Do infants really expect others to act efficiently?

A critical test of the rationality principle

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Abstract

Recent experiments suggest that infants' expectations about agents' actions are guided by a principle of rationality: in particular, infants expect agents to pursue their goals *efficiently*, expending as little effort as possible. However, these experiments have all presented infants with infrequent or odd actions, leaving the results open to alternative interpretations and making it difficult to determine whether infants possess a general expectation of efficiency. Here we devised a critical test of the rationality principle that did not involve infrequent or odd actions. In two experiments, 16-month-olds watched events in which an agent faced two identical goal objects; although both objects could be reached by typical, everyday actions, one object was physically (Experiment 1) or mentally (Experiment 2) more accessible than the other. In both experiments, infants expected the agent to select the more accessible object, providing new evidence that infants possess a general and robust expectation of efficiency.

As adults, our expectations about others' actions are guided by a principle of *rationality*: all other things being equal, we expect agents to act rationally—indeed, this is what makes it possible for us to predict their actions (e.g., Dennett, 1987; Fodor, 1987). Do infants also expect agents to act rationally? Beginning with the seminal efforts of Csibra, Gergely, and their colleagues, a great deal of research has focused on infants' sensitivity to one corollary of the rationality principle, *efficiency*: agents should expend as little effort as possible to achieve their goals (e.g., Csibra, Bíró, Koós, & Gergely, 2003; Csibra, Gergely, Bíró, Koós, & Brockbank, 1999; Gergely, Bekkering, & Király, 2002; Gergely, Nádasdy, Csibra, & Bíró, 1995). To date, two types of tasks have provided evidence that infants expect agents to act efficiently.

In one type of task, infants first watch an agent pursue a goal in a scene; next, physical constraints in the scene are altered, and the task examines whether infants expect the agent to adopt the most efficient means possible to achieve the goal (e.g., Gergely et al., 1995; Kamewari, Kato, Kanda, Ishiguro, & Hiraki, 2005; Phillips & Wellman, 2005; Sodian, Schoeppner, & Metz, 2004). To illustrate, Gergely et al. (1995) habituated 12-month-olds to an event in which agent-A jumped over an obstacle to reach agent-B. In the test phase, the obstacle was removed and infants saw two test events. In the inefficient-action event, agent-A approached agent-B using the same jumping action as in the habituation trials. In the efficient-action event, agent-A approached agent-B by travelling in a straight line. Infants looked reliably longer at the inefficient-action event, suggesting that they expected agent-A to approach agent-B in a straight line, as this was now the most efficient path available.

The other type of task involves showing infants an apparently inefficient action and examining whether they can generate an explanation for this action (e.g., Csibra et al., 2003; Gergely et al., 2002; Schwier, van Maanen, Carpenter, & Tomasello, 2006; Zmyj, Daum, &

Aschersleben, 2009). For instance, Csibra et al. (2003) tested whether 12-month-olds could infer the presence of an obstacle to justify an inefficient action. Infants viewed a habituation event similar to that in Gergely et al. (1995) except that a large screen occluded the middle portion of agent-A's path. In the test events, the screen was removed to reveal either an obstacle or empty space, and agent-A again approached agent-B via a jumping action. Infants looked reliably longer at the no-obstacle event, suggesting that they (a) made sense of agent-A's inefficient jumping motion in the habituation phase by positing an obstacle behind the screen, and therefore (b) detected a violation in the test phase when the screen was removed to reveal a clear path.

One important limitation of the two types of tasks described above is that *infants always see inefficient actions*, leaving the results open to two alternative interpretations. The *no-efficiency* interpretation stems from recent proposals that early expectations about agents' actions are statistical rather than teleological or mentalistic in nature (e.g., Paulus et al., 2011a; Paulus, Hunnius, Vissers, & Bekkering, 2011b; Perner, 2010; Ruffman, Taumoepeau, & Perkins, in press). In this view, infants gather a wealth of statistical information about the actions agents produce in daily life. Because inefficient actions are *infrequent*, they elicit novelty responses; thus, infants look longer when an agent jumps for no apparent reason, not because this action is inefficient, but because it deviates from learned statistical regularities. A second alternative, the *weak-efficiency* interpretation, derives from proposals that infants engage in mentalistic reasoning and attempt to generate explanations for any *odd* actions they observe, whether inefficient, inconsistent, or novel (e.g., Chow & Poulin-Dubois, 2009; Hoicka & Wang, 2011; Koenig & Echols, 2003; Luo, 2010; Onishi, Baillargeon, & Leslie, 2007). Such proposals leave open the possibility that infants consider efficiency constraints when prompted by unusual actions, but not in more usual situations involving typical, everyday actions.

One way to address these alternative interpretations is to create a critical test of the efficiency principle that does not involve infrequent or odd actions. Here we devised a novel type of task in which an agent faced two identical goal objects; although both objects could be reached by typical, everyday actions, one object was *physically* (Experiment 1) or *mentally* (Experiment 2) more accessible than the other. At issue was whether infants would expect the agent to select the more accessible object, in accordance with the efficiency principle, and hence would look longer when the agent selected the less accessible object instead.

We reasoned that positive findings in both experiments would provide new evidence that infants possess an expectation of efficiency, would demonstrate that infants apply this expectation even in tasks without infrequent or odd actions, and would indicate that infants consider mental as well as physical effort when evaluating the efficiency of agents' actions.

Experiment 1

In the *identical-objects* condition of Experiment 1, 16-month-olds watched live events in which a female experimenter selected one of two identical objects (Fig. 1). Infants received four familiarization trials and one test trial; each trial had an initial and a final phase. At the start of each familiarization trial, a female agent sat centered behind two toy pigs; each pig stood in front of a long support (first two trials) or in front of a short platform resting on a long support (last two trials). During the (17-s) initial phase of each trial, an experimenter's gloved hand reached into the apparatus through a window in the right wall, placed each pig on its support or platform, and then left. Next, the agent grasped the handle of the right or left support (counterbalanced across trials), pulled it, grasped the pig, and paused. During the final phase, infants watched this paused scene until the trial ended. The familiarization trials thus served to establish that the agent wanted a pig and did not care which pig she obtained.

At the start of the test trial, a transparent cover (with a wooden knob at the top) and a transparent container stood centered on the right and left supports, respectively. During the initial (24-s) phase of the trial, the gloved hand placed the right pig on its support and covered it with the transparent cover; next, the hand moved the container to the front end of the left support, placed the pig in the container, and left. The agent then grasped the handle of the support with the pig under the cover (more-effortful event) or the handle of the support with the pig in the container (less-effortful event) and paused, without pulling the support. During the final phase, infants watched this paused scene until the trial ended. If infants (a) attributed to the agent the goal of obtaining a pig (e.g., Spaepen & Spelke, 2007), (b) determined that retrieving the pig in the container would require fewer actions (pull support, grasp pig) than retrieving the pig under the cover (pull support, lift cover, grasp pig), and (c) expected the agent to choose the pig that could be obtained with less effort, then they should expect her to grasp the support with the container. Infants should thus look reliably longer if shown the more- as opposed to the less-effortful event.

Additional infants were tested in two other conditions. The *different-objects* condition served to rule out low-level interpretations (e.g., infants simply preferred the support with the cover). In this condition, one of the pigs was replaced by a toy apple. In the familiarization trials, the agent pulled the right or left support (counterbalanced across trials) to retrieve the apple. In the test trial, the apple was placed under the cover (Fig. 2). If infants realized that the agent preferred the apple, then they should expect her to grasp the support with the cover: although the apple was physically less accessible to the agent, she should make this additional effort to obtain her preferred object. Infants should thus look reliably longer if shown the less- as opposed to the more-effortful event.

Finally, the *modified-identical-objects* condition served to confirm the results of the identical-objects condition and to ensure that infants were not simply expecting the agent to choose whichever pig *they* could more easily obtain (Fig. 2). This condition was identical to the identical-objects condition except that the test events differed. For half the infants (*two-cover* group), the container was replaced with a transparent cover that was rotated so that its opening faced the agent. For the other infants (*two-container* group), two transparent containers were used, one with its opening rotated toward the agent, and one with its opening rotated toward the infant. In both groups, fewer steps were required for the agent—but not the infant—to retrieve the pig from the cover or container whose opening faced the agent (less-effortful event) than the other pig (more-effortful event). If infants were reasoning about which pig was easier for the *agent* to obtain, they should look reliably longer if shown the more- as opposed to the less-effortful event, as in the identical-objects condition.

Method

Participants

Participants were 48 healthy full-term infants, 24 male (15 months, 18 days to 16 months, 13 days, M = 16 months, 0 day). Another 14 infants were excluded because they were fussy (5), active (2), or distracted (1), looked the maximum time allowed in the test trial (4), or had test looking times over 3 standard deviations from the condition mean (2). Equal numbers of infants were randomly assigned to each combination of condition (identical-, different-, or modified-identical-objects) and test event (more- or less-effortful).

Apparatus and Stimuli

The apparatus consisted of a brightly lit display booth (201 cm high X 102 cm wide X 57 cm deep) with a large opening (46 cm X 95 cm) in its front wall; between trials, a supervisor

lowered a curtain in front of this opening. Inside the apparatus, the back and side walls were white, and the floor was covered with pastel adhesive paper.

The agent wore a blue shirt and sat behind a window (63.5 cm X 42 cm) in the back wall of the apparatus; a screen behind the agent hid the testing room. The experimenter wore a silver glove on her right hand and sat behind a window (51 cm X 38 cm and filled with a fringed curtain) in the right wall of the apparatus. A metronome beat softly to help the agent and experimenter adhere to the events' second-by-second scripts.

Stimuli included two purple pigs (each 6.5 cm X 7 cm X 8 cm at the largest points) decorated with flowers; an apple (7 cm X 7 cm X 7 cm) made of red foam; two long yellow supports (each 0.5 cm X 12 cm X 30 cm, with a handle 9.5 cm X 12 cm X 0.5 cm); two short green platforms (each 3.5 cm X 10.5 cm X 10.5 cm); and two transparent covers and containers (each 10 cm X 10 cm X 10 cm).

During each testing session, a camera captured an image of the events, and another camera captured an image of the infant. The two images were combined, projected onto a television set located behind the apparatus, and monitored by the supervisor to confirm that the events followed the prescribed scripts. Recorded sessions were also checked offline for accuracy.

Procedure

Infants sat on a parent's lap centered in front of the apparatus; parents were instructed to remain silent and close their eyes during the test trial. Each infant's looking behavior was monitored by two naive observers hidden on either side of the apparatus; looking times during the initial and final phases of each trial were computed separately using the primary observer's responses. Interobserver agreement during the final phases of the trials averaged 94% per trial per infant.

Infants were highly attentive during the initial phases of the familiarization and test trials; across conditions, they looked, on average, for 98% of each initial phase. The final phase of each trial ended when the infant (a) looked away for 2 (familiarization) or 1 (test) consecutive seconds after having looked for at least 5 (familiarization) or 10 (test) cumulative seconds or (b) looked for a maximum of 40 (familiarization) or 30 (test) cumulative seconds (criteria were established through pilot work and used for all conditions).

Preliminary analyses revealed no differences between the two-cover and two-container groups of the modified-identical-objects condition, and no significant interaction of condition and event with infant's sex; the data were therefore collapsed across these factors.

Results and Discussion

Infants' looking times during the final phase of the test trial (Fig. 3) were subjected to an analysis of variance (ANOVA) with condition (identical-objects, different-objects, or modified-identical-objects) and event (more- or less-effortful) as between-subjects factors. The analysis yielded a significant main effect of event, $F(1, 42) = 4.30$, $p = .044$, and a Condition × Event interaction, $F(2, 42) = 9.90$, $p < .001$ (no such interaction was found in an identical analysis of the averaged familiarization data, $F(2, 42) < 1$). Planned comparisons revealed that, as predicted, infants in the identical-objects condition looked reliably longer if shown the more-effortful event ($M = 19.7$, $SD = 5.8$) as opposed to the less-effortful event ($M = 13.7$, $SD = 2.0$), $F(1, 42) = 8.69$, $p = .005$, Cohen's $d = 1.39$; infants in the different-objects condition looked reliably longer if shown the less-effortful event ($M = 18.1$, $SD = 4.1$) as opposed to the more-effortful event ($M = 13.1$, $SD = 2.8$), $F(1, 42) = 5.91$, $p = .019$, $d = 1.42$; and infants in the modified-identical-objects condition looked reliably longer if shown the more-effortful event ($M = 17.9$, $SD = 6.1$) as opposed to the less-effortful event ($M = 11.5$, $SD = 1.2$), $F(1, 42) = 9.49$, $p = .004$, $d = 1.44$.

Infants in the identical-objects condition expected the agent to select the pig in the container, which could be retrieved with fewer actions, and thus less effort, than the pig under the cover. In forming this expectation, infants considered which pig was physically more accessible to the agent rather than to themselves: similar results were obtained in the modified-identical-objects condition, even though the relative accessibility of the two pigs differed for the agent and the infant. Finally, the positive results in these two conditions are unlikely to reflect low-level factors: in the different-objects condition, infants expected the agent to reach for the less accessible but preferred apple. Together, these results indicate that 16-month-olds consider efficiency in physical effort when determining which of two identical objects an agent is likely to select, even when not prompted by infrequent or odd actions.

Experiment 2

In Experiment 2, we asked whether 16-month-olds would consider efficiency in *mental* effort when determining which of two identical objects an agent would choose. If one object was placed under a transparent cover and the other object was placed under an opaque cover, would infants view the visible object as mentally more accessible (i.e., easier to attend to or keep in mind) than the hidden object, even though similar actions were required to obtain either object?

Infants in the *identical-objects* condition received four familiarization trials and one test trial. At the start of each familiarization trial, a female agent sat centered behind two identical toy pigs; each pig stood in front of a placemat (first two trials) or shallow container (last two trials) (Fig. 4). During the (16-s) initial phase of each trial, a gloved hand placed each pig on its placemat or inside its container and then left. The agent then grasped the right or left pig (counterbalanced across trials) and paused. During the final phase, infants watched this paused scene until the trial ended. In the test trial, an opaque and a transparent cover (each with a

wooden knob at the top) stood behind the right and left pigs, respectively. A small screen lay flat on the apparatus floor, centered in front of the left pig. After infants looked at the scene for three seconds, the screen was rotated upwards to hide the pig. During the ensuing initial (15-s) phase of the trial, the hand covered each pig with its cover and then left; infants could see the top portion of the transparent cover above the screen. Next, the agent grasped the knob of the opaque cover (more-effortful event) or the transparent cover (less-effortful event) and paused. During the final phase, infants watched this paused scene until the trial ended. If infants (a) attributed to the agent the goal of obtaining a pig, (b) kept track of the fact that the pig under the transparent cover was visible to the *agent*, even though the screen prevented *them* from seeing it (e.g., Moll & Tomasello, 2004), (c) determined that, for the agent, the pig visible under the transparent cover was mentally more accessible than the pig hidden under the opaque cover, and (d) expected the agent to choose the pig that could be obtained with less effort, then they should expect her to reach for the transparent cover. Infants should thus look reliably longer if shown the more- as opposed to the less-effortful event.

Additional infants were tested in a *different-objects* condition, to rule out low-level interpretations (e.g., infants simply preferred the opaque cover). In this condition, one of the pigs was replaced with an apple. The agent reached for the apple in all four familiarization trials (side was counterbalanced), and the apple was placed under the opaque cover in the test trial. If infants realized that the agent preferred the apple, then they should expect her to reach for the opaque cover: although the apple was mentally less accessible to the agent, she should make this additional effort to obtain her preferred object. Infants should thus look reliably longer if shown the less- as opposed to the more-effortful event.

Method

Participants

Participants were 32 healthy full-term infants, 16 male and 16 female (15 months, 18 days to 17 months, 5 days, *M* = 15 months, 29 days). Another 7 infants were excluded because they were fussy (2) or inattentive (1), looked the maximum time allowed in the test trial (2), or had test looking times over 3 standard deviations from the condition mean (2). Equal numbers of infants were randomly assigned to each combination of condition (identical- or different-objects) and test event (more- or less-effortful).

Apparatus and Stimuli

The apparatus and stimuli in Experiment 2 were identical to those in Experiment 1 except that stimuli also included two yellow placemats (each 0.5 cm X 10.5 cm X 10.5 cm), two green containers (each 3.5 cm X 10.5 cm X 10.5 cm), a transparent and a beige cover (each 12.5 cm X 12.5 cm X 13 cm), and a green screen (9 cm X 16 cm) mounted on a rod that protruded through the right wall of the apparatus and could be rotated, out of sight, by the experimenter.

Procedure

The procedure in Experiment 2 was identical to that in Experiment 1, except that the test trial ended when the infant (a) looked away for 0.5 consecutive seconds after having looked for at least 5 cumulative seconds or (b) looked for a maximum of 25 cumulative seconds (the final phase of the test events was visually less interesting than in Experiment 1, because both pigs were hidden from the infants' view). Infants were highly attentive during the initial phases of the familiarization and test trials; across conditions, they looked, on average, for 97% of each initial phase. Interobserver agreement during the final phases of the trials averaged 94% per trial per infant. Preliminary analyses revealed no significant interaction of condition and event with infant's sex; the data was therefore collapsed across sex.

Results and Discussion

Infants' looking times during the final phase of the test trial (Fig. 3) were subjected to an ANOVA with condition (identical- or different-objects) and event (more- or less-effortful) as between-subjects factors. The analysis yielded only a significant Condition × Event interaction, $F(1, 28) = 16.23$, $p < .001$ (no such interaction was found in an identical analysis of the averaged familiarization data, $F(1, 28) < 1$). Planned comparisons revealed that, as predicted, infants in the identical-objects condition looked reliably longer if shown the more-effortful event ($M = 14.1$, $SD = 5.4$) as opposed to the less-effortful event ($M = 8.2$, $SD = 2.9$), $F(1, 28) = 7.40$, $p = .011$, $d = 1.37$; and infants in the different-objects condition looked reliably longer if shown the less-effortful event ($M = 15.8$, $SD = 4.9$) as opposed to the more-effortful event ($M = 9.3$, $SD = 3.8$), $F(1, 28) = 8.86$, $p = .006$, $d = 1.48$.

Infants in the identical-objects condition expected the agent to reach for the pig under the transparent cover: they realized that, because this pig was visible to her, it could be retrieved with less mental effort than the other, hidden pig. Importantly, infants' expectation was based on what the agent could see, rather than on what they could see, as neither pig was visible to them. These results are unlikely to reflect low-level factors: in the different-objects condition, infants expected the agent to reach for the opaque cover to obtain her preferred apple. Together, these results indicate that 16-month-olds consider efficiency in mental effort when determining which of two identical objects an agent is likely to select, even when not prompted by infrequent or odd actions.

General Discussion

When an agent faced two identical objects, one of which was physically (Experiment 1) or mentally (Experiment 2) more accessible than the other, 16-month-olds expected the agent to

expend minimal effort and reach for the more accessible object. These findings provide new evidence of sensitivity to efficiency in the second year of life, and they expand our understanding of this sensitivity in several ways. First, they demonstrate that infants attend to efficiency even in typical, everyday scenes that do not involve inefficient or odd actions. Second, the results of Experiment 1 indicate that, when reasoning about physical effort, infants evaluate not only the *shortest path* possible for reaching a target (e.g., Csibra et al., 2003; Gergely et al., 1995), but also the *shortest action sequence* possible for obtaining a target. Third, the results of Experiment of 2 indicate that infants consider mental as well as physical effort when reasoning about efficiency. Finally, the results of Experiments 1 and 2 make clear that, in comparing the physical or mental efficiency of different actions an agent might perform, infants adopt the agent's perspective rather than their own.

The present results also bear on another corollary of the rationality principle, *consistency* (Baillargeon et al., in press). As adults, we generally expect rational agents to act in a manner consistent with their goals, attitudes, and beliefs, and there is considerable evidence that infants also expect agents to act in accordance with this consistency principle: for example, infants detect a violation when an agent changes preference (e.g., Woodward, 1998) or goal (e.g., Csibra et al., 2003) for no apparent reason. The different-objects conditions in Experiments 1 and 2 pitted consistency against efficiency: they examined whether infants expected the agent to continue to seek her preferred apple in the test trials, even though it was now physically (Experiment 1) or mentally (Experiment 2) less accessible than the pig. The results of these conditions indicate that infants rank consistency above efficiency, at least in situations where the effort required for obtaining a more preferred object is only slightly greater than that required for a less preferred object.

Together, the present results indicate that, by the second year of life, infants possess rich and context-sensitive expectations about what efficient actions agents should produce in a variety of situations, including everyday situations where one object is slightly more accessible than another in terms of physical or mental effort.

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Figure captions

Figure 1. Familiarization and test events shown in the identical-objects condition of Experiment 1. In the familiarization trials, as an agent watched at the back of the apparatus, a gloved hand placed each pig on the front end of its support (first two trials) or on a platform on the front end of its support (last two trials); the agent then pulled one of the supports (counterbalanced across trials) and grasped the pig. In the test trial, a transparent cover and a transparent container stood centered on the right and left supports, respectively. The gloved hand placed the right pig on the front end of its support and covered it with the transparent cover; next, the hand moved the container to the front end of the left support and placed the left pig inside it. The agent then grasped the handle of the support with the cover (more-effortful event) or the handle of the support with the container (less-effortful event). During the trials, the agent never made eye contact with the infant: she watched the gloved hand's actions and looked at the objects she acted on, but otherwise kept her eyes on a neutral mark on the apparatus floor.

Figure 2. Test events shown in the different-objects and modified-identical-objects conditions of Experiment 1. The events shown in the different-objects condition were identical to those in the identical-objects condition except that one of the pigs was replaced with an apple. In the familiarization trials (not shown), side was counterbalanced and the agent always retrieved the apple; in the test trial, the apple was placed under the cover. In the modified-objects condition, two pigs were again used, and the familiarization events were identical to those in the identical-objects condition; only the test events differed. In the *two-cover* group, the container was replaced with a cover. The cover initially stood upright; while moving the cover to the front of the support, the gloved hand rotated it so that its opening faced the agent; the hand then slid the pig inside the cover. In the *two-container* group, two containers were used; the opening of the

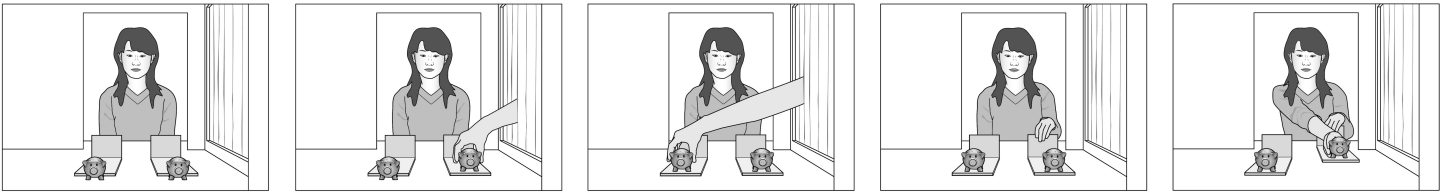
right container faced the infant, and the opening of the left container faced the agent. The gloved hand moved the right container to the front of the support, slid the right pig inside it, and then repeated these actions with the left container and pig.

Figure 3. Mean looking times at the more- or less-effortful event in the identical-, different-, and modified-identical-objects conditions of Experiment 1, and in the identical- and different-objects conditions of Experiment 2. Errors bars represent standard errors, and an asterisk denotes a significant difference between events ($p < .05$ or better).

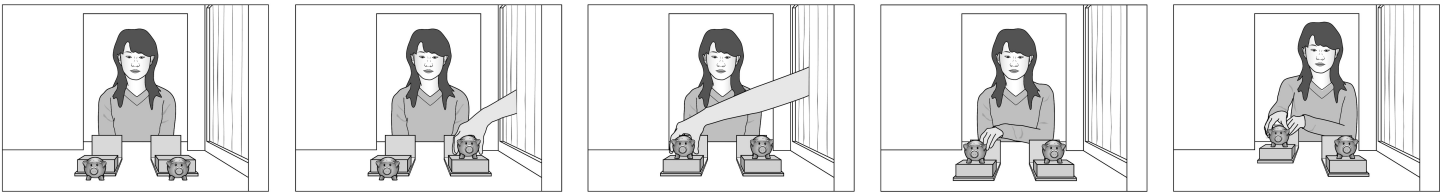
Figure 4. Familiarization and test events shown in the identical-objects condition of Experiment 2. In the familiarization trials, as the agent watched, the gloved hand placed each pig on its placemat (first two trials) or inside its shallow container (last two trials); the agent then grasped one of the pigs (counterbalanced across trials). In the test trial, an opaque and a transparent cover stood behind the right and left pigs, respectively. After infants looked at the scene for three seconds, a small screen was rotated upwards to hide the left pig. Next, the hand covered each pig with its cover; the agent then grasped the knob of the opaque cover (more-effortful event) or the transparent cover (less-effortful event).

Identical-objects Condition

Familiarization trials 1 and 2

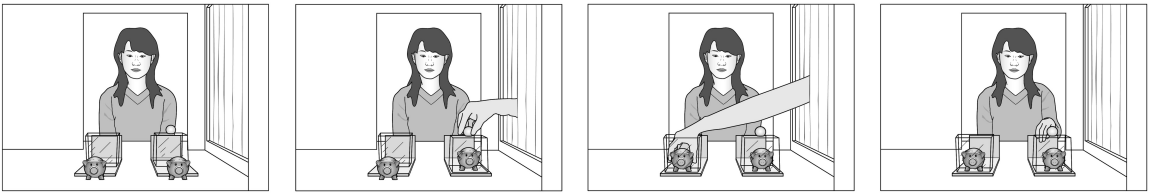


Familiarization trials 3 and 4

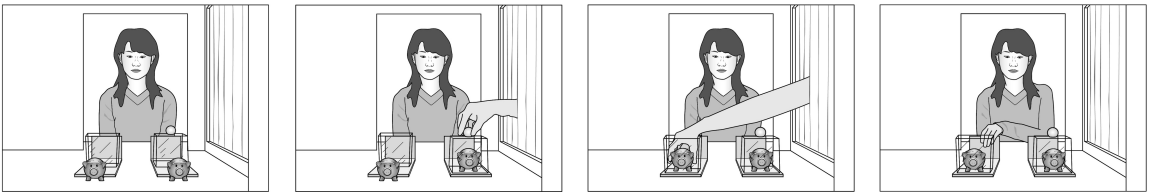


Test trial

More-effortful Event

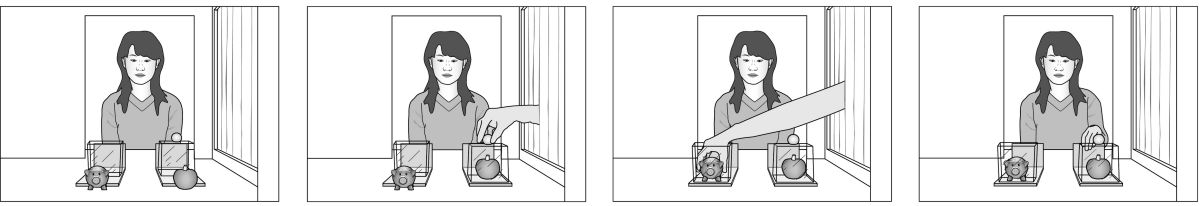


Less-effortful Event

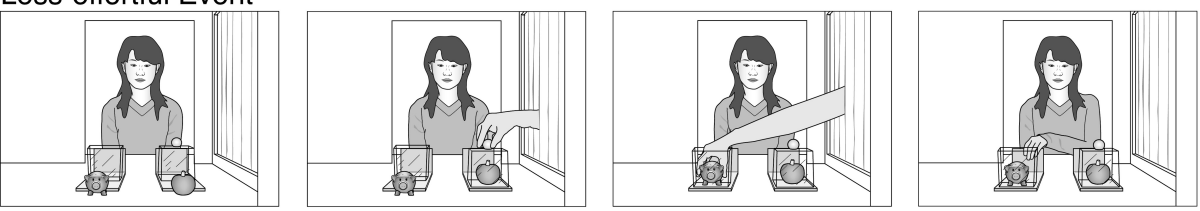


Different-objects Condition

More-effortful Event



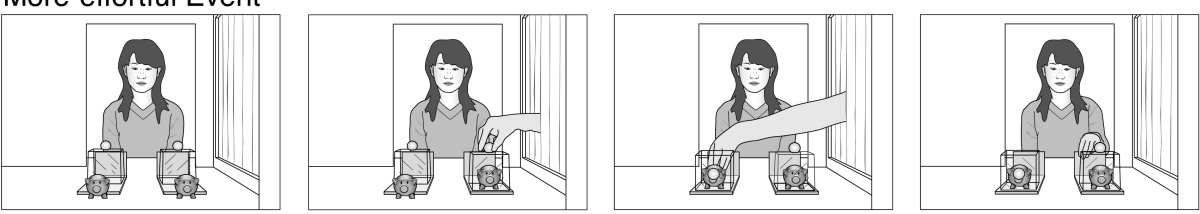
Less-effortful Event



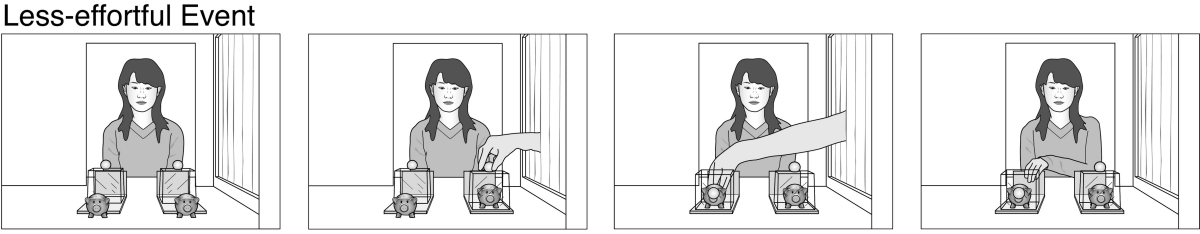
Modified-identical-objects Condition

Two-cover Group

More-effortful Event

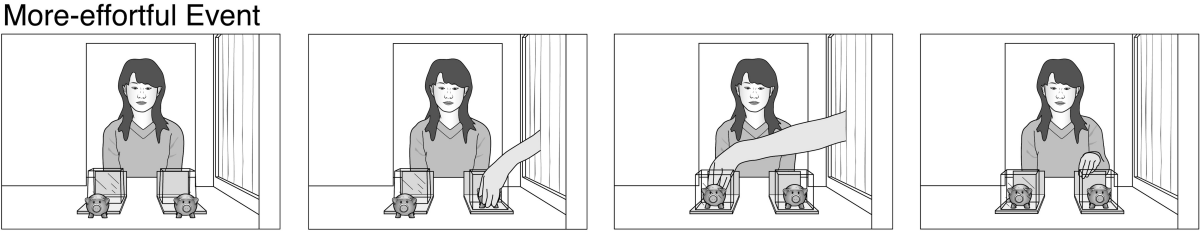


Less-effortful Event

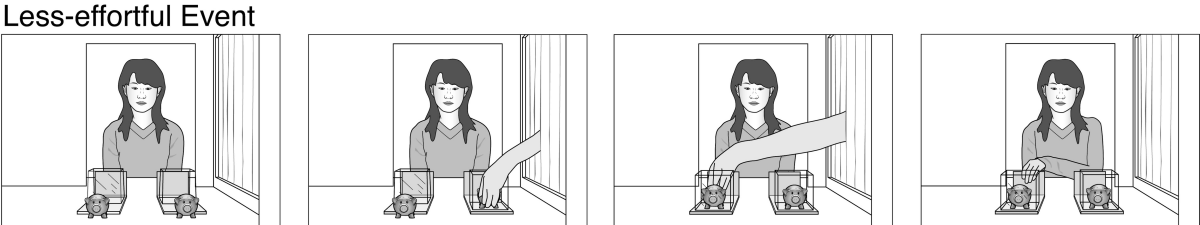


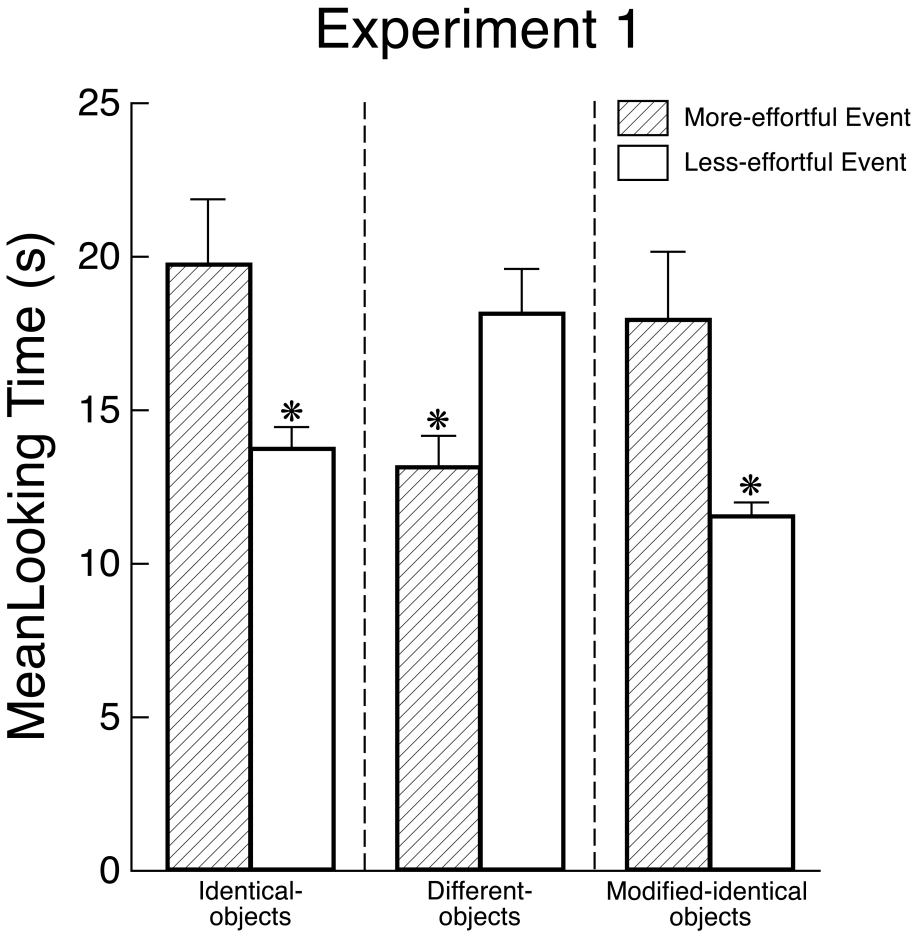
Two-container Group

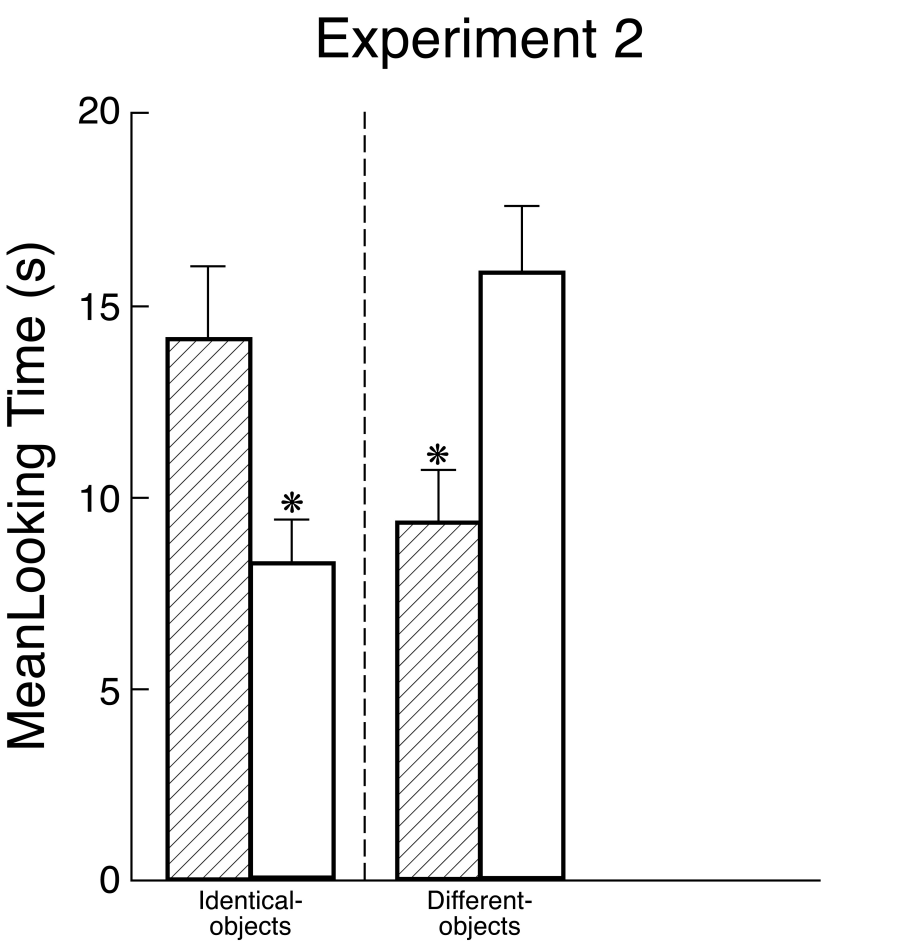
More-effortful Event



Less-effortful Event

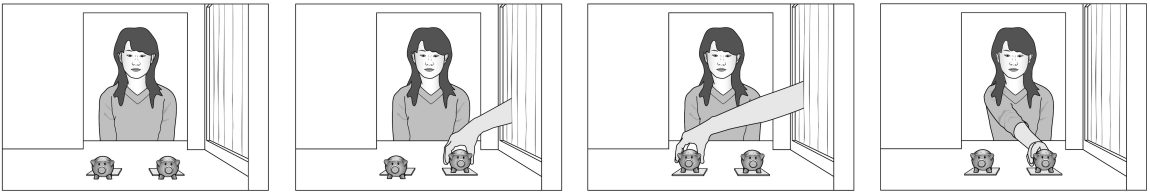



Experiment 1
More-effortful Event
Less-effortful Event
MeanLooking Time (s)
25
20
15
10
5
0
*
*
*
Identical-objects
Different-objects
Modified-identical objects

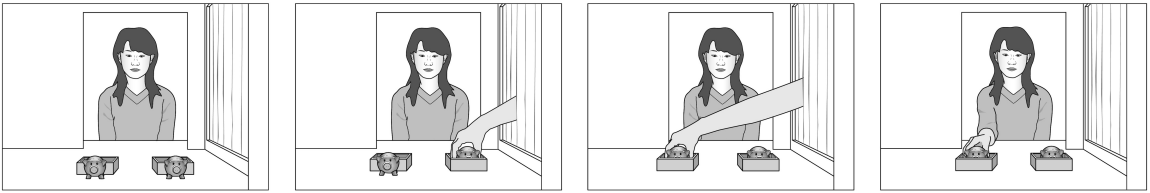

Experiment 2
MeanLooking Time (s)
20
15
10
5
0
*
*
Identical-objects
Different-objects

Identical-objects Condition

Familiarization trials 1 and 2



Familiarization trials 3 and 4



Test trial

More-effortful Event

Less-effortful Event