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# Reasoning about a hidden object after a delay: Evidence for robust representations in 5-month-old infants

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## Abstract

The present research examined two alternative interpretations of violation-of-expectation findings that young infants can represent hidden objects. One interpretation is that, when watching an event in which an object becomes hidden behind another object, infants form a prediction about the event's outcome while both objects are still visible, and then check whether this prediction was accurate. The other interpretation is that infants' initial representations of hidden objects are weak and short-lived and as such sufficient for success in most violation-of-expectation tasks (as objects are typically hidden for only a few seconds at a time), but not more challenging tasks. Five-month-old infants succeeded in reasoning about the interaction of a visible and a hidden object even though (1) the two objects were never simultaneously visible, and (2) a 3- or 4-min delay preceded the test trials. These results provide evidence for robust representations of hidden objects in young infants.

### Keywords

Infant cognition; Object permanence; Memory

## 1. Introduction

Piaget (1936/1954) observed that infants aged less than 8 months do not search for hidden objects, and concluded that young infants cannot represent hidden objects. This conclusion was generally accepted until findings from new methods, such as the violation-of-expectation method, suggested that young infants can represent hidden objects (for recent reviews, see Baillargeon, 2002; Baillargeon & Luo, 2002). In one experiment, for example, 4.5-month-old infants were habituated to a screen that rotated back and forth through a 180° arc, first away from and then back toward the infants (Baillargeon, 1987). Next, a box was placed behind the screen, and the infants saw two test events. In one, the screen rotated until it reached the hidden box (expected event); in the other event, the screen rotated through a full 180° arc, as though the box was no longer present (unexpected event). The infants looked reliably longer at the unexpected than at the expected event. This and control results suggested that the infants (1) represented the hidden box behind the screen, (2) expected the



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screen to stop against the box, and (3) were surprised when this expectation was violated. In recent years, several alternative interpretations have been proposed for this and other reports that young infants can represent hidden objects (e.g. Bogartz, Shinskey, & Speaker, 1997; Haith & Benson, 1998; Munakata, 2001a; Munakata, McClelland, Johnson, & Siegler, 1997). Here we address two such alternatives.

A first account suggests that, when watching an event in which an object becomes hidden behind another object, infants do not in fact represent the hidden object (Munakata, 2001a). Instead, infants form a prediction about the event's outcome while both objects are still visible, and later check whether this prediction was accurate. To return to the rotating-screen task, this account suggests that the infants did *not* represent the hidden box behind the screen. At the start of each test event, when the screen and box were both visible, the infants predicted that the screen would stop rotating when it encountered the box. The infants then monitored the event to determine whether it unfolded as predicted, and they looked reliably longer when their prediction was violated.

According to a second account of reports that young infants represent hidden objects (Munakata et al., 1997; see also Haith, 1998), infants' representations of hidden objects are not all-or-none but graded representations that become gradually stronger with experience. Although infants' initial representations are weak and short-lived, they are still sufficient for success in most violation-of-expectation tasks, because objects are typically hidden for only a few seconds at a time. However, these representations are not sufficient for success in more challenging tasks, such as tasks that require searching for a hidden object, or remembering it for a substantial delay. To return once again to the rotating-screen task, this account suggests that the infants *did* represent the box behind the screen, but this representation was weak and fragile; it allowed the infants to detect the violation in the unexpected event, but it would not have enabled them to search for the hidden box, or to remember it for a long delay.

In the present experiment, 5-month-old infants received test trials in which they saw a tall cylinder move back and forth behind a short screen (see Fig. 1). Prior to the test trials, the infants were shown in familiarization trials that a short box was hidden behind the screen. In the thick-box condition, the box filled the space between the screen and the back wall of the apparatus; in the thin-box condition, the box was much thinner so that a substantial gap remained between the screen and the box. We reasoned that if the infants (1) remembered the thick or thin box behind the screen, and (2) realized that the cylinder could pass behind the screen when the thin but not the thick box was present, then they should be surprised when this last expectation was violated. The infants in the thick-box condition should thus look reliably longer than those in the thin-box condition.

To address the two alternative interpretations discussed above, the five familiarization trials were designed to satisfy two objectives. First, the box and cylinder were never visible at the same time. In the first familiarization trial, an experimenter placed the thick or thin box behind the screen, which lay flat on the apparatus floor. In the next three familiarization trials, the screen was raised, once at the start of each trial, to hide the box. After the screen was raised at the start of the fourth trial, it remained upright for the rest of the experiment. In

the fifth and last familiarization trial, the experimenter introduced the cylinder and placed it on the apparatus floor next to the screen. We reasoned that if young infants can only generate predictions about the interaction of a visible and a hidden object while both are still visible (Munakata, 2001a), then the infants in the present experiment, who did not see the cylinder or its motion until after the box was hidden for the last time, should be unable to form a prediction about the interaction of the cylinder and box. The infants in the thick- and thin-box conditions should thus look about equally during the test trials.

Second, a delay was inserted prior to the test trials. When the first test trial began, the infants had not seen the thick or thin box for either 3- or 4-min (3- or 4-min condition). After the screen was raised for the last time at the start of the fourth familiarization trial, a timer was initiated. As the timer ran, the infants completed the fourth and fifth familiarization trials. Following these trials, parents played with their infants until the end of the delay. We reasoned that if young infants can only form weak representations of hidden objects (e.g. Haith, 1998; Munakata et al., 1997), then the infants in the present experiment, who had to remember the hidden box for 3 or 4 min prior to the test trials, should be unable to form a representation of the hidden box robust enough to withstand this long delay. The infants in the thick- and thin-box conditions should thus look about equally during the test trials.

## 2. Experiment

### 2.1. Method

**2.1.1. Participants—**The participants were 24 healthy term infants, 12 male and 12 female (age range: 4 months, 18 days to 5 months, 18 days, $M$ = 5 months, 4 days). Another eight infants were eliminated because they were fussy (4), active (2), distracted (1), or required a diaper change (one). Six infants were randomly assigned to the four groups formed by crossing the two box (thick- or thin-box) and the two delay (3- or 4-min) conditions.

**2.1.2. Apparatus—**The apparatus consisted of a wooden cubicle 126 cm high, 102 cm wide, and 27 cm deep, mounted 76 cm above the room floor. The infant sat on a parent's lap and faced an opening 47.5 cm high and 95 cm wide in the front of the apparatus. Between trials, a muslin-covered frame, 60 cm high and 101 cm wide, was lowered in front of the opening. The floor of the apparatus was covered with gray marbled contact paper, the side walls were painted white, and the back wall was covered with black marbled contact paper. At the bottom of the back wall was an opening 5.5 cm high, 102 cm wide, and filled with a black fringe. In the left wall (from the infant's perspective) was a window 51 cm high, 15 cm wide, and filled with a muslin curtain; an experimenter, wearing long white gloves, used this window to manipulate the box and cylinder.

The screen was 16 cm high, 22.5 cm wide, 0.5 cm thick, and made of foam core. It was centered on the apparatus floor, 15 cm in front of the back wall. The front of the screen was covered with blue contact paper, and the back with the same gray marbled contact paper as the floor. The screen was mounted on a wooden dowel with two metal clips. The dowel was 1 cm in diameter, 63 cm long, and fastened to the floor by two plastic brackets. The dowel's

right end protruded through a hole in the right wall of the apparatus; an experimenter rotated this end to raise the screen.

The boxes were 13.5 cm high, 17 cm wide, made of foam core, and covered with red and green striped contact paper. The thick box was 14 cm thick, and the thin box 0.5 cm thick.

Two cylinders were used, one in the last familiarization trial and the other in the test trials. Each cylinder was 30 cm high, 8 cm in diameter, made of white cardboard, and decorated with small blue dots, a 1-cm blue stripe at the top, and a 2.5-cm blue fringe at the bottom. The test cylinder was mounted on a hidden carrier 0.2 cm above the apparatus floor. This carrier consisted of an L-shaped rod; the vertical portion of the rod was attached to the back of the cylinder, and the horizontal portion protruded through the opening at the bottom of the back wall. Behind the wall, the rod was attached to a felt-covered base that rested on a Plexiglas track. As an experimenter slid the base along the track, the cylinder moved smoothly and silently across the apparatus, its fringe brushing noiselessly against the floor.

**2.1.3. Procedure—**Two observers monitored the infant's looking behavior through peepholes in large cloth-covered frames on either side of the apparatus. The primary observer's looking times were used to determine the endings of the trials (see below). Interobserver agreement during the familiarization and test trials was calculated for 23 of the 24 infants and averaged 93% per trial per infant.

**2.1.3.1. Familiarization trials:** The infants received five familiarization trials (see Fig. 1). In the first trial, the infants were familiarized with the thick or thin box. The trial ended when the infants (1) looked away for 2 consecutive seconds after having looked for at least 28 cumulative seconds, or (2) looked for 40 cumulative seconds. The 28-s minimal value corresponded to two event cycles and was chosen to give the infants ample exposure to the box. The infants in the thick- ($M$ = 38.4, SD = 3.7) and thin-box ($M$ = 37.2, SD = 4.3) conditions looked about equally during the trial ($F(1, 22) = 0.58$).

In the next three trials, the infants were familiarized with the screen being raised in front of the thick or thin box. The screen was raised at the beginning of the trial and the infants watched this static scene until the trial ended. This occurred when the infants (1) looked away for 2 consecutive seconds after having looked for at least 7 cumulative seconds, or (2) looked for 40 cumulative seconds. The infants in the thick- ($M$ = 13.0, SD = 7.1) and thin-box ($M$ = 13.6, SD = 8.2) conditions looked about equally during the trials ($F(1, 22) = 0.06$).

In the fifth and last trial, the infants were familiarized with the cylinder. Because the screen remained upright, the infants in the thick- and thin-box conditions saw the same event. The trial ended when the infants (1) looked away for 2 consecutive seconds after having looked for at least 16 cumulative seconds, or (2) looked for 40 cumulative seconds. The 16-s minimal value corresponded to two event cycles and was chosen to give the infants ample exposure to the cylinder. The infants in the thick- ($M$ = 36.9, SD = 7.3) and thin-box ($M$ = 35.6, SD = 7.4) conditions looked about equally during the trial ($F(1, 22) = 0.20$).

As the screen was rotated upward in the fourth familiarization trial, a 3- or 4-min delay was initiated by starting a timer. During the delay, the infants completed the fourth and then the

fifth familiarization trial. In the time that remained until the end of the delay, parents played with their infants while remaining seated in front of the apparatus; at the same time, the experimenters quietly removed the box from the apparatus and substituted the test for the familiarization cylinder. The only difference between the two delay conditions was thus that the infants in the 4-min condition interacted with their parents for slightly longer than the infants in the 3-min condition.

**2.1.3.2. Test trials:** Each infant received two blocks of three test trials in which they saw the cylinder move back and forth behind the screen. Because the screen was raised, the infants in the thick- and thin-box conditions saw the same event. Each trial ended when the infant (1) looked away for 2 consecutive seconds after having looked for at least 12 cumulative seconds, or (2) looked for 60 cumulative seconds. The 12-s minimum value corresponded to one event cycle and ensured that the infants had the opportunity to observe the cylinder's passage back and forth behind the screen.

Preliminary analyses revealed no significant interaction involving sex; the test data were therefore collapsed across this factor in subsequent analyses.

### 2.2. Results

The infants' looking times during the test trials (see Fig. 2) were analyzed by a 2 × 2 × 2 × 3 analysis of variance with box condition (thick- or thin-box) and delay condition (3- or 4-min) as between-subjects factors, and block (block1 or block2) and trial (trial1, trial2, or trial3) as within-subject factors. The analysis yielded significant main effects of block ($F(1, 100) = 35.75$, $P < 0.0001$) and trial ($F(2, 100) = 5.16$, $P < 0.05$), indicating that the infants looked reliably less as the experiment progressed. The analysis also revealed a significant box condition × block interaction ($F(1, 100) = 9.63$, $P < 0.005$). Planned comparisons indicated that, whereas in block1 the infants in the thick- ($M = 52.8$, SD = 13.1) and thin-box ($M = 53.4$, SD = 12.2) conditions looked about equally ($F(1, 100) = 0.04$), in block2 the infants in the thick-box condition ($M = 46.7$, SD = 18.0) looked reliably longer than those in the thin-box condition ($M = 34.0$, SD = 16.7) ($F(1, 100) = 17.64$, $P < 0.0001$).

Additional comparisons involving block2 revealed that the infants in the thick-box condition looked reliably longer than those in the thin-box condition (1) in each delay condition (see Fig. 3: 3-min delay condition: thick-box $M = 48.0$, SD = 17.3, thin-box $M = 37.2$, SD = 19.2, $F(1, 100) = 6.42$, $P < 0.025$; 4-min delay condition: thick-box $M = 45.4$, SD = 19.2, thin-box $M = 30.8$, SD = 13.6, $F(1, 100) = 11.60$, $P < 0.001$), and (2) in each trial (see Fig. 2: trial1: thick-box $M = 51.3$, SD = 13.4, thin-box $M = 38.0$, SD = 15.6, $F(1, 100) = 6.54$, $P < 0.025$; trial2: thick-box $M = 47.6$, SD = 17.5, thin-box $M = 33.4$, SD = 16.0, $F(1, 100) = 7.44$, $P < 0.001$; trial3: thick-box $M = 41.1$, SD = 22.2, thin-box $M = 30.7$, SD = 19.0, $F(1, 100) = 3.96$, $P < 0.05$).

## 3. Discussion

In block1, the infants in the thick- and thin-box conditions responded at or near ceiling, no doubt because they had never seen the cylinder move across the apparatus floor. Of the 72

looking times recorded in these trials (24 infants × 3 trials), 50 (25 in each box condition) were 60 s, the maximum allowed.

In block2, the infants in the thick-box condition looked reliably longer than those in the thin-box condition; this finding held for the 3- and 4-min delay conditions, and for the fourth, fifth, and sixth test trials. These results suggest that the infants (1) remembered the thick or thin box behind the screen through the 3- or 4-min delay as well as the test trials, (2) realized that the cylinder could pass behind the screen when the thin but not the thick box was present, and (3) were surprised when this last expectation was violated.

These results challenge the alternative interpretations raised in the Introduction (Section 1). The thick or thin box was hidden for the last time in the fourth familiarization trial; the infants did not see the cylinder until the fifth familiarization trial, and they did not see it pass behind the screen until the first test trial. If infants could only reason about the interaction of a visible and a hidden object while both were still visible (Munakata, 2001a), then the infants in the present experiment should have failed. The fact that they did not suggests that they represented the hidden box and used this representation to predict what would happen when the cylinder moved behind the screen.

Furthermore, the infants' representation of the hidden box was neither weak nor short-lived (e.g. Haith, 1998; Munakata et al., 1997), but persisted through a substantial delay. The infants had to remember the presence of the box behind the screen not only during the 3- or 4-min delay, but also during the test trials. The infants' mean looking time during block1 was 53.1 s per trial, and the inter-trial interval was about 10 s. Thus, at the start of the fourth test trial, the infants had not seen the box for about 189.3 s, in addition to the 3- or 4-min delay – about 6 or 7 min in all. The finding that the infants could remember the hidden box for several minutes is consistent with reports that young infants can recall facial gestures, actions, and routines after significant delays (e.g. Ashmead & Perlmutter, 1980; Carver & Bauer, 1999; Mandler & McDonough, 1995; Meltzoff, 1988; Meltzoff & Moore, 1994).

It might be objected that an alternative interpretation of the present results is possible that does not grant infants the ability to represent hidden objects. As the screen rotated toward the box in the screen-familiarization event, the infants in the thick-box condition might have predicted that no additional object could fit behind the screen, and they might have maintained this prediction during the rest of the experiment, causing them to be surprised in the test trials when it was violated. According to this alternative interpretation, the infants formed a prediction about a hypothetical object and its motion: were a new object to enter and move across the apparatus, it could not pass behind the screen. One difficulty here, we would argue, is that it is doubtful whether granting infants the ability to form and maintain predictions about hypothetical objects is more parsimonious, or more plausible, than granting them the ability to represent and remember hidden objects. Another difficulty is that, to our knowledge, there is no evidence in the developmental literature that infants can engage in physical reasoning about hypothetical objects.

If infants can represent and remember hidden objects at 5 months of age, why do they not search for them until several months later (Piaget, 1936/1954)? Many factors appear to

contribute to infants' difficulties with means-end tasks, though the exact nature of these factors and how they interact are still matters for debate. For example, one proposal suggests that infants fail at search tasks because standard search situations (which often require multiple updatings) allow them to form only weak representations of the hidden objects (e.g. Munakata, 2001b; Munakata et al., 1997). According to another proposal, infants fail at a means-end task when the combined processing demands created by reasoning about the task and planning appropriate actions overwhelm their limited resources (e.g. Boudreau & Bushnell, 2000; Clifton, Johnson, Sylvia, & Berthier, in press; Hespos & Baillargeon, 2003).

Whatever the reason for young infants' failure to search for hidden objects, the present research provides further evidence that young infants can represent hidden objects, and also suggests that these representations can persist for significant delays.

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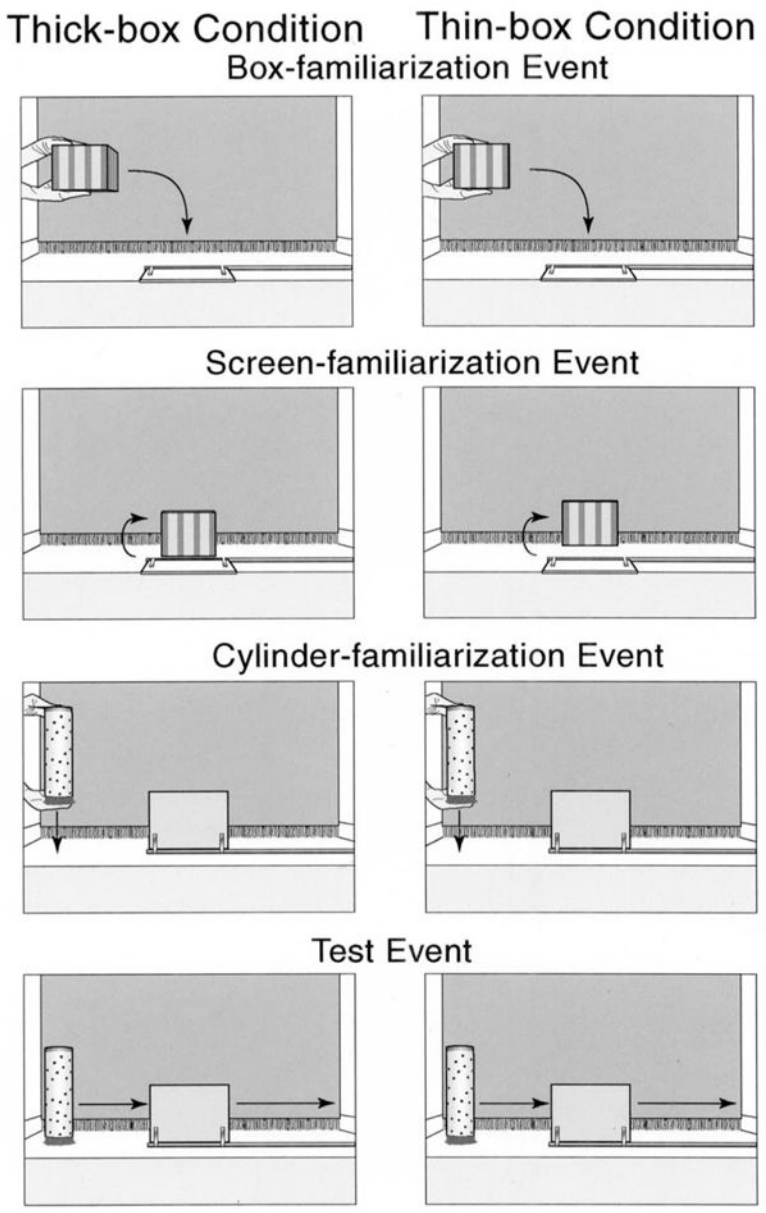


**Fig. 1. Thick-box condition**

*(a) Box-familiarization event.* At the start of the event, the screen lay flat on the apparatus floor. An experimenter held the top and bottom of the thick box 20 cm above the apparatus floor, 0.5 cm from the back wall, and 7 cm from the left wall. The experimenter placed the box against the back wall, centered behind the screen (4 s). Next, the experimenter tapped with her right index finger first on the back wall above the box (2 s), and then on the top (2 s) and front (2 s) of the box. The experimenter then grasped the box and returned it to its starting position (3 s). After a 1-s pause, the event was repeated. Each event cycle thus lasted about 14 s; cycles were repeated until the trial ended. *(b) Screen-familiarization event.* At the start of the event, the screen lay flat on the apparatus floor, with the thick box centered behind it, against the back wall; there was a 1-cm gap between the box and screen. When the computer signaled that the infant had looked for 2 cumulative seconds, the screen was

rotated 90° upward to hide the box (2 s); this static scene was shown until the trial ended. *(c) Cylinder-familiarization event.* At the start of the event, the screen was upright, hiding the box. The experimenter held the top and bottom of the familiarization cylinder 12.5 cm above the apparatus floor, 5 cm from the back wall, and 7 cm from the left wall. She lowered the cylinder to the apparatus floor (2 s) and then tapped its top (2 s) and front (2 s). Next, the experimenter returned the cylinder to its starting position (1 s). After a 1-s pause, the event was repeated. Each event cycle thus lasted about 8 s, and cycles were repeated until the trial ended. *(d) Test event.* At the start of the event, the screen was upright, and the test cylinder stood in the left corner of the apparatus, 5 cm from the back wall and 7 cm from the left wall. After a 1-s pause, the cylinder slid to the right at a speed of 16 cm/s; the cylinder passed behind the screen and continued until it stood in the right corner of the apparatus, 7 cm from the right wall (5 s). After a 1-s pause, the sequence was repeated in reverse. Each event cycle thus lasted about 12 s; cycles were repeated until the trial ended. *Thin-box condition. (a–d)* The events shown in the thin-box condition were identical to those in the thick-box condition with two exceptions. First, the thin box was used; when the box was in position behind the screen, a 14.5-cm gap separated the box and screen. Second, in the box-familiarization event, the experimenter tapped the back wall above the box (2 s), the front of the box (2 s), and finally the apparatus floor in front of the box (2 s), thus calling the infants' attention to the presence of the gap.

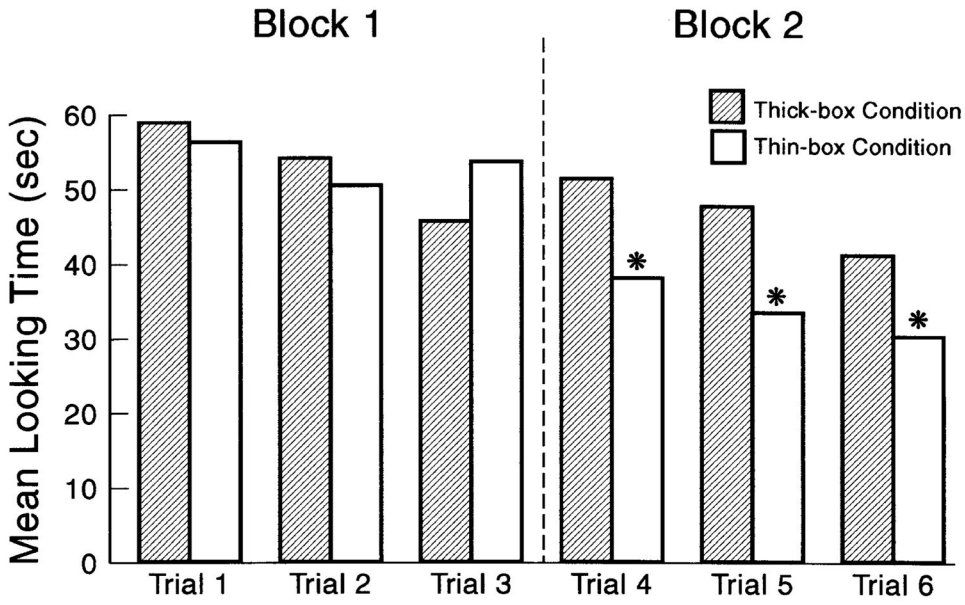


**Fig. 2.**

Mean looking times of the infants in the two box conditions during the two blocks of test trials.

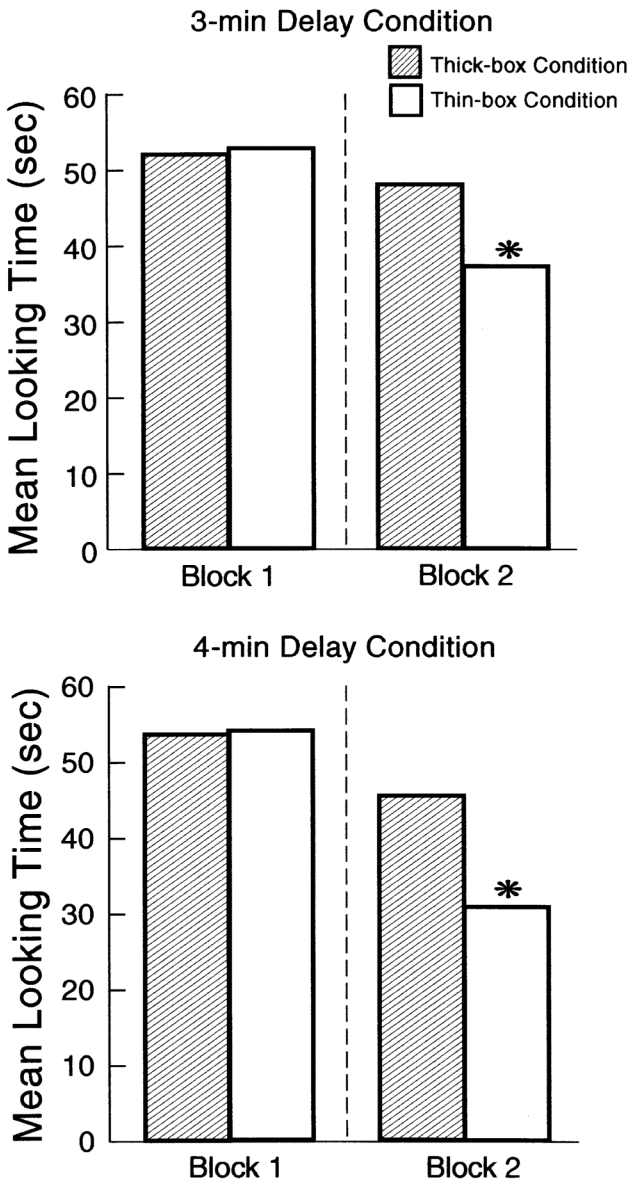


**Fig. 3.**

Mean looking times of the infants in the two delay conditions during the two blocks of test trials.