to the effects that were produced by the demonstrated target actions. Those target actions that were followed by an interesting acoustical effect were exhibited more often than target actions without this effect.

Table 2 Number of 18-month-old infants performing the target action shaking before returning or returning before shaking in the two effect groups

	Shaking before returning	Returning before shaking	Total
"Shaking with effect" group	11	1	12
"Returning with effect" group	5	7	12
Total	16	8	24

Overall, the results of the 18-month-old infants resemble those obtained in the 12-month-olds in many respects. They also produced those target actions that were followed by an interesting effect more often and with a lower latency, and the corresponding action step was shown before the other target action that did not produce an effect. Thus, the presentation of action effects led to a similar action pattern for both age groups, although, however, the overall performance, measured by the imitation score, was somewhat lower in the 12-month-olds, indicating developmental differences in the 2nd year of life.

General discussion

The aim of the present study was to demonstrate that infants control actions by anticipating their effects when they know about specific action-effect relations. In a three-step action sequence demonstrated by an experimenter, the second or the third action step was followed by a salient action effect. The results show that 12-month-old infants (Experiment 1) as well as 18-month-old infants (Experiment 2) produced those target actions that were followed by an acoustical effect more often than target actions that were presented without an effect. Thus, infants in the "shaking with effect" group who saw an experimenter shaking the cylinder and producing an acoustical effect during demonstration, showed the target action shaking with higher frequency, whereas infants in the "returning with effect" group who saw the experimenter producing the acoustical effect while returning the cylinder to the barrier in front of the bear, showed the target action returning more often than infants who saw the corresponding target action without the salient action effect.

These results support our hypothesis that infants in their 2nd year of life control their actions by anticipating desired action effects. Additionally, infants in the three experimental groups were equally able to perform the three action steps. The imitation score, which counts the presence or absence of an action step in each infant, indicated that there were no differences between experimental groups, neither in the 12-month-olds nor in the 18-month-olds. Imitation scores were rather high in both age groups (2.3 and 2.6, respectively) compared with those reported in the literature (about 1.0 in 12-month-olds and between 1.5 and 2.0 in 18-month-olds; e.g., Barr, Dowden, & Hayne, 1996; Barr & Hayne, 1996; Eskritt, Donalds, & Muir, 1998). However, most studies used a deferred imitation paradigm with a delay of several hours or days between demonstration and test phase, which is one possible explanation for the reduced imitation score. More important in the present context is the fact that we had chosen an action sequence with action steps that were already in the action repertoire of the infants.

Moreover, infants in the three experimental groups were equally interested in performing the actions. A first indicator was already the imitation score, which did not differ between groups. However, as an interesting action effect was only presented in two out of the three experimental groups it might well be that infants in these two groups were more interested and more motivated to perform the actions. If this were the case, it should show up in a reduced latency to the first touch. Again, this variable did not differ between experimental groups in the 12-month-olds or in the 18-month-olds. In both age groups, latency to the first touch was very short, only a few seconds, indicating that the infants were highly motivated to play with the objects. Thus, we can be sure that the group differences observed for the other dependent variables were not caused by a general difference in motivation or in the ability to perform the action steps in the three groups.

As described above, the results concerning the frequencies of the performed action steps seem to indicate that the target actions produced by the infants are strongly influenced by the effects they expect to produce with these actions. However, it may be argued that as a consequence of the action effects being present in the test phase as well as in the demonstration phase, the result pattern observed in the frequencies had been caused by instrumental learning during the test phase, i.e., infants learned the contingencies between the actions they performed and the effects that followed these actions whereby the action effects served as reinforcers. The fact that even very young infants are able to learn contingencies between self-performed movements and the environmental events following these movements had already been demonstrated in the 1960s (e.g., Papousek, 1967; Rovee & Rovee, 1969). But we can clearly rule out this alternative explanation on the basis of our results concerning the latency to the first occurrence of the target actions (shaking and returning). As predicted, infants' actions were affected above all by the anticipation of the desired action effects. The experimental groups showed differences in the latency to the first occurrence of the target actions (shaking and returning) and in the order of these target actions. In more detail, the latency to the first occurrence of the target action that the infants anticipate would produce an effect was shorter than the latency to the first occurrence of the other target action. Moreover, more infants performed the target action that they anticipated would produce an effect before the other target action, i.e., there was also a difference in the number of infants showing one or the other order. The alternative explanation, however, that infants had learned the action-effect contingencies in the test phase, did not predict any group differences for the latencies or for the order of the target actions. For both age groups, the latency to the first target action and their order differed between experimental groups and the group differences are as predicted.

Another possibility to test the alternative explanation would have been the introduction of control conditions, in which the action effect was presented in the demonstration phase only, whereas no effect was present in the test phase. The advantage of such control conditions is that the possibility of instrumental learning taking place during the test phase is excluded. However, the introduction of these control conditions would cause other problems. Above all we would introduce confounding factors that make it impossible to clearly interpret the results in an unambiguous way. Infants in these control groups would have been exposed to a situation in which the action-effect contingencies changed from the demonstration phase to the test phase. In the demonstration phase, they would first learn that, for example, shaking the cylinder causes an interesting acoustical effect. In the test phase, however, they would experience that the same target action does not produce this effect any more. First evidence indicates that 15- and 18-month-old infants, but not 12-month-olds, distinguish situations in which they produced the same action effects they had seen in a demonstration phase from situations in which the action-effect contingencies had changed (Elsner & Aschersleben, in press). They showed significantly fewer target actions when the action-effect contingencies had changed than when they remained the same. Concerning the present study, the factor whether or not infants are able to detect a change in the contingencies would have influenced our results. Moreover, our additional dependent variables, the latency to the first target action and their order are not influenced by the presence or absence of action effects in the test phase and, thus, these results would remain the same.

Overall, the results confirm that 12- and 18-month-old infants control actions by anticipating their effects when they know about specific action-effect relations. Although the main effects had been found in both age groups, there are nevertheless differences between the age groups. First of all, imitation scores in the 18-month-olds were significantly higher than the imitation scores in the 12-month-old infants. This result replicates the developmental differences that have been reported in the literature (e.g., Barr et al., 1996). Moreover, age-related differences also showed up in the frequencies. Whereas the total frequency of shaking and returning is about the same in the 18-month-olds (148 and 152 respectively), in the 12-month-olds the frequency for returning is clearly reduced (167 and 72, respectively). A 2×2 χ^2-test yielded a significant interaction between the target actions and the age groups, $\chi^2(1, N = 539) = 23.11$, $p < .001$. Thus, although the 12-month-olds are, in principle, able to produce that target action (67% of the infants showed the target action returning at least once) they did not show it as often as the target action shaking. One possible reason for this difference is the fact that returning is motorically more demanding than shaking and, thus, infants in this age group are a bit more hesitant to perform that action. Moreover, at the age of 12 months infants only start to give back a new toy (whereas 9-month-olds do not do that at all; e.g., Bayley, 1993; Elsner & Aschersleben, 2003), even if the return produces an acoustical effect. This observation is supported by the latency to the first target action. In the 12-month-olds, the pattern of results for the latency to the first shaking is more evident and less variable than the result pattern for the latency to the first returning. However, these age-related differences do not belittle the general finding that infants already control their actions by anticipating the effects at the age of 12 months. It only demonstrates that the experimenter has to be very careful in the choice of the action steps to be performed.

The results obtained in the present study can be taken as evidence of a goal representation that is defined in terms of action effects. In both effect groups a certain effect was produced. In the ''shaking with effect'' group, shaking is recognized to be the main goal, whereas in the ''returning with effect'' group the act of returning is more prominent. Since each goal was linked to a specific and unambiguous effect, it might be reasoned that this effect is crucial for a complete and unequivocal goal representation. This goal representation can be used not only for action control but also for action understanding. The important role of action effects in the interpretation of other persons' actions has recently been demonstrated by Jovanovic et al. (2003). By using a habituation-dishabituation paradigm they were able to show that 6-month-old infants are able to interpret other persons' actions as goal directed if they are followed by a salient action effect—even if the action seen is an unfamiliar one. This indicates that object-directed action effects can serve to specify action goals in infants and in this sense it is important for action understanding.

Another important role of action effects is that they help to parse action sequences and to infer the intentions of other persons. Action analysis is central to inferring intentions and at natural breakpoints the links between action and intention are especially strong (Baldwin & Baird, 1999). For example, it has been shown that 10-month-old infants parse observed sequences of continuous everyday actions along intention boundaries (Baldwin, Baird, Saylor, & Clark, 2001). This supports the notion that infants are sensitive to the occurrence of action effects that mark the completion of intentions. Overall, the present study suggests action effects as an essential component of the construction of goal representations. This means in turn that action goals defined in terms of action effects are rather important in infants' understanding of intentional action. Zacks, Tversky, and Iyer (2001) argued that the interaction and the conjunction of an object with an action enables interpretations of events as being goal directed, purposeful, and intentional. Accordingly, we do not assume that action effects exclusively guide the understanding of intentional action. But focusing on action effects helps infants to facilitate the acquisition of relevant knowledge about the world. Moreover, the age-related results of the study imply that there is an age-specificity for goal representations in the sense that certain goals are more relevant than others depending on the age of the infant.

The aim of the present study was to analyze the role of action effects in infants' action control. Based on the common coding approach (Hommel et al., 2001; Prinz, 1990, 1997) we assumed that action goals are coded in terms of anticipated action effects and that action effects play an important role in action control. While the relevance of action effects has been extensively investigated in adults, the present study is one of the few recent studies to investigate the question of whether this principle applies to infants' action perception and production as well. For action perception, the dominant role of action effects has recently been demonstrated by Jovanovic et al. (2003). However, the results of the present study extend these findings in that they demonstrate that infants in their 2nd year of life use the anticipation of action effects to control their own actions.

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