

Action–effect anticipation in infant action control

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Abstract There is increasing evidence that action effects play a crucial role in action understanding and action control not only in adults but also in infants. Most of the research in infants focused on the learning of action–effect contingencies or how action effects help infants to infer goals in other persons' actions. In contrast, the present research aimed at demonstrating that infants control their own actions by action–effect anticipation once they know about specific action–effect relations. About 7 and 9-month olds observed an experimenter demonstrating two actions that differed regarding the action–effect assignment. Either a red-button press or a blue-button press or no button press elicited interesting acoustical and visual effects. The 9-month olds produced the effect action at first, with shorter latency and longer duration sustaining a direct impact of action–effect anticipation on action control. In 7-month olds the differences due to action–effect manipulation were less profound indicating developmental changes at this age.

Introduction

The study of action control has a long history in adult research that can be traced back to the nineteenth century. The ideomotor theory, which can be seen as the first cognitive approach to action control, assumes that goal representations, which are in the view of this approach functional anticipations of action effects play a crucial role in action control (James, 1890; Lotze, 1852). Nowadays, various approaches agree that adults control their movements by the anticipation of desired effects and that this anticipation plays an important role in the planning, the programming, and the execution of movements (e.g., Greenwald, 1970; Jeannerod, 1994; Prinz, 1997; Rosenbaum & Krist, 1996). In particular, the Common Coding approach (Hommel, Müsseler, Aschersleben, & Prinz, 2001; Prinz, 1990, 1997) emphasizes the crucial role of action effects for both action perception and action control and underlines consequently the fact that actions are represented and controlled by their anticipated action effects (the action–effect principle; Prinz, 1997). Even though the relevance of action effects has been extensively investigated in adults (for overviews see Hommel et al., 2001; Nattkemper & Ziessler, 2004) the question of whether this principle applies to infant action control as well, has only recently become a topic of research.

Interestingly, it is well known 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, very young infants learn the relation between leg kicks and the contingent movements of a mobile (e.g., Rovee & Rovee, 1969; Rovee-Collier & Shyi, 1993), between leg kicks and the sounds of a rattle (Rochat & Morgan,

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1998) or between a certain frequency of sucking and hearing a particular (i.e., their mother's) voice (DeCasper & Fifer, 1980). Nevertheless, researchers focused only in recent times on the role of action–effect relations in infants' online action control, that is, whether they use the anticipation of action effects in situations when they already know about action–effect contingencies (as has been demonstrated in adults in various different tasks like the timing of movements, stimulus–response compatibility, or bimanual coordination, see e.g., Aschersleben, 2002; Hommel, 1996; Mechsner, Kerzel, Knoblich, & Prinz, 2001).

When 12-month-old infants copy target actions they take into account whether their actions would bring out an effect or not (Carpenter, Nagell, & Tomasello, 1998). Fifteen-month olds (but not 9 and 12-month olds) detect whether their own actions led to the same effects as the model's actions (Elsner & Aschersleben, 2003) demonstrating that infants at this age are able to use specific action–effect relations to control their own actions. Furthermore, Hauf, Elsner, and Aschersleben (2004) showed that 12-month olds produced an action step that was followed by an interesting action effect not only more often but also with shorter latency than other action steps, which were not combined with such an effect, indicating that infants anticipated the effect when producing an action step for the first time (see also Klein, Hauf, & Aschersleben, 2006).

Further support for the important role of action effects in infant action control comes from recent studies on infant action understanding. Hofer, Hauf, and Aschersleben (2006a) added a salient action effect to an unfamiliar back-of-hand movement. This led 6-month-old infants to interpret this movement as goal-directed, which was not the case in the original study without such an action effect (Woodward, 1999) indicating that infants use action effects to specify action goals (for similar findings with 6–10-month olds, see Hofer, Hohenberger, Hauf, & Aschersleben, 2006b; Kiraly, Jovanovic, Prinz, Aschersleben, & Gergely, 2003). Furthermore, Baldwin, Baird, Saylor, and Clark (2001) could show that action effects help 10-month-old infants to parse continuous sequences of everyday intentional actions and to infer goals of other persons. These results suggest that already in their first year of life infants benefit from action–effect relations while perceiving other person's actions.

Taken together, there is first evidence that action–effect relations play a crucial role in both infant action understanding and action control. Nevertheless, it has to be pointed out that the importance of action effects in action understanding could be demonstrated already in 6–10-month olds, whereas an influence on action

production was not yet shown before 12 months of age. On one hand side, it seems reasonable as detecting action–effect relations in other persons' actions is straightforward, whereas watching such action–effect relations and transferring this knowledge into own actions is probably much more demanding. This requires not only observational learning but also the transfer from others' actions to own actions. Moreover, action production is constrained by motor development, especially in the first year of life. On the other hand, research on infant imitation indicates that imitative learning develops at the age of 6–9 months (Barr, Dowden, & Hayne, 1996; Meltzoff, 1988). Thus, young infants are at least able to produce previously observed action steps.

Accordingly, the present study aimed at demonstrating the role of action effects in action production in the first year of life. Simple target actions were demonstrated (button press), which were followed by multiple effects (sound and light). By means of such an undemanding paradigm even young infants might be able to detect action–effect relations and to use this information for controlling their own actions. To trace developmental changes two experiments were performed on different age groups (9 and 7-month olds).

Experiment 1

The purpose of the first experiment was to demonstrate that 9-month-old infants control their own actions by anticipating the effects of these actions once they know about specific action–effect relations. To make sure that infants are able to perform the target action, this action must already be a part of their action repertoire. In the present study, an experimenter demonstrated two undemanding actions: a red-button press and a blue-button press. Each button press was demonstrated three times to each infant. It was manipulated between subjects whether the red-button press or the blue-button press was followed by salient action effects (sound and light). As a control, there was a no-effect group, in which neither button press produced any effect at any time. If, as expected, action effects are important for infants' action control, the behavior of the three groups in the subsequent test phase should differ. The existence of salient action effects should allow the infants in the two effect groups to infer different goals of the demonstrated actions and, thus, infants' own subsequent behavior should differ in line with this manipulation. The action that was followed by effects should be shown at first, with shorter latency and with longer duration than the action that did not elicit salient effects.

Methods

Participants

Participants were 36 healthy term infants ($M = 9$ months 3 days; range = 8 months 18 days to 9 months 23 days). Another 12 infants took part but their data were eliminated from further analyses because of general inactivity, refusal to remain seated and parental interference. Infants were randomly assigned to the red-with-effect condition, the blue-with-effect condition, and the no-effect condition. Within each condition, half of the infants received a demonstration starting with a red-button press and half with a blue-button press.

Apparatus

The apparatus consisted of a black box ($7 \times 39 \times 15$ cm) with a red and a blue button (6 cm diameter each) sticking out of two holes in the lid of the box. Inside the buttons were small light bulbs and sound speakers (see Fig. 1). Due to the condition either the red button, the blue button or none of them was lighting up and producing a hooting sound by pressing. The parent and experimenter faced each other across a small table, with infants on their parents' laps. Two cameras were focused to include the experimenter's hands, the button box, and the most of the tabletop as seen from the infant's side of the table during the demonstration phase and to include the infant's head, torso, hands and most of the tabletop during the test phase.

Procedure

The experiment was divided into a demonstration phase conducted by an experimenter and a test phase, in which it was the infant's turn to explore the button

box. Each infant received a red-with-effect, or a blue-with-effect, or a no-effect demonstration. In either case the infant saw an experimenter pressing one button three times and then pressing the other button three times. According to the condition either the red button press, the blue button press, or none of the button presses elicited an interesting acoustical and visual effect. After this demonstration the test phase followed immediately. The experimenter slid the button box across the table and for a 90-s response period the infant was allowed to explore the box. The action-effect assignment in the test phase was identical to the preceding demonstration phase.

Each videotaped demonstration and test phase was scored separately by an observer, who was blind to the infants' group assignment. In addition, 25% of the infants were coded by a second independent observer. Interobserver agreement was high in all conditions ($0.95 < r < 0.99$). During the demonstration phase, it was coded how long the infant was attentively watching the red-button press and the blue-button press, respectively. During the test phase, it was coded, which button infants pressed at first and the latency to the first press of each button. Additionally, the total duration of button press was coded.

Results and discussion

Preliminary analyses revealed no significant interaction involving condition, order of demonstration, and sex; the data were therefore collapsed in subsequent analyses. To test the prediction that the presentation of an interesting acoustical and visual action effect has a differential impact on the behavior of infants, the infants' first button press, the latency to the first press of each button, and the total duration of pressing either

Fig. 1 Button box used for the different conditions. In the red-with-effect condition only a red-button press elicited an acoustical and visual effect, but not the blue-button press. In the blue-with-effect condition a red-button press elicited no effects, whereas a blue-button press did, and in the no-effect condition neither a red-button press nor a blue-button press elicited any effects

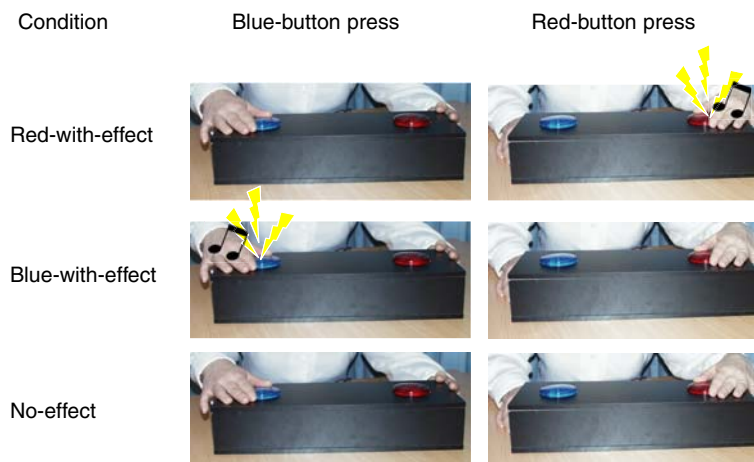
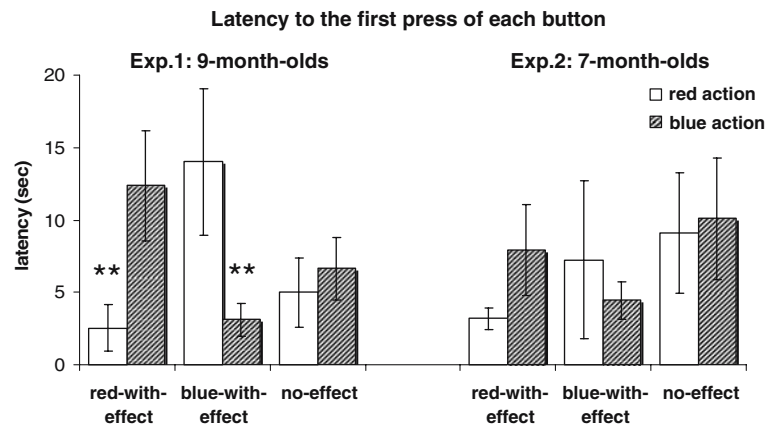


Fig. 2 Mean latency to the first button press in the red-with-effect, the blue-with-effect, and the no-effect condition for Exp.1 (9 months) and Exp.2 (7 months). Error bars indicate standard error and (double asterisks) depict significant differences



one or the other button was analyzed. The time during which infants pressed both buttons simultaneously was subtracted from the total duration of button press.

In the no-effect condition, an equal number of infants started with pressing the red button or the blue button, respectively. In the two effect conditions, however, the number of infants that started with the effect button ($n = 19$) was significantly higher than the number of infants that pressed the non-effect button at first ($n = 5$; $P = 0.007$; sign test). This pattern of results was confirmed by a 2×2 χ^2 -test revealing a significant interaction between the first button press and the effect conditions, $\chi^2(1, N = 24) = 8.71$, $P = 0.003$. Thus, the results indicate that the button press that has been followed by an acoustical effect in the demonstration phase was also the first button that infants pressed during the subsequent test phase.

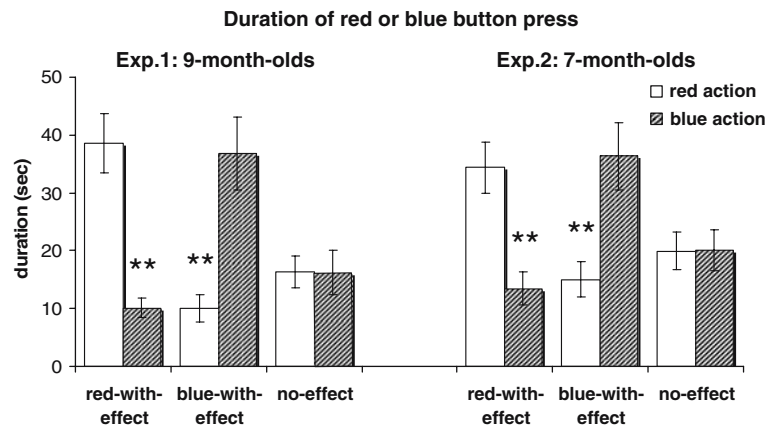
In order to underline this result, the latency to the first press of each button was analyzed by a 3×2 analysis of variance (ANOVA) with condition (red-with-effect, blue-with-effect, no-effect) as the between-subjects factor and button press (red-button press, blue-button press) as the within-subject factor. The analysis revealed no significant main effects ($P > 0.613$), but a significant condition \times button press interaction, $F(2,33) = 6.10$, $P = 0.006$, indicating that infant's first button press was modulated by the previous demonstration (see Fig. 2). In the red-with-effect condition infants generated a red-button press with shorter latency ($M = 2.54$ s, $SE = 1.49$) than a blue-button press ($M = 12.37$ s, $SE = 3.79$), $t(11) = 2.692$, $P = 0.010$ (one-tailed). Similarly, infants in the blue-with-effect condition pressed the blue button with shorter latency ($M = 3.11$ s, $SE = 1.15$) compared to the red button ($M = 14.02$ s, $SE = 5.07$), $t(11) = 1.979$, $P = 0.037$ (one-tailed). No difference in latency was observed in the no-effect condition (red-button press: $M = 5.00$ s, $SE = 2.41$; blue-button press: $M = 6.63$ s, $SE = 2.18$; $t(11) = 0.516$, $P = 0.616$).

Infants' duration of the respective button press was analyzed by a 3×2 ANOVA with condition (red-with-effect, blue-with-effect, no-effect) as the between-subjects factor and button press (red-button press, blue-button press) as the within-subject factor. The analysis of the duration revealed no significant main effect of button press ($P = 0.865$), but a significant main effect of condition, $F(2,33) = 3.38$, $P = 0.046$. Separated t -tests specified a significantly shorter duration of button press in the no-effect condition than in the red-with-effect condition, $t(22) = 2.748$, $P = 0.012$, or in the blue-with-effect condition, $t(22) = 2.180$, $P = 0.040$, whereas the duration of button press did not differ between the two effect conditions ($P = 0.802$). A significant condition \times button press interaction, $F(2,33) = 21.04$, $P < 0.001$ identified that infants' button press behavior was modulated by the applied condition. Planned comparisons indicated that infants in the red-with-effect condition pressed the red button longer ($M = 61.93$ s, $SE = 4.64$) than the blue one ($M = 33.43$ s, $SE = 6.26$), $t(11) = 4.920$, $P < 0.001$. Likewise, infants in the blue-with-effect condition pressed the blue button longer ($M = 63.47$ s, $SE = 5.32$) than the red one ($M = 36.66$ s, $SE = 7.19$), $t(11) = 3.180$, $P = 0.001$. No difference in duration was observed in the no-effect condition (red button: $M = 36.71$ s, $SE = 5.04$; blue button: $M = 36.62$ s, $SE = 7.27$; $t(11) = 0.019$, $P = 0.985$) (see Fig. 3)¹.

Looking time in the demonstration phase was analyzed to control whether infants watched the button press with effects more attentively than the button press without effects. No difference between infants' looking time was observed between conditions ($P = 0.181$). Furthermore, a 3×2 ANOVA with condition (red-with-effect, blue-with-effect, no-effect) as

¹ The test sessions were also scored and analyzed with respect to the frequency of each button press. In both experiments, the pattern of results was identical to the pattern of results obtained for the duration of button press.

Fig. 3 Mean duration of red-button press and blue-button press in the red-with-effect, the blue-with-effect, and the no-effect condition for Exp.1 (9 months) and Exp.2 (7 months). Error bars indicate standard error and (double asterisks) depict significant differences



between-subjects factor and button press (red-button press, blue-button press) as within-subject factor revealed only a significant main effect of button press, $F(1,33) = 58.294$, $P < 0.001$, but neither an effect of condition ($P = 0.237$) nor a condition \times button press interaction ($P = 0.172$). Infants preferred to watch a red-button press but this preference was not modulated by the factor condition, thus, it was independent of whether this button press elicited effects or not.

Finally, we analyzed the latency to the first touch of the button box as an indicator for the general motivation of the infants to explore the box. This latency was very low in all conditions (red-with-effect: $M = 2.37$ s, $SE = 1.58$; blue-with-effect: $M = 0.69$ s, $SE = 0.29$; no-effect: $M = 1.29$ s, $SE = 0.48$) and did not differ between groups ($P = 0.442$). This indicates that the presented object and the target action can be considered suitable for 9-month olds, and that the observed differences in button-press behavior can be traced back to the action–effect manipulation and were not caused by a general difference in motivation or in the ability to perform the target action.

At the age of 9 months, infants' actions control seemed to be strongly influenced by the demonstrated action–effect relations. The button press that elicited an interesting acoustical and visual effect (sound and light) was exhibited at first, faster, and with a longer duration than the button press without these effects. Especially the first button press and the latency to the first button press indicates that infants learned about the action–effect relations already while watching the demonstration and that they used this information to differentially control their own subsequent button-press behavior.

Experiment 2

To further investigate the development of the infants' ability to use the knowledge about action

effects for their own action selection, the second experiment was conducted with even younger infants.

Method

Participants

Participants were 36 healthy term infants ($M = 7$ months 3 days; range = 6 months 16 days to 7 months 15 days). Another 11 infants took part but their data were eliminated from further analyses, because of general inactivity, technical problems, and parental interference.

Apparatus and procedure

The apparatus and procedure were identical to those already described in [Experiment 1](#). Again each experimental group consisted of 12 infants.

Results and discussion

In the no-effect condition, an equal number of infants started with pressing the red and blue button, respectively. The same results occurred in the two effect conditions. Twelve infants started with pressing the effect button and 12 infants pressed the no-effect button at first. This was confirmed by an analysis of the latency to the first button press of each button. A 3×2 ANOVA with condition (red-with-effect, blue-with-effect, no-effect) as the between-subjects factor and button press (red-button press, blue-button press) as the within-subject factor revealed neither significant main effects nor a significant interaction (all P s > 0.425). Nevertheless, infants' latency to the first button press illustrated numerical differences pointing

in the same direction as the significant results of the 9-month-old infants (see Fig. 2). Infants in the red-with-effect condition generated a red-button press with a slightly shorter latency ($M = 3.18\text{s}$, $SE = 0.73$) than a blue-button press ($M = 7.94\text{s}$, $SE = 3.15$). In the same way, infants in the blue-with-effect condition pressed the blue-button with a little shorter latency ($M = 4.45\text{s}$, $SE = 1.30$) compared to the red button ($M = 7.25\text{s}$, $SE = 5.45$). This was not the case in the no-effect condition where infants pressed equally fast both buttons (red-button press: $M = 9.09\text{s}$, $SE = 4.16$; blue-button press: $M = 10.10\text{s}$, $SE = 4.18$).

Infants' duration of their red- and blue-button press was analyzed by a 3×2 ANOVA with condition (red-with-effect, blue-with-effect, no-effect) as between-subjects factor and button press (red-button press, blue-button press) as within-subject factor. The analysis of the duration revealed no significant main effects ($P > 0.055$), but a significant condition \times button press interaction, $F(2,33) = 9.873$, $P < 0.001$ (see Fig. 3). Planned comparisons indicate that infants in the red-with-effect condition pressed the red button longer ($M = 34.40\text{s}$, $SE = 4.45$) than the blue one ($M = 13.48\text{s}$, $SE = 2.88$), $t(11) = 3.304$, $P = 0.004$ (one-tailed), and infants in the blue-with-effect condition generated longer blue-button presses ($M = 36.35\text{s}$, $SE = 5.76$) compared to their red-button presses ($M = 15.01\text{s}$, $SE = 3.04$), $t(11) = 2.827$, $P = 0.008$ (one-tailed). This modulation in infants' button-press behavior did not occur in the no-effect condition (red-button press: $M = 19.19\text{s}$, $SE = 3.23$; blue-button press: $M = 20.15\text{s}$, $SE = 3.57$; $t(11) = 0.154$, $P = 0.880$).

Again these differences were not caused by differential attention during the demonstration phase; total amount of looking time did not differ between the three conditions ($P = 0.828$). An additional 3×2 ANOVA with condition (red-with-effect, blue-with-effect, no-effect) as between-subjects factor and button press (red-button press, blue-button press) as within-subject factor revealed neither significant main effects nor a significant interaction (all P s > 0.114). These results confirmed that the 7-month-old infants watched equally attentive the demonstration of the red-button press and the blue-button press in all conditions. In addition, they were highly motivated and able to perform the target action in all conditions as indicated by the latency to the first object touch (red-with-effect: $M = 0.88\text{s}$, $SE = 0.12$; blue-with-effect: $M = 0.51\text{s}$, $SE = 0.13$; no-effect: $M = 0.69\text{s}$, $SE = 0.15$) that did not differ between conditions ($P = 0.140$).

Overall, the results of the 7-month-olds resemble those obtained in the 9-month-old infants in some respects. Even though they didn't produce those

actions that were followed by interesting effects at first, they did it with lower latency (at least numerically) and for longer durations. Thus, the presentation of action effects led to similar action pattern for both age groups, although, however, the differences due to the action-effect manipulation were less profound in the 7-month-olds, indicating developmental changes between 7 and 9 months of age.

General discussion

The present study provides first evidence that already infants in the first year of life use the anticipation of action effects to control their own actions once they know about specific action-effect relations. Infants at the age of 7 and 9 months were exploring the relation between a self-performed button press and the environmental outcome (sound and light) as indicated by a higher duration of the corresponding actions. More importantly, 9-month-old infants were not only detecting action-effect relations while observing another person's demonstration but they also transferred this knowledge into their own action control and, thus, expected their own actions to be effective as well. This was demonstrated by pressing the corresponding button at first and with a shorter latency. In contrast, the 7-month-olds pressed both buttons equally often at first and did not yet show significant differences in latencies.

It is important to note that the action (button press) chosen to study action-effect anticipation in infants had already been in the action repertoire of the 9 and the 7-month-old infants and that infants in all conditions were equally interested in performing these actions. Moreover, the duration of the target action was clearly modulated by the action-effect placement; the button that elicited the effects was pressed for a longer amount of time in both age groups. However, based on the duration of target action alone it is not possible to separate observational learning during the demonstration phase from instrumental learning during the test phase as action effects were available in both experimental phases. Nevertheless, it is clear that infants benefited from the action-effect relations. They were highly motivated and interested to press the buttons supporting that both the target action (button press) as well as the action effects (sound and light) were suitable to both age groups—an important precondition for the investigation of action-effect anticipation in infants.

But do we have evidence for action-effect anticipation? As already pointed out, even very young infants

are able to learn action–effect relations by doing (cf. Rovee-Collier, 1987; Rochat & Morgan, 1998). Accordingly, we have to assume that instrumental learning took place during the test phase of the present study as well – but only after the first button press. Before the first button press, infants did not know whether their own action would elicit the desired effects as well or not. Thus, the first button press and the related latency can be taken as an important marker for action–effect anticipation as this latency could not be explained in terms of instrumental learning. In fact, 9-month-old infants showed differences in latencies depending on the action–effect manipulation. They pressed the button that they had observed in combination with an effect (and, thus, expected to produce an interesting effect again) at first and significantly faster than the other button. This was not the case in 7-month-old infants. Although 7-month olds were able to perform the target actions and the effects were interesting to them as demonstrated by their button-press duration they showed no clear signs of effect anticipation. Infants at this age have been shown to understand action–effect relations while observing other persons' actions (Hofer et al., 2006a, b). But they seem not yet to be able to transfer this knowledge about action–effect contingencies into their own action production. Possible reasons may be that infants at this age focus more on either action observation or action production. They seem to be less sophisticated in linking both aspects of action control. Evidence for such an explanation derives from different research areas. Imitation studies have demonstrated that 6-month olds need twice as many demonstration trials to achieve the same imitation level as 9-month olds (Barr et al., 1996). Furthermore, studies on agentive experience have shown that the observation of actions performed by others was influenced by previous action production in 9-month olds, but not in 7-month olds (Hauf, Aschersleben, & Prinz, 2006), pointing toward important developmental changes between 7 and 9 months of age.

The present results demonstrate action–effect anticipation in 9-month-old infants whereas in the literature the impact of known action–effect relations on action control was not shown before 12 months of age (Carpenter et al., 1998; Elsner & Aschersleben, 2003; Hauf et al., 2004). One reason might be that the target actions and/or the action–effect relations used in these studies were too complex for younger infants. For example, in the study by Elsner and Aschersleben (2003) a novel object was introduced to the infants that allowed two target actions to be performed (pressing a plastic ring down or pulling it toward the infant) and two effects to be obtained (either producing a sound or

a light effect). Results indicated that 9-month olds did not learn the action–effect relations by observation and even though 12-month olds benefited from observing the model, they did not yet understand the specific action–effect relations indicating that the demonstrated action–effect relations were too difficult for the age groups investigated. This interpretation is supported by Hauf et al. (2004) who demonstrated action–effect anticipation in 12-month-old infants with the target action “shaking” an object but not with the target action “returning” this object to a toy bear, indicating that the two target actions were differentially challenging for the infants investigated. In the present study rather simple actions (button presses) were used, which differed only with regard to the action–effect placement (red or blue button) leading to a strong inflection of action production by previously demonstrated action–effect relations already at the age of 9 months.

Taken together, the findings of the present experiments impressively showed that action–effect anticipation plays an important role in infant action control already during the first year of life, which broadens the theoretical significance of the ideomotor theory and the action–effect principle (Prinz, Aschersleben, & Koch, 2006). The present research offers a promising approach for understanding how infants acquire knowledge about action–effect relations, and how this knowledge influences their own subsequent actions. Finally, it supports the assumption that action–effect knowledge may be the basis for the production and understanding of goal-directed action.

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