Supporting Information

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SI Data

1.1. Analysis of Habituation Trials. An initial exploratory analysis tested whether the proportion of looking to efficient vs. inefficient test trials was related to age, sex, counterbalancing order, or whether habituation was reached. No effects of these variables were found in any of the experiments, so the reported analyses collapse across these variables. We also compared habituation rates and overall attention during the habituation phase across experiments. Habituation criterion was defined as three consecutive trials on which looking time was less than half the average of the first three trials (subjects were included in subsequent analyses regardless of whether they habituated). There were no differences across the five experiments in the average number of trials to habituation [$F(4,111) = 0.250$, $P = 0.909$], and a comparable number of subjects habituated in each condition. A repeated-measures ANOVA comparing looking time for the first and last three habituation trials (Fig. S1) revealed a main effect of temporal position [first three vs. last three trials, $F(1,107) = 13.575$, $P = 0.0004$], and no interaction with experiment [$F(4,107) = 0.377$, $P = 0.824$]. Furthermore, there was no effect of experiment on overall duration of looking during the habituation phase [$F(4,107) = 0.829$, $P = 0.509$].

1.2. Analysis of Raw Looking Time. Preliminary analyses revealed an effect of test trial position [$F(1,111)$, $= 5.700$, $P = 0.019$] across the five experiments, with duration of looking decreasing across successive test trials. To avoid underweighting the later test events relative to earlier ones, we calculated the proportion of looking to the inefficient action within each test pair and averaged across the three test pairs for our main analyses. However, we also compared the raw looking time to the two test trial types across experiments (Fig. S2). For experiments 1 to 3, a mixed-design ANOVA revealed a significant trial type (efficient vs. inefficient) × training condition (effective, ineffective, or no training) interaction [$F(2,57) = 3.586$, $P = 0.034$]. Infants in the effective action condition looked longer at the inefficient actions [$t(19) = 1.871$, $P = 0.038$, one-tailed], and no reliable effect was observed in the ineffective action condition [$t(19) = -1.902$, $P = 0.073$] or the no-training condition [$t(19) = -1.416$, $P = 0.173$]. There was a significant difference between the effective action condition and each of these control conditions [$F(1,38) = 7.078$, $P = 0.011$; $F(1,38) = 4.950$, $P = 0.032$]. In experiments 4 and 5, infants who viewed the constrained action habituation again looked longer at the inefficient actions [$t(25) = 2.853$, $P = 0.009$], replicating the results of experiment 1. Infants in the control condition (unconstrained action) showed no effect of efficiency at test [$t(25) = 0.123$, $P = 0.903$]. The interaction between trial type (efficient vs. inefficient) and habituation condition (constrained action vs. unconstrained action) was not significant when analyzing raw looking time [$F(1,50) = 2.776$, $P = 0.102$].

SI Procedures

2.1. Participants. Recruitment for experiments 1 and 2 was conducted simultaneously, and subjects were randomly assigned to one of the two training conditions. Subjects were subsequently recruited for experiment 3. Subjects were recruited from a database of households in the greater Cambridge, MA, area that had expressed interest in participating in cognitive development research. Recruitment letters were sent to households from ethnically and socially diverse communities; however, the diversity of the sample was not assessed. All methods were approved for use with human subjects by the institutional review board at Harvard University. Paternal consent was obtained before the study via a written consent form. A total of 60 infants successfully participated in these three experiments ($n = 20$ in each), and an additional 54 infants were tested but not included in the analyses as a result of excessive fussiness during the training phase ($n = 2$) or the looking time task ($n = 35$), inattentiveness ($n = 8$), online coding error ($n = 2$), experimenter error ($n = 4$), or parental interference ($n = 3$).

Recruitment was similarly conducted simultaneously for experiments 4 and 5, and subjects were randomly assigned to one of two habituation conditions. Given the size of the effects in experiments 1 to 3, we chose to recruit a slightly larger sample in experiments 4 and 5 ($n = 26$ in each) to ensure sufficient power. An additional 34 infants were tested, but not included in the analyses as a result of excessive fussiness during the training phase ($n = 3$) or the looking time task ($n = 22$), equipment failure ($n = 3$), online coding error ($n = 2$), experimenter error ($n = 1$), or parental interference ($n = 3$). Although these retention rates are low, comparable rates are found in studies that used similar paradigms with this age group (ref. 1, 2; the steps taken to maximize retention are detailed in section 2.4).

2.2. Training Procedure. Infants were first given an opportunity to freely interact with the training objects. However, if, after 45 s, a subject had not engaged with either object, the experimenter placed each object into contact with the subject's hand. If a subject in the effective action condition made contact with an object but disengaged attention from it for more than 3 s, the experimenter removed the object from the mittened hand and placed it on the table. If a subject pushed an object away, the experimented replaced the object within the infant's reach.

2.3. Looking Time Coding Procedure. Subjects sat in an infant seat 1.5 m from the screen, and caregivers were seated behind the subject to ensure that they did not bias looking behavior. Subjects' gaze was monitored and recorded on video for offline coding. The experimenter presenting the materials was seated in an enclosure out of view from the infant. This experimenter was not blind to the training condition, but was blind to the video stimuli being presented (which trials were efficient vs. inefficient). An experimenter in an adjacent room, blind both to training condition and to the video stimuli being presented, monitored attention to the stimuli by using XHAB software. Each trial was ended when subjects looked away from the stimulus for 2 s consecutively, or if they looked for a cumulative 45 s. Video recordings of looking behavior were then coded offline by an experimenter blind to condition. A total of 25% of the test trial data were double-coded by a second experimenter, also blind to condition, and there was a high correlation between these two coders ($R^2 = 0.90$).

2.4. Procedural Differences Between Experiments 1 and 2 and Experiments 3 to 5. Several changes were made to the procedure for experiments 3 to 5 based on observations from the first two studies. For the training phase, we altered the surface on which we presented the objects to the infant. We noticed that infants' arms could slide off the table, and that they occasionally required assistance in replacing their arms on the table surface. To avoid discomfort for the infant and to remove the need for assistance from the experimenter, we used a modified table in experiments 4 and 5. We cut a small (21 cm^2) opening into a large board and

seated the child within this opening such that they were fully surrounded by a smooth surface on three sides. This also eliminated the possibility that infants gained experience navigating their reaches around the edge of the table surface.

To improve retention rate and facilitate smooth presentation of the displays, we also altered the "attention grabber" used to regain attention at the start of every trial. In experiments 1 and 2, attention was reengaged with an auditory cue at the beginning of the video display. This cue was yoked to the onset of the stimulus, meaning that the cue could not be repeated without repeating presentation of the display. In experiments 3 to 5, infants' attention was gained with an auditory and visual cue (a salient geometric object appearing at the center of the screen), and this cue could be presented repeatedly until the infant was attending to the screen. This facilitated the presentation of the stimuli, and reduced the need to solicit attention verbally.

1. Sommerville JA, Woodward AL, Needham A (2005) Action experience alters 3-month old infants' perception of others' actions. *Cognition* 96(1):B1–B11.

2. Gerson SA, Woodward AL (2013) Learning from their own actions: the Unique effect of producing actions on infants' action understanding. *Child Dev*, 10.1111/cdev.12115.

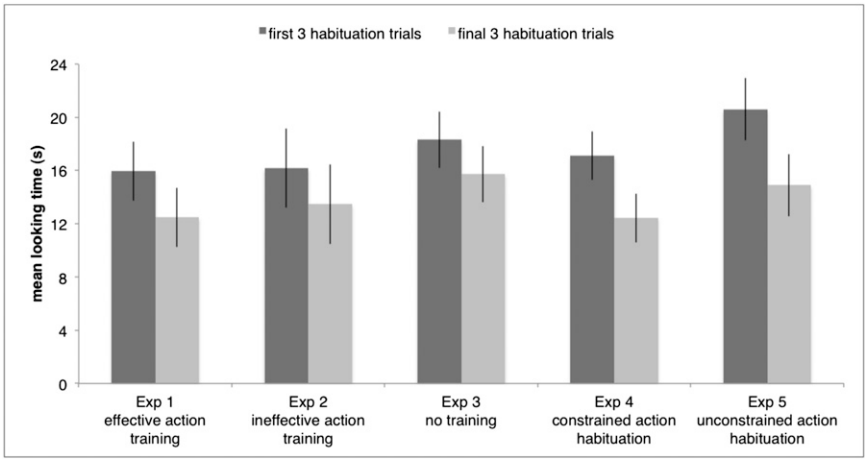

Fig. S1. Duration of looking to first and last three habituation trials for experiments 1 to 5 (n = 112). Error bars reflect ±1 SEM (within-subject).

Fig. S2. Duration of looking to inefficient vs. efficient test trials for experiments 1 to 5 (n = 112). Error bars reflect ±1 SEM (within-subject).