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Infants' Representations of Same and Different in Match- and Non-Match-to-Sample

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Abstract

Three experiments investigated the representations that underlie 14-month-old infants' and adults' success at match-to-sample (MTS) and non-match-to-sample (NMTS) tasks. In Experiment 1, 14-month-old infants were able to learn rules based on abstract representations of sameness and/or difference. When presented with one of eighteen sample stimuli (A) and a choice between a stimulus that was the same as the sample (A) and a different stimulus (B), infants learned to choose A in MTS and B in NMTS. In Experiments 2 and 3, we began to explore the nature of the representations at play in these paradigms. Experiment 2 confirmed that abstract representations are at play, as infants generalized the MTS and NMTS rules to stimuli unseen during familiarization. Experiment 2 also showed that infants tested in MTS learned to *seek* the stimulus that was the same as the sample, whereas infants tested in NMTS did not learn to *seek* the different stimulus, but instead learned to *avoid* the stimulus that was the same as the sample. Infants appeared to only use an abstract representation of the relation same in these experiments. Experiment 3 showed that adult participants, despite knowing the words "same" and "different", also relied on representations of sameness in both MTS and NMTS in a paradigm modeled on that of Experiment 2. We conclude with a discussion of how young infants may possibly represent the abstract relation same.

Keywords

same; different; match-to-sample; non-match-to-sample; infants

Introduction

The science of infant cognition has undergone a revolution in the past decades. William James' "blooming buzzing confusion," as well as the Piagetian proposal that innate

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representations are limited to sensorimotor primitives, has been convincingly challenged. In recent years, there has been an accumulation of evidence supporting the view that infants' cognition consists in part of a collection of domain-specific representational systems, sometimes called systems of "core cognition," which enable infants to represent and learn about objects, agents, numbers, and the social world (e.g., Baillargeon, Scott & Bian, 2016; Carey, 2009; Carey & Spelke, 1994; Spelke & Kinzler, 2007). But systems of core cognition do not exhaust the whole of human cognition, as human adults also possess abstract representations that participate freely in domain-general combinatorial processes, enabling language and logical inference. While linguistic abilities provide strong evidence that human adults have such representations, the case of young infants remains little studied. At issue is whether—in addition to sensorimotor, perceptual, and core cognition representations—prelinguistic infants possess the capacity for domain-general, abstract, combinatorial thought.

One case study relevant to this question is the representation of sameness and difference. Same and different are abstract relations, and are not exclusively tied to any specific domain of knowledge. Furthermore, the concepts same and different are linked by negation: different means not same, thus raising the possibility that a representation of different may be combinatorially composed. Finding evidence that infants and non-human animals have representations of sameness – and, crucially, of difference – might then support the hypothesis that a combinatorial *language of thought* precedes language development in human infants and may also be found in a wide range of non-human species. This would support the view of a continuity between infant and adult cognition, as well as between animal and human cognition. Here we report the fruits of an initial study of the abstract representations of same and different in infancy. We ask whether infants represent both relations.

There is no doubt that nonhuman animals and human infants can perceive sameness (or similarity); match computations underlie our sense of familiarity, are needed for recognition and memory, and are reflected in habituation. Similarly, the perception of differences (or novelty) is reflected in discrimination abilities and dishabituation. However, these computations do not necessarily require abstract representations with the content same or different, abstract symbols that can themselves guide actions or play a role in inference.

There is a large literature in comparative psychology (see Addyman & Mareschal, 2010; Thompson & Oden, 1996 for reviews) that is often taken to support the conclusion that nonhuman animals create mental symbols for the abstract relations same and different. The most widely used paradigm in support of this conclusion is match to sample and non-match to sample. A wide range of animals, from bees to apes, can be trained to match to sample (MTS). If shown a stimulus, the sample, and then given a choice between a stimulus that is the same as the sample and a stimulus that is different from the sample, they can be trained to choose the stimulus that matches the sample. They generalize the rule to entirely novel samples, consistently selecting the choice that is the same as the sample. Similarly, in a non-match to sample task (NMTS), animals can be trained to choose the stimulus that is different from the sample and generalize the rule to novel stimuli (e.g., bees: Giurfa et al., 2001;

pigeons: Blough, 1959; Wright et al., 1988; dolphins: Harley et al., 2003; rats: Mumby, 2001; apes: Oden, Thompson & Premack, 1988).

These studies, by using a wide variety of sample stimuli and including generalization trials to novel stimuli, demonstrate that animals that succeed are doing so on the basis of some abstract representations; they cannot succeed by merely learning a series of specific associations. However, these studies leave open the question of which specific abstract representations and computations are being used. The present studies begin to fill this gap, focusing on infants rather than nonhuman animals. We first look for evidence that infants use abstract representations in MTS and NMTS tasks, and then ask what those representations might be. While we focus on MTS and NMTS, in the general discussion we also consider the representations that might underlie infants' success on other tasks that probe repesentations of sameness and difference, including habituation to pairs of objects that are the same or to pairs of different objects (Addyman & Mareschal, 2010; Ferry et al., 2015; Tyrell et al., 1991), habituation to patterns specified by pairs of identical elements; e.g., ABA or ABB (Dawson & Gerken, 2009; Johnson et al., 2009; Marcus et al., 1999; Rabagliati et al., 2012; Saffran et al., 2007), and conditioned responses on pairs of identical elements (Hochmann, 2010; Hochmann et al., 2011; Kovács, 2014; Tyrell et al., 1993; Walker & Gopnik, 2014).

The few MTS and NMTS studies that have been conducted with infants do not necessarily tap abstract representations of same and different. The initial studies of MTS and NMTS in infancy were used to study working memory and the maturation of frontal lobe structures that underlie it. In these Delayed MTS and NMTS tasks, working memory capacity is assessed by manipulating the delay between the presentation of the sample and the choice stimuli (Diamond, 1990, 1994). Infants first act on a sample object to get a reward, for example, removing it to uncover a well in which a toy is found. After variable-length delays, they are presented with a replica of the initial object (the match) and a novel object (the non-match) over two different wells. In Delayed MTS, the well covered by the match contains a rewarding toy; in Delayed NMTS, the well covered by the non-match contains the reward. Initial studies with infants found success at Delayed NMTS beginning at 21 months and with Delayed MTS only much later, after 3 years of age (Diamond, 1990; Overman, 1990).

There are two puzzling aspects of these findings. First, what leads to the asymmetry between Delayed MTS and NMTS? Overman (1990) argued that Delayed MTS is harder than Delayed NMTS because it requires inhibiting a prepotent novelty preference. Indeed, animals tested in this version of Delayed MTS and NMTS also find NMTS much easier (Mishkin & Delacour, 1975; Overman et al., 1983) – in fact, animals are often tested only in NMTS for that reason. But a simple novelty preference should be found in all of the animal MTS and NMTS studies. Contrary to this expectation, in paradigms where animals do not act manually on the sample, but rather just look at it, there is no asymmetry between MTS and NMTS (e.g., Giurfa et al., 2001; Smirnova et al., 2000). Why should paradigms where subjects act on the sample lead to an asymmetry between MTS and NMTS? One possible explanation is that in the classic Delayed MTS and NMTS tasks, infants and animals may assume that the same individual is presented twice, as both the sample and the match. Since they already retrieved the reward associated with this object when it was the sample, they no longer have any reason to search under the match, and they instead try the non-match. If this interpretation is correct, this paradigm successfully tests working memory of individual objects, but not the representation of the abstract relations same or different. A simple modification, however, may allow us to test for the representation of abstract relations: showing that the sample, the match, and the mismatch are three distinct objects.

A second surprising aspect of these findings is that children do not succeed on either task until a relatively advanced age. Diamond (2006) hypothesized that this is due to younger children not appreciating the relevance of the objects to the rewards hidden under them. Accordingly, a variation of the task with an intrinsic connection between the correct object and the reward – the reward was attached to the bottom of the object, rather than just being in a well under the object – led to infants succeeding on Delayed NMTS at just 9 months of age (Diamond, 2006). To the best of our knowledge, this modification has not been implemented for MTS, leaving open the question of when infants might begin to succeed at MTS in this more favorable context.

A recent study by Kaldy, Guillory and Blaser (2015) provides initial evidence that infants might indeed succeed on MTS much younger than 3 years of age in such a paradigm. Inspired by the card game *Memory,* their Delayed Match Retrieval paradigm involves a series of videos where three cards are presented. Initially, the backs of the three cards are presented. Then, two cards flip, each revealing a different symbol. These two cards flip back so that their symbols are now hidden, and the third card (the sample) flips to reveal the same symbol as one of the two previous cards. After a short delay, the card that displayed the same symbol as the sample is animated. The authors showed that 10-month-olds, but not 8-month-olds, learned to anticipate the animation of the correct card in less than 24 trials. However, this study used only two pairs of symbols, and did not test for generalization to novel symbols. Thus, this paradigm instantiates what is sometimes called a "match/oddity" task in the animal literature, rather than an abstract MTS task. Kaldy and colleagues' results are thus compatible either with a general rule based on the abstract relation same (*look at the card that is the same as the sample*), or, as assumed by early developers of match/oddity tasks (e.g., Carter & Eckerman, 1975; Skinner, 1950), with learning exactly four specific associative rules (e.g., *if the sample is a heart, choose the heart; if the sample is a star, choose the star*; etc.).

In Experiment 1, we build on the Delayed Match Retrieval paradigm by teaching 14-month-olds to look at a picture that is the same as a sample picture (MTS). While we simplify the task by removing its memory component, we increase the number of pairs of symbols in order to tap an abstract representation of the relation same. We also extend Kaldy and colleagues' work by adding an NMTS condition, teaching infants to look at the picture that is different from the sample. Thus, we can ask whether infants, like many animal species, learn NMTS and MTS equally easily.

In Experiments 2 and 3, we begin to clarify the content of the abstract representations that are involved in MTS and NMTS. A common interpretation of success in MTS and NMTS is that participants learn exactly what experimenters intend to teach them: they learn to choose the alternative that is the *same* as the sample in MTS, thus evidencing a representation of the relation same; and to choose the alternative that is *different* from the sample in NMTS, thus evidencing a representation of the relation different. While generalization behaviors in MTS and NMTS indicate an ability to represent *some* abstract relation, participants need not represent both the relation same and the relation different to succeed in MTS and NMTS. In particular, if participants have the capacity to represent only the relation same, they may *seek* the same picture in MTS, and *avoid* the same picture in NMTS. In the latter case, they would end up opting for the different picture only because that is the one alternative left. Experiments 2 (infants) and 3 (adults) thus ask whether the rules infants and adults are following in MTS and NMTS are formulated only over the concept same. If no evidence for a concept different emerges, then success on NMTS cannot be taken as evidence for a representation that composes the abstract concepts not and same.

Experiment 1 – MTS and NMTS in an anticipatory looking paradigm

Following Kaldy et al. (2015), infants were shown a series of animated videos on the screen of an eye-tracker, each consisting of three cards with various pictures on them. The left and right cards always had different pictures on them, while the middle card (the sample) displayed the same picture as one of the other cards. After all three cards were introduced, one of the side cards began spinning and making a noise – this was the card that was the same as the sample in the MTS condition, and the card that was different from the sample in the NMTS condition. The dependent measure was anticipatory looking. Do infants learn the rules in both MTS and NMTS, and anticipate the spinning before it begins?

This design builds on previous work in three important ways. First, although separate studies have found that 10-month-old infants can succeed at MTS with 2 pairs of stimuli (Kaldy et al., 2015) and at delayed NMTS generalizing to novel stimuli (Diamond, 2006), these studies used very different paradigms from one another. We tested infants on both MTS and NMTS, allowing us to compare performance on the two rules. Second, by showing infants the sample and the two alternatives at the same time, we could ensure that they were responding based on the relation between the sample and one of the alternatives, rather than because they thought the sample was the same individual object as one of the alternatives. Third, the use of nine pairs of stimuli renders it unlikely that a success would be based on learning a series of associative rules, since infants would have to learn 18 of them; instead, success is likely to be based on an abstract representation of same or different.

Material and methods

Participants—Thirty-six infants were tested in this experiment, 18 in the MTS condition and 18 in the NMTS condition (mean age 14 months 13 days; range: 13 months 10 days to 15 months 27 days; 21 girls and 15 boys). Thirteen additional infants were tested but excluded for fussiness (6 in MTS; 7 in NMTS). Infants who participated in Experiments 1 and 2 were identified from publicly available birth records and families were invited to bring their babies to the laboratory. Parents were largely middle class and Caucasian, with a few children of Hispanic, African American, or East Asian backgrounds, reflecting the ethnicity and social class of the database of volunteers this method of recruitment generates. The infants were given a small gift and parents were given a $5 travel reimbursement.

Procedure—Infants were seated on their caregiver's lap, in a darkened room, facing a Tobii Eye-tracker T60. Caregivers were asked to close their eyes for the duration of the experiment. The experiment consisted of 36 trials. In each trial, we showed infants a 10-second video in which three cards appeared successively on the screen, and one card – specified by the MTS or NMTS rule – started spinning (see Figure 1). Using the eye-tracker, infants' gaze position was tracked as they watched these videos.

Each trial was structured in the same way. Two seconds after the start of a trial, one card descended from the top on either the left or right side of the screen, taking one second to reach its final position. One second later, a second card descended from the top on the opposite side of the screen, taking one second to reach its position. These two side cards displayed different symbols. One second later, a third card ascended from the bottom in the middle of the screen, taking one second to reach its position. After a delay of one second (the anticipatory period), one of the side cards started spinning (360 degrees) for one second. This spinning card was the one that was the same as the middle card in the MTS condition, and the one that was different from the middle card in the NMTS condition. A cheering sound was played while the card was spinning. The trial ended one second after the card stopped spinning. The side of the correct card, the side of the first card to appear (left or right), and its relation to the sample (same or different) were counterbalanced across trials.

Stimuli—Nine pairs of arbitrary symbols were selected (e.g., ✕ and Δ; ç and n; § and •). The two symbols in a pair were presented in different colors (orange, blue, purple or green). Each pair of symbols appeared in four trials, so that each symbol was reinforced twice, once on the right card and once on the left card.

Analysis—Trials where participants did not fixate both of the two side cards prior to the middle card were not further analyzed; nor were trials where participants did not fixate the middle card (6% of all trials were excluded from analysis on the basis of one of these two criteria). Furthermore, as our dependent measures were anticipatory looks, trials with no anticipation (i.e., trials where infants did not fixate one or the other side card after fixating the middle card, and before the correct card started spinning) were not further analyzed. Infants anticipated in 44% of all trials (Block 1: 48%; Block 2: 41%; Block 3: 42%). All but 3 of the 36 infants contributed anticipatory data to each block of trials; those 3 infants (2 in MTS and 1 in NMTS) contributed data to only the first 2 blocks of trials. As a result, only 33 infants were included in the final analyses reported below.

The anticipatory period was the 1 second after the middle card had settled into its position, but before one of the side cards started spinning. The correct card was the same as the middle card (the same-alternative) in MTS, and was different from the middle card (the different-alternative) in NMTS. Two measures were taken during the 1-second anticipatory period: first fixation and cumulative looking time. For the first fixation analysis, we coded which card the infant looked at first during the anticipatory period. For the cumulative looking time analysis, we coded which card the infant spent more time looking at during the anticipatory looking period.

We then combined the anticipation data for all the infants, and for each analysis computed a difference score for each successive block of 12 trials (trials 1–12; trials 13–24; trials 25–36): ds = (# correct anticipation − # incorrect anticipation)/(# correct anticipation + # incorrect anticipation). We asked both whether infants improved as the experiment progressed, to account for any baseline preferences, and whether they eventually performed better than chance. The 12-trial block size was chosen in advance based on previous infant and animal MTS studies (e.g., Giurfa et al., 2001; Kaldy et al., 2015).

Results

The results of Experiment 1 are presented in Figure 2. The left panel depicts the cumulative looking time analysis and the right panel depicts the first fixation analysis. Positive scores reflect more correct than incorrect anticipations; scores of 0 reflect random behavior.

The overall pattern of results is that infants were at chance in Block 1. As the experiment progressed and they were exposed to more evidence about which card would spin, they began to anticipate the spinning of the correct card. They did this in Block 2 for MTS (increasing their looking to the card that was the same as the sample), and Block 3 for NMTS (increasing their looking to the card that was different from the sample). Detailed analyses are presented below.

As reported above, two infants tested in MTS and one tested in NMTS showed no anticipation in the third block. As a result, only 33 infants were included in the repeated measures ANOVAs presented below. For each analysis, we conducted an ANOVA with Block (1, 2, 3) as a within-subject factor and Task (MTS, NMTS) as a between-subject factor.

For the cumulative looking time analysis, the ANOVA revealed no significant main effect of Block or Task. However, there was a significant interaction of Block and Task; F(2,62) = 3.54; $P = .035$; $\eta^2 = .103$. In MTS, infants performed better in Block 2 ($M = .23$) than in Block 1 ($M = -.15$; $P = .02$, Fisher's LSD). In NMTS, infants performed better in Block 3 ($M = .29$) than in Block 1 ($M = -.02$; $P = .05$) and Block 2 ($M = -.05$; $P = .036$). Other differences were not significant.

The same pattern was observed for first fixations, though the effects are not as robust. A main effect of Block was marginally significant; F(2,62) = 2.94; $P = .06$; $\eta^2 = .087$: infants' performance increased marginally between Blocks 1 and 2 ($P = .07$) and significantly between Blocks 1 and 3 ($P = .02$). The interaction of Block and Task approached significance; F(2,62) = 2.52; $P = .088$; $\eta^2 = .075$. In MTS, there was a marginal improvement between Blocks 1 ($M = -.10$) and 2 ($M = .18$; $P = .065$). In NMTS, there was a significant improvement between Blocks 1 ($M = -.10$) and 3 ($M = .29$; $P = .01$), and a marginal improvement between Blocks 2 ($M = .01$) and 3 ($P = .062$). Other differences were not significant.

Finally, we compared infants' performance to chance levels of responding, by measuring if the difference scores were significantly different from 0. In MTS, infants performed better than chance in Block 2 using cumulative looking time ($M = .23$; t(15) = 2.37; $P = .03$;

Cohen's d = 1.22), but not using first fixation (*M* = .18; t(15) = 1.53; *P* = .14; *d* = .79). In NMTS, infants performed better than chance in Block 3 using both measures; cumulative looking time: *M* = .29; t(16) = 2.55; *P* = .02; *d* = 1.275; first fixation: *M* = .29; t(16) = 2.57; *P* = .02; *d* = 1.285.

Discussion

In Experiment 1, we showed that 14-month-old infants can learn to identify a target that is specified by its relation to a referent sample, either as being identical to that target or different from it. Infants tested in MTS looked in anticipation to the card that was the same as the sample, whereas those tested in NMTS looked in anticipation to the other card, the one different from the sample. Furthermore, learning a rule about sameness (MTS) did not appear harder, and if anything appeared easier, than learning a rule about difference (NMTS).

It should be noted, however, that the success of infants tested in MTS appeared only transient. They succeeded in Block 2, but behaved at chance in Block 3. It is possible that infants lost interest in the task after they learned it. In contrast, infants tested in NMTS were still learning in Block 2 and succeeded only in Block 3.

Paradigms teaching participants to choose a match or a non-match do not all necessarily tap representations of the abstract relations same and different. Two features of Experiment 1 make it likely that infants could only succeed by responding based on abstract relations like same and different. First, the sample, the match, and the non-match were unambiguously three separate objects. Second, nine pairs of stimuli were used so that the number of specific associative rules to learn in 12 to 24 trials would be too high even for an adult.

Experiment 2. What rules are infants learning?

Experiment 1 has several limitations. First, perhaps because the time for anticipation was only 1 second, infants looked to one of the side cards in anticipation of spinning (either correct or incorrect) in less than half of the trials. To increase the frequency of anticipations, in Experiment 2, we increased the anticipation period to 2 seconds. Second, Experiment 1 had no test of generalization to new stimuli. It did use nine pairs of stimuli, so that infants were unlikely to have learned separate associative rules for each pair, and instead probably learned an abstract rule. But to ensure that infants could succeed only by using an abstract rule, Experiment 2 included a generalization test involving novel stimuli.

Besides providing a replication of Experiment 1, the main goal of Experiment 2 was to uncover the content of the representations that underlie infants' success in MTS and NMTS. Infants could succeed on MTS by representing a rule formulated over the relation same (*look at the side card that is the same as the middle card*) or by representing a rule formulated over the relation different (*avoid the side card that is different from the middle card*). Likewise, infants could succed in NMTS, by representing the rules *look at the side card that is different from the middle card* or *avoid the side card that is the same as the middle card*.

This question was anticipated in the animal literature with what is called the match/oddity paradigm (Carter & Eckerman, 1975; Skinner, 1950; Zentall et al., 1981). In this paradigm, like in Kaldy and colleagues' (2015), participants see a small number of pairs of stimuli (so they certainly could be learning specific associative rules), and are trained to select either specific matching stimuli, or specific non-matching oddity stimuli. For example, in a 1-pair match/oddity task with stimuli A and B, the rules in the Match condition would be: *if A, pick A*, and *if B, pick B.* In the Oddity condition, the rules would be: *if A, pick B*, and *if B, pick A.* Zentall and colleagues (1981) observed that instead of learning these two associative rules in the Oddity condition, animals could learn *if A, avoid A* and *if B, avoid B*. They tested what rules pigeons actually learn by using 4 stimuli (e.g., A, B, C and D). One given sample could appear with two comparison stimuli in the training session (e.g., for sample A, the choice pairs would be A or B, and A or C). The fourth stimulus was introduced in the test. In the Match condition, if pigeons learned associative rules like *if A, pick A*, they should continue to succeed when the fourth stimulus replaced the non-matching choice (for sample A, choice A or D), and indeed they did. In the Oddity condition, if pigeons learned associative rules like *if A, pick B*, they should succeed when the fourth stimulus replaced the matching choice (for sample A, choice D or B). But subjects in the Oddity condition failed these trials; instead, they succeeded on the same trials as the pigeons in the Match condition. Zentall et al. concluded that the pigeons had learned a rule based on *seeking* A in the Match condition, and *avoiding* A in the Oddity condition. Zentall et al. used these results to rule out the associative account of success at the match/oddity paradigm, but their logic can be extended to ask whether, in an abstract MTS/NMTS paradigm, infants will learn the rule *seek same* in MTS and *avoid same* in NMTS, or whether they will learn *seek different* in NMTS.

Infants were first trained in a procedure similar to that of Experiment 1 (Figure 3), but with 6 pairs of stimuli. In a subsequent test phase (Figure 4), infants were shown cards with novel symbols on them, thus testing for generalization. Moreover, in test trials, only one of the side cards was revealed (and rehidden), while the second side card was never revealed. Then, the middle card was revealed. On half of the test trials, the revealed side card displayed the same symbol as the middle card (visible-Same test trials), and on the other half it displayed a different symbol (visible-Different test trials). Thus, infants only had information about one of the alternatives: either the one that was the same, or the one that was different, from the middle card. After a delay, the rewarding sound was played, even though the child could not see which hidden symbol might be animated. We measured infants' looking at the two side cards.

If infants in MTS have learned the rule *look at the side card that is the same as the middle card* they should succeed at visible-Same test trials; and if infants in NMTS have learned the rule *look at the side card that is different from the middle card,* they should succeed at visible-Different test trials. However, if infants are succeeding at both tasks using a representation of the relation same (*look at the side card that is the same as the middle card* for MTS, and *avoid the side card that is the same as the middle card* for NMTS), they might paradoxically fail on the visible-Different test trials in NMTS, even though the previously revealed cards are actually the antecedent to the rule NMTS is designed to test for.

Material and methods

Participants—Fifty 14-month-old infants (mean 14 months 12 days; range 13 months 20 days to 15 months 13 days; 29 boys and 21 girls) participated in this experiment. Of these, 26 were tested in the MTS condition, and 24 were tested in the NMTS condition). Twenty-one additional infants were tested, but excluded for fussiness (9 in MTS; 12 in NMTS). Children were recruited and compensated in the same way as Experiment 1, and, as they were drawn from the same database, the overall demographics were also similar.

Procedure—As in Experiment 1, infants were seated on their caregiver's lap, in a darkened room, facing a Tobii Eye-tracker T60. Caregivers were asked to close their eyes for the duration of the experiment. The experiment consisted of 24 familiarization trials (Figure 3) followed by 12 test trials (Figure 4).

The familiarization trials had the same general structure as Experiment 1. In each familiarization trial, infants were shown a 15-second video displaying three cards aligned horizontally. All three cards were initially face down; the backs of the right and left cards were blue, and the back of the middle card (the sample) was red. The three cards then flipped over sequentially (with 1.5 seconds between flips and each flip lasts .5 second), revealing symbols on their fronts. The two side cards flipped before the middle card; the side of the card that flipped first was counterbalanced across trials. The two side cards always displayed different symbols, and the middle card displayed a symbol that was the same as one of the two side cards, counterbalanced across trials. After a 2-second delay (the anticipatory period), one of the side cards was animated by the symbol on it looming back and forth for 3 seconds, accompanied by a rewarding sound played from a centrally located speaker. The card that was animated was the one with the same symbol as the middle card in the MTS condition, and the card with a different symbol than the middle card in the NMTS condition. Finally, the three cards flipped back in the same order as they had originally flipped.

Test trials were similar to familiarization trials, except that one of the side cards flipped back before the middle card flipped, and the other side card remained unflipped throughout, with the symbol never revealed (Figure 4). We refer to these two cards as the *revealed side card*, and the *unknown side card*, respectively. As in the familiarization trials, each test trial began with the three cards facedown. Next, one of the side cards flipped and revealed its symbol for 1.5 seconds, and then flipped back. After 1 second, the middle card flipped to reveal its symbol. Two seconds later the rewarding sound was played for 3 seconds from a centrally located speaker, and the trial ended after one additional second. During the whole 6-second period in which infants' looking time was measured, only the middle card's symbol was visible.

There were two types of test trials. In the six visible-Same test trials, the revealed side card had the same symbol on it as the middle card. In the six visible-Different test trials, the revealed side card had a different symbol on it than the middle card. Visible-Same and visible-Different trials were presented in pseudorandom order, so that no more than 2 trials of the same type followed each other. The side of the card that was the same as the middle card (whether it was visible or not) was counterbalanced across test trials. Test trials were identical for infants tested in the MTS condition and infants tested in the NMTS condition, although the correct response was the opposite in the two conditions.

Stimuli—We used the same pairs of stimuli as in Experiment 1. For each participant, six pairs were randomly selected for use in familiarization trials, and the 3 remaining pairs were used in the test trials.

Analysis—The analysis of the familiarization trials was the same as for Experiment 1, with the exceptions that the length of the anticipatory period was increased from 1 second to 2 seconds, and there were only two blocks of trials. On average, 16% of familiarization trials were not coded as participants failed to fixate the middle card before the rewarded card was animated. Furthermore, trials with no anticipation were not further analyzed. Infants anticipated in 70% of all familiarization trials.

The anticipatory period during the familiarization trials was the 2 seconds after the middle card had flipped and revealed its symbol, but before one of the side cards was animated. During this period, we used the same two measures as in Experiment 1 to analyze whether infants looked at the correct or incorrect card: cumulative looking time and first fixation. The familiarization trials were divided into two blocks of 12 trials each, and in each block we calculated difference scores for each of these measures – (#correct − #incorrect)/(#correct + #incorrect).

Test trials where participants did not fixate the revealed side card before it flipped back, or where they did not fixate the middle card after its symbol was revealed, were not further analyzed (14% of all test trials). Furthermore, trials with no searching behavior (i.e., where infants did not fixate one or the other side card after fixating the flipped middle card) were not further analyzed. Infants searched in 64% of all test trials. For each trial, infants' looking behavior was coded after they looked at the flipped middle card, through to the end of the trial, giving a maximum time of 6 seconds. During the coding window, neither of the symbols on the side cards were visible. We first coded whether participants looked at the previously revealed side card or the unknown side card, according to their first fixation and cumulative looking time. For each measure, infants who were biased to look at either the revealed side card or the unknown side card were removed from the analysis. To identify biased participants, we tested whether the number of trials where a participant looked at the previously revealed side card differed from chance (two-tail binomial test $P < .1$). The revealed side card was the correct response ½ of the time and incorrect ½ of the time, depending upon whether it was a visible-Same trial or a visible-Different trial, so such biases were unrelated to the rule that infants had been taught.

The remaining infants' looking behavior was recoded based on whether they looked at the correct or the incorrect side card. For MTS, the correct card was the revealed card in visible-Same trials, and the unknown card in visible-Different trials. For NMTS, the correct card was the unknown card in visible-Same trials, and the revealed card in visible-Different trials. Difference scores were computed for each type of test trial and each measure separately.

Results – Familiarization trials

Familiarization results are presented in Figure 5. The increased anticipation period indeed led to a higher rate of anticipation (45% of the first 24 familiarization trials in Experiment 1, compared to 70% of the 24 familiarization trials in Experiment 2). Perhaps because of the increased time to fixate the two side cards in Experiment 2, there was a robust novelty preference on the first 12 familiarization trials: infants in both the MTS and NMTS conditions looked more at the side card that was different from the middle card initially (see Figure 5). This card being the correct one in NMTS, and the wrong one in MTS, this led to a significant main effect of task. As in Experiment 1, infants in the MTS condition showed evidence of learning by the second block of familiarization trials, increasing their looking to the side card that was the same as the middle card. Infants in the NMTS condition did not significantly improve between Block 1 and Block 2, perhaps because they already had a tendency to look at the card that was different from the middle one. However, their performance was better than chance in Block 2. Detailed analyses follow.

Cumulative looking time and first fixations were each analyzed with a repeated measures ANOVA with Block (1, 2) as a within-subjects factor and Task (MTS, NMTS) as between-subjects factor. In the cumulative looking time analysis, the ANOVA revealed a main effect of Task; $F(1, 48) = 26.49$; $P < .001$; $\eta^2 = .356$, with infants looking more to the correct card in NMTS than MTS. The effect of Block approached significance; $F(1,48) = 3.04$; $P = .088$; $\eta^2 = .06$; infants looked more to the correct card in Block 2 than Block 1. The interaction of Block and Task was not significant; $F(1,48) = 1.12$; $P = .29$; $\eta^2 = .023$. The results from the first fixation analysis were very similar: there was a main effect of Task; $F(1,48) = 10.90$; $P = .002$; $\eta^2 = .185$; as well as a main effect of Block; $F(1, 48) = 5.07$; $P = .03$; $\eta^2 = .096$. The interaction of Block and Task was not significant; $F(1,48) = 1.27$; $P = .26$; $\eta^2 = .026$. Planned comparisons showed that infants tested in MTS improved between Block 1 and Block 2 (cumulative looking time: $t(25) = 2.43$; $P = .02$; *Cohen's* $d = .97$; first fixation: $t(25) = 2.98$; $P = .006$; $d = 1.19$), while infants tested in NMTS did not.

Finally, planned one-sample t-tests tested infants' performance against chance for each Block and each Task separately. In MTS, infants' performance was different from chance in the wrong direction in Block 1 with both first fixation and cumulative looking time as dependent measures (cumulative looking time: $M = -.27$; $t(25) = -4.21$; $P < .001$; $d = 1.68$; first fixation: $M = -.22$; $t(25) = -3.30$; $P = .003$; $d = 1.32$). Infants' performance in MTS was at chance in Block 2 for both measures (cumulative looking time: $M = -.05$; $t(25) = -.74$; $P = .47$; $d = .30$; first fixation: $M = .02$; $t(25) = .35$; $P = .73$; $d = .14$). In NMTS, infants' performance was at chance for both measures in Block 1 (cumulative looking time: $M = .12$; $t(23) = 1.76$; $P = .09$; $d = .73$; first fixation: $M = .085$; $t(23) = 1.28$; $P = .21$; $d = .53$). In Block 2, infants performance in NMTS was significantly better than chance for cumulative looking time ($M = .17$; $t(23) = 2.09$; $P = .047$; $d = .87$) and marginally better than chance for first fixation ($M = .16$; $t(23) = 1.92$; $P = .067$; $d = .80$).

Results – Test trials

Results for test trials are presented in Figure 6. The overall results for MTS are that infants looked at the correct card (the same-alternative) on trials where the same-alternative had been previously revealed, but not on trials where the different-alternative had been revealed. Remarkably, this pattern also held for NMTS: infants looked at the correct card (the different-alternative) on trials where the same-alternative had been previously revealed, but not on trials where the different-alternative had been revealed. Detailed analyses follow.

Infants searched in 64% of test trials. Three participants tested in MTS were not included in the first fixation analysis, two due to a bias to look at the *unknown* side card (11/11 trials; $P = .001$, binomial test; 7/8 trials; $P = .07$) and one due to a bias to look at the *revealed* side card (7/8 trials; $P = .07$). One participant tested in MTS was not included in the cumulative looking time analysis due to a bias to look at the unknown side card (9/11 trials; $P = .06$). None of the participants tested in NMTS were excluded for a bias in either analysis. Cumulative looking time and first fixations were analyzed with repeated measures ANOVAs with Trial Type (visible-Same, visible-Different) as a within-subjects factor and Task (MTS, NMTS) as between-subjects factor.

For the cumulative looking time analysis, the ANOVA yielded a main effect of Trial Type; $F(1,47) = 6.31$; $P = .015$; $\eta^2 = .118$, with infants looking more to the correct side card in visible-Same trials than visible-Different trials. The effect of Task and the interaction were not significant. One-sample t-tests showed that infants' performance was better than chance for visible-Same trials; $M = .18$; $t(48) = 2.33$; $P = .024$; $d = .67$; but not for visible-Different trials; $M = -.07$; $t(48) = -.78$; $P = .43$; $d = .23$.

Analyzing first fixations, the main effect of Trial Type approached significance; $F(1,45) = 3.1$; $P = .085$; $\eta^2 = .064$. The effect of Task and the interaction were not significant. One-sample t-tests again showed that infants' performance was better than chance for visible-Same trials; $M = .22$; $t(46) = 3.09$; $P = .003$; $d = .91$; but not for visible-Different trials; $M = .03$; $t(46) = .42$; $P = .67$; $d = .12$.

Planned one-samle t-tests further tested infants' performance against chance for each Trial Type and each Task separately. Infants tested in MTS performed better than chance on visible-Same trials with first fixation as the dependent variable; $M = .21$; $t(22) = 2.07$; $P = .05$; $d = .88$; with cumulative looking time as the dependent variable, infants were not successful; $M = .08$; $t(24) = .87$; $P = .39$; $d = .35$. Infants tested in NMTS performed better than chance on visible-Same trials using *both* measures (first fixation: $M = .24$; $t(23) = 2.26$; $P = .03$; $d = .94$; cumulative looking time: $M = .28$; $t(23) = 2.33$; $P = .03$; $d = .97$). In contrast, infants performed at chance in visible-Different trials in both MTS (first fixation: $M = .11$; $t(22) = .85$; $P = .40$; $d = .36$; cumulative looking time: $M = -.11$; $t(24) = .79$; $P = .44$; $d = .32$) and NMTS (first fixation: $M = -.03$; $t(23) = -.33$; $P = .74$; $d = .14$; cumulative looking time: $M = -.03$; $t(23) = -.24$; $P = .81$; $d = .10$).

In sum, infants in both MTS and NMTS performed significantly better on visible- Same test trials than on visible-Different test trials. Infants in both conditions were at chance on Visible-Different test trials, and performed better than chance on visible-Same test trials.

Finally, we asked whether performance in familiarization and in test were correlated. In particular, we asked whether the performance in visible-Same trials and visible-Different trials correlated with the performance in Block 2 of the familiarization and with the improvement of performance between Block 1 and Block 2 of the familiarization. We found a significant correlation between infants' first fixation performance in visible-Same trials and their improvement between Block 1 and Block 2 of the familiarization ($R^2 = .105$; $P = .026$; Figure 7). Other correlations were not significant (all $Ps > .33$).

Discussion

In both MTS and NMTS, during the first block of familiarization, infants tended to look at the side card that was different from the middle card, possibly because it is perceptually salient. In MTS, infants overcame this tendency by the second block of familiarization, reflecting learning that the card that was the same as the middle one would be animated, whereas in NMTS, they maintained the initial preference. Thus, although infants showed little statistical evidence of learning during the NMTS familiarization, they performed better than chance by the second block. That they were indeed learning an abstract rule was confirmed by the test trials.

The test trials provided a significant challenge to infants. Not only were the symbols new, and the side symbols hidden at the time of response, but infants had seen only one of the side symbols and had to rely on memory of it to infer which hidden symbol was animated and making a noise. Nonetheless, infants succeeded robustly on the visible-Same test trials: when they had previously seen the symbol that matched the middle card, they looked back to that card (whose symbol was now hidden) in MTS, and looked at the other card in NMTS. Furthermore, this performance in the test correlated with infants' improvement in the familiarization. In contrast, infants failed on the visible-Different trials, both in MTS and NMTS.

The most important result from Experiment 2 is the abject failure in visible-Different trials in the NMTS condition, evident in both the first fixation and the cumulative looking time analyses. If infants had learned a rule predicting that the symbol different from the sample would pulsate, they should have succeeded on these trials, since they had seen the antecedent to this rule. Instead, they succeeded on the visible-Same test trials in the NMTS condition. This finding confirms they had learned an abstract rule, since the symbols were different from those they had been trained on. It also suggests that the rule they had learned was *avoid the card that is the same as the sample*, rather than *seek the card that is different from the sample*.

Experiment 2 thus shows that infants succeed in both MTS and NMTS by detecting the card that is the same as the sample. They *choose* that card in MTS and *avoid* it in NMTS. Infants do not use any abstract representation of different in these experiments.

Experiment 3: Adults

The results of Experiment 2 suggest that infants only use a representation of same in both MTS and NMTS. There are several reasons this might be so: the relation same may be more salient than the relation different, or it may be easier to process representations of the relation same than representations of different, or it may even be that the relation different is not represented in infancy at all. In Experiment 3, we ask whether adults, despite undoubtedly having abstract mental symbols for the relations same and different (for they have words for each relation), also rely on a representation of same in both MTS and NMTS.

Experiment 3 was closely modeled on the infant study, except that we explicitly pointed out to the adult participants the rule they should follow. If adults use a representation of same in MTS, reaction times and errors on the visible-Same trials should be lower than those on the visible-Different trials, for the visible symbols in the visible-Same trials are the input to the instructed rule. Since adults surely represent the relation different, we do not expect them to be at chance on visible-Different trials for NMTS, as infants are. Instead, if adults follow a rule using a representation of different in NMTS, reaction times and errors on the visible-Different trials should be lower than those on the visible-Same trials, for the visible symbols in visible-Different trials are the input to the instructed rule. However, it is also possible that adult errors and reaction times will pattern with the infant results, such that the visible-Same trials are easiest for both MTS and NMTS. This would suggest that for adults, as well as for infants, computations of sameness are primary: it is more natural to represent the rule in NMTS as *avoid same* than *seek different*, even after having been verbally instructed that the task is to indicate the symbol that is different from the sample.

Material and methods

Participants—Twenty adult volunteers were recruited (age range 18–31 years; 17 female and 3 male) from among the research assistants in Harvard's Laboratory for Developmental Studies. Participants were tested on MTS in one session and NMTS in another session, separated by at least 24 hours, with the order of the sessions counterbalanced across participants. The participants were unfamiliar with the nature and goals of this study.

Stimuli—We used the same pairs of stimuli as in Experiments 1 and 2. For each participant, in each session, six pairs were randomly selected for use in all-visible familiarization trials, and the 3 remaining pairs were used in the visible-Same and visible-Different trials.

Procedure—Each session consisted of 90 trials: 66 all-visible trials, 12 visible-Same trials, and 12 visible-Different trials. The first 18 trials were all-visible trials, and the remaining 72 trials were randomly chosen from the three trial types. Participants watched videos of the trials on a computer screen and responded by pressing keys on the computer keyboard.

The paradigm of Experiment 3 is depicted in Figure 8. In every trial, three filled white squares were presented side by side on a black background. Participants were instructed that pictures would successively appear and disappear in each square, with the middle square always going last. Only the white frame of the square remained visible after the picture it contained disappeared. Each picture was shown for 400 ms, with 600 ms between pictures.

The instructed rules for MTS and NMTS were *choose same* and *choose different*, respectively; the word "different" was not used in the instructions for MTS, and the word "same" was not used in the instructions for NMTS. In MTS, participants were instructed to press ‘q’ (left) if the picture that appeared on the left was the *same* as the middle one, and ‘p’ (right) if the picture that appeared on the right was the *same* as the middle one, thus indicating which side picture had been the same as the middle one. In NMTS, participants were instructed to press ‘q’ (left) if the picture that appeared on the left was *different* from the middle one, and ‘p’ (right) if the picture that appeared on the right was *different* from the middle one, thus indicating which side picture had been different from the middle one. In each trial, participants had 2 seconds to respond, beginning at the appearance of the middle picture.

In all-visible trials, each square displayed a picture. In visible-Same and visible-Different trials, one of the two side pictures was replaced by a blank white square. Participants were not aware of this manipulation, but were told that, in some trials, one picture might appear so fast that it could not be perceived. Participants still needed to answer as if they had seen all three pictures. They were provided with an explicit example: for example, in NMTS, “if you see a circle on the left, nothing on the right, and a circle in the middle, the invisible symbol was different from the middle one, and the correct answer is Right. Therefore press ‘p’.”

Results

Two repeated measures ANOVAs examined the effects of Order (MTS first, NMTS first), Task (MTS, NMTS) and Trial Type (all-visible, visible-Same, visible-Different) on the dependent variables of reaction time for correct trials (RTs) and accuracy. The results are plotted in Figure 9 (RTs) and Figure 10 (accuracy). The most striking result from these analyses is that in NMTS, in spite of being instructed to indicate the side picture that was different form the middle one, participants were slower and made more errors on the visible-Different test trials than on the visible-Same trials. As with the infants, the overall effects of the visible-Same and visible-Different manipulation were the same in MTS and NMTS. Detailed analyses follow.

Reaction times—The ANOVA on RTs found no main effect and no interactions involving Order[1], all *Ps* > .2. There was a main effect of Task, F(1, 18) = 29.78; $P < .001$; $\eta^2 = .623$, reflecting slower RTs in NMTS ($M = 848$ ms) than in MTS ($M = 696$ ms). There was also a main effect of Trial Type; F(2, 36) = 26.95; $P < .001$; $\eta^2 = .6$. Paired t-tests (Bonferroni-corrected for three comparisons) revealed that participants had slower RTs on visible-Different trials ($M = 903$ ms) than on visible-Same trials ($M = 722$ ms); t(19) = 5.63; $P < .0001$; and slower RTs on visible-Different trials than on all-visible trials ($M = 691$ ms); t(19) = 5.30; $P < .0002$. There was no difference in RTs between all-visible trials and visible-Same trials; t(19) = 1.64; $P = .35$. The interaction between Task and Trial Type was not significant; F(2, 36) = 2.22; $P = .12$; $\eta^2 = .11$.

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[1] The pattern of results did not differ whether participants were tested first on NMTS or MTS. Most importantly, participants who saw NMTS first were slower in that task in visible-Different trials ($M = 1091$ ms) than in all-visible trials ($M = 779$ ms); t(9) = 3.26; $P < .01$; and in visible-Same trials ($M = 808$ ms); t(9) = 3.62; $P = .006$. They also committed more errors in visible-Different trials than in all-visible trials; t(9) = 3.70; $P = .005$; and in visible-Same trials; t(9) = 3.67; $P = .005$.

Accuracy—Participants did not respond on 0.3% of MTS trials and 3% of NMTS trials (3% of visible-Same trials, 6% of visible-Different trials, and 3% of all-visible trials). These missing trials were coded as incorrect answers, but the results of the following analyses are unchanged if the trials with no response are simply left out of the analyses.

The accuracy results largely mirrored those of the RT analysis above. The ANOVA on accuracy yielded no main effect or interactions involving Order; all $Ps > .18$. There was a main effect of Task; $F(1, 18) = 9.3$; $P = .007$; $\eta^2 = .341$; reflecting participants' worse performance on NMTS ($M = 89\%$) than on MTS ($M = 98\%$). There was also a main effect of Trial Type; $F(2, 36) = 11.89$; $P < .001$; $\eta^2 = .398$. Paired t-tests (Bonferroni-corrected for three comparisons) revealed that participants performed worse on visible-Different trials ($M = 88\%$) than either visible-Same trials ($M = 96\%$; $t(19) = 3.37$; $P = .010$) or all-visible trials ($M = 97\%$; $t(19) = 3.50$; $P = .007$). The difference between performance on visible-Same trials and all-visible trials was not significant; $t(19) = 2.33$; $P = .09$.

Unlike the RT analysis, there was also a significant interaction between Task and Trial Type (see Figure 10; $F(2,36) = 15.07$; $P < .001$; $\eta^2 = .456$), driven by the fact that performance was worse on the visible-Different trials in NMTS, whereas it was uniformly high on all other trials. The source of the interaction was confirmed by paired comparisons: accuracy was lower on the visible-Different trials in the NMTS condition ($M = 79\%$), than on all other trial types (all $Ps < .03$, Bonferroni-corrected for 15 comparisons), and no other trial types differed from each other.

In sum, the accuracy analysis converged with the RT analysis in showing that visible-Different trials in the NMTS condition posed the greatest difficulty for participants. In these trials, the antecedent to the rule they had been instructed to follow ("indicate the card that is different from the middle card") had been seen, and yet these were the hardest trials of all.

Discussion

Unlike Experiment 2 with infants, the task in Experiment 3 was easy for adults, with participants committing almost no errors – except in visible-Different trials of NMTS. The data suggest that adults, like infants, carry out both MTS and NMTS in this paradigm by representing rules articulated in terms of sameness: for MTS, *select the side with same symbol* or *seek same*, and for NMTS, *avoid the side with same symbol* or *avoid same*.

The reaction time data are consistent with this conclusion and provide further evidence about the processes underlying adults' performance. First, participants were overall faster in MTS than in NMTS. *Seek same* may be an easier or faster behavioral rule to implement than *avoid same*, because *avoid same* does not specify *what* to seek or *where* to look, whereas *seek same* does. Also, *avoid same* requires identifying which two symbols were the same and then shifting attention to the opposite side, whereas *seek same* requires no such shift of attention. Second, in both MTS and NMTS, adult participants responded faster to visible-Same trials than to visible-Different trials. Our interpretation of this effect is that visible-Different trials require an inference in order to identify the card that should be sought or avoided when following a *seek same* or *avoid same* rule. These two effects are independent and, in the reaction time data, additive. The combination of both effects – in other words, the cost of inferring which card has the same symbol and the subsequent decision to avoid that card – led to the substantial 20% error rate on the visible-Different trials in NMTS.

Despite the availability of the word “different” as a discrete symbol to represent the relation different, adult participants in NMTS spontaneously reformulated the instructed rule “indicate different” as *avoid same*, suggesting that the detection of matches is primary in adults, just as in infants. If the relations same and different are not independent, but linked by negation, it is therefore likely that adults represent different as the negation of same, rather than same as the negation of different. Furthermore, the remarkable developmental continuity from infancy to adulthood strengthens the conclusions from Experiment 2: infants’ performance in Experiments 1 and 2 is most likely subserved by a representation of same alone.

However, there is also an important discontinuity between infants and adults in these tasks. Unlike infants, adults were well above chance on the visible-Different trials in the NMTS condition. If adults and infants are operating on the rule *avoid same*, then success on these trials requires two decisions: an inference that the hidden card is the same, and then switching attention away from that card. Infants’ failure may be due to the difficulty to make the logical inference, or to the difficulty of combining two successive decisions.

General Discussion

An exploration of infants’ representations of same and different is a case study within the more general project of exploring the origin of abstract, combinatorial thought in infancy. The present studies confirm that infants as young as 14 months of age can learn rules that allow them to succeed at both MTS and NMTS. They learn to do so across 9 different pairs of stimuli in Experiment 1 or across 6 different pairs, generalizing to never before seen stimuli, in Experiment 2. These data converge with the literature on MTS in animals, and with other studies that reflect representations of same or different in infancy, such as habituation to pairs of objects that are the same or to pairs that are different (Addyman & Mareschal, 2010; Ferry et al., 2015; Tyrell et al., 1991), habituation to patterns specified by pairs of identical elements such as ABA or ABB (Dawson & Gerken, 2009; Johnson et al., 2009; Marcus et al., 1999; Rabagliati et al., 2012; Saffran et al., 2007), and conditioned responses on pairs of identical elements (Hochmann, 2010; Hochmann et al., 2011; Kovács, 2014; Tyrell et al., 1993; Walker & Gopnik, 2014).

Finding evidence for representations with the abstract content same or different is just the first step. Here, we explored what representations actually underlie MTS and NMTS. In particular, we asked whether infants represent both the relation same and the relation different, or only one of them. Our results suggest that infants only use a representation of same in these paradigms. In Experiment 2, we found that 14-month-old infants apparently solve NMTS by following a rule like *avoid the stimulus that is the same as the sample*, rather than a rule like *seek the stimulus that is different from the sample*. Future studies using the design of Experiment 2 could confirm this pattern of findings with animals. Given Zentall and colleagues’ (1981) findings described above, we would expect animals, like our human subjects, to have greater difficulty or to fail outright on visible-Different trials in NMTS.

Infants' exclusive reliance on a representation of same in these studies has suggestive implications for their capacity for abstract combinatorial thought. That infants *do not* deploy a representation of different in Experiment 2 is consistent with the possibility that they *cannot* form such a representation. Why might the representation of same that is deployed in these studies not compose with a representation of negation? One possibility is that infants' representation of same may not be in a format that supports such combination. Another possibility is that infants may lack a mental symbol for negation. The avoidance rule we have proposed to explain success in NMTS (*avoid the stimulus that is the same*) implies some negative attitude towards a given stimulus, which may behaviorally operationalize negation. However, it does not constitute a full-fledged logical negation, if it is not symbolized in a way that supports conceptual combination. In either case, evidence for the absence of a representation of different in prelinguistic thought is consistent with limitations on the combinatorial properties of the representations available in infancy.

In Experiment 3, we show that adults also do not deploy a representation of different in the NMTS paradigm, even though adults are undoubtedly able to form a representation of different, given that they use the word "different." These results strengthen our interpretation of infants' behavior, as they show that the relation same is primary even for adults. This supports the hypothesis that a representation of same may be developmentally antecedent to a representation of different.

However, the finding that adults depend on a representation of same in Experiment 3, despite being able to represent different, also suggests that NMTS may not be the best paradigm to detect a representation of different. Below, we discuss several experiments using other paradigms in search of a representation of different in infancy.

More absence of evidence for a representation of different

Several other studies have found that although infants appear to represent same, there is no evidence that they represent different in similar circumstances. In predictive rule learning paradigms, Kovács (2014) and Hochmann (2010) taught infants that pairs of identical stimuli would predict a reinforcer appearing in one location on a screen (e.g., the right window), and that pairs of different stimuli would predict a reinforcer appearing in another location (e.g., the left window). Across several studies, where the stimuli were pairs of syllables (e.g., "ki ki", "la la" for same; "pa du", "li be" for different) or pairs of colored shapes, 6- to 12-month-old infants learned to predict the location of the reinforcer for the identical pairs, while remaining at chance for the different pairs (Hochmann, 2010; Kovács, 2014). Furthermore, Gervain and colleagues showed that left temporal and frontal cortical areas of newborns react to triplets of syllables containing a repetition, such as "mu ba ba" and "pe na na"; in constrast, no cortical area selectively responds to triplets of three different syllables such as "mu ba ge" and "pe na ku" (Gervain, Macagno, Cogoi, Peña & Mehler, 2008; Gervain, Berent & Werker, 2012).

Thus, across three different paradigms with newborns, 6- to 12-month-olds, and 14-month-olds (Experiment 2 of the present studies), evidence for representation of same is found in the face of lack of evidence for representation of different. It stands to reason that the relation same may be more salient, or less complex, than the relation different in infancy. If different is composed from same and not, then it is a more complex representation than same, and thus plausibly more difficult to represent. Additionally, it would not be surprising for sameness to be more salient than difference; after all, as we look out into our environment, most objects are different one from another, and it is sameness that calls out for explanation. However, it is possible that the asymmetry between representations of sameness and difference in infancy goes beyond matters of complexity and salience – infants may not form representations of the abstract relation different at all. We explore whether this possibility is viable below.

Can Infants Form Representations of Different?

A number of results in the literature may be – and have been – interpreted as evidence that infants can form a representation of different. However, for each of them, we believe that there exists a more parsimonious interpretation of infants' success, one that does not implicate a representation of different.

First, in an anticipatory looking experiment, Addyman and Mareschal (2010) taught infants that two pairs of different shapes (a square and a circle, or a circle and a square) entering a T-maze would reappear on one side of the T-maze, whereas two pairs of same shapes (two circles or two squares) would reappear on the other side. Unlike in the studies discussed above, they found that 8-month-old infants learned to predict the trajectory of the pairs of different shapes and not that of the same shapes, and argued that this shows infants represent the relation different. However, to demonstrate that infants represent an abstract relation same or different, one needs to show that they can generalize whatever rule they have learned to novel, never experienced, stimuli. Infants in this study failed to generalize the rule to novel pairs (e.g., a triangle and a star), suggesting that they learned to predict the trajectory of the specific pairs of stimuli (*a square and a circle go right*), rather than a rule based on the abstract relation different.

Second, several studies have found that young infants can learn and generalize patterns such as ABA and ABB (Dawson & Gerken, 2009; Johnson et al., 2009; Kovács & Mehler, 2009; Marcus et al., 1999; Rabagliati et al., 2012; Saffran et al., 2007). When habituated to many different exemplars of one such pattern (e.g., for ABA: "pi la pi," "zu ta zu," "ga mi ga," etc.), infants generalize their habituation to novel instantiations of this pattern (e.g., "fo de fo") and recover interest when presented with a different pattern (e.g., "fo de de"). To distinguish between ABA and ABB, however, infants only need to learn the position of the repeated elements – knowing that the first and last elements should be the same in ABA or that the last two elements should be the same in ABB. Representing only the relation same is therefore sufficient.

Third, habituation studies show that infants can be habituated to pairs of different objects (Addyman & Mareschal, 2010; Ferry et al., 2015; Tyrell et al., 1991), and will then dishabituate to a pair of same objects. Again, one need not posit a representation of different to explain these results. Instead, infants may habituate to a representation of two objects, without encoding the relation between the two. A pair of same objects might still be surprising when first encountered in the test; the dishabituation would be due to the first appearance of a repeated object. These studies also show that infants habituate to pairs of objects that are the same, and then dishabituate when shown novel pairs that are different. Again, this certainly demonstrates a representation of same that is instantiated during habituation, and sensitivity to its first absence, but does not show a positive representation of different.

Finally, some experiments have found that young children and animals are able to learn to act on a pair of different objects. For example, in one such study, 18- to 30-month-old toddlers were shown that two pairs of different objects activated a toy (a “blicket detector”), while two pairs of same objects did not activate the toy. Given a choice between a novel pair of same objects and a novel pair of different objects, they chose the pair of different objects (Walker & Gopnik, 2014). But in these studies the stimuli always contrast a pair of different objects with a pair of objects that are the same. Thus, children may in fact learn to *avoid* the pair of same objects, rather than learn to choose the pair of different objects.

In sum, to the best of our knowledge, there exists no convincing evidence from habituation or rule learning studies that infants represent the abstract relation different.

Proposed formalism for a representation of same: Same as a repeated variable

So far, we have discussed the content of the representations at play in paradigms designed to tap the abstract relations same and different. We have argued that the content same is certainly represented, but an open question remains: *how* is this content instantiated in the infant’s or animal’s mind? Is there a unitary symbol for same that can enter into rules held in working memory? If so, what is its format? For the remainder of the discussion, we speculate about the answers to these questions. Our proposals are tentative and testable; we offer them in the hope of stimulating others to join in the endeavor of characterizing the nature of representations of same.

In match/oddity experiments that do not test for rule generalization (e.g., Carter & Eckerman, 1975; Skinner, 1950; Zentall et al., 1981; Kaldy et al., 2015), it seems likely that participants hold a representation of each sample in working memory, e.g., circle, square, etc., and set up the procedure for each possible sample in the study *encode circle*, *seek circle; encode square*, *seek square*; etc., for the match condition and *encode circle, avoid circle; encode square, avoid square*; etc., for the oddity condition. What is held in working memory is simply a representation of the sample; same is implemented in a computation of matching or recognizing. That is, for these studies no symbol with the content same need be involved at all.

A similar possibility is open for MTS and NMTS with generalization, but with one important difference: the infant must be able to set up a procedure that operates on a variable. That is, infants may learn a procedure to seek or avoid *whatever sample* is placed in working memory, hence representing *encode V, seek V* and *encode V, avoid V*, where V is a variable that can be repeated and is instantiated by any individual in the domain of possible samples. For instance, implementing this procedure when the sample is a triangle, in MTS, the infant encodes Δ, and subsequently seeks Δ. On this proposal, abstractness is accomplished by the domain of the variable that can fill the role of sample. The representation of sameness is still implicit rather than symbolized, and is carried by a match computation allowing recognition rather than by a unitary symbol.

However, the representations needed for predictive rule learning (Hochmann, 2010; Kovács, 2014; Walker & Gopnik, 2014) and habituation (Addyman & Mareschal, 2010; Ferry et al., 2015; Tyrell et al., 1991) do require some symbol with the content same. Speculatively, for a pair of entities that are the same (*all* of the infant studies of representations of the relation same concern pairs) such a symbol consists in a repeated variable {V V} (i, below). A representation of this format could be held in working memory, and would stand for any pair of repeated individuals. Once the value of the first occurrence of V is set, the value of the second occurrence is constrained to take the same value. The variable repetition thereby implements the relation same. Infants may habituate to multiple occurrences of the repetition operation, and may be conditioned to respond in a particular way to repetitions (e.g., *look right* in Hochmann, 2010; Kovács, 2014 or *seek* or *avoid* in the context of the blicket detector; Gopnik & Walker, 2014).

Interestingly, this formalism may explain why different is more complex than same. The relation different cannot simply be represented by two variables {V W} (ii, below). In {V W}, once the value of V is set, there is no constraint on the value of W; both variables can take any value in the domain (Σ) considered, including the *same* value. Thus, the extension of the representation {V W} is simply two elements, which is broader than the extension of different. To represent different, one must additionally implement a constraint on the possible values of W after having assigned the value of V (iii, below).

i. $V \in \Sigma$, $\{V\ V\}$ instantiates the relation same.

ii. $V \in \Sigma$, $W \in \Sigma$, $\{V\ W\}$ instantiates the number two.

iii. $V \in \Sigma$, $W \in \Sigma^*$, $\{V\ W\}$, *where* Σ^* *is* Σ *except for* V instantiates the relation different.

To our knowledge, there is currently no evidence that infants have representations such as those we are proposing in (iii). However, the pattern learning paradigm may provide an avenue to find evidence for such representations. As discussed above, young infants can learn and generalize patterns such as ABA and AAB (Dawson & Gerken, 2009; Johnson et al., 2009; Kovács & Mehler, 2009; Marcus et al., 1999, Rabagliati et al., 2012; Saffran et al., 2007). In these patterns, same may again be represented by a repeated variable, V, within a triplet: {V V W}. Importantly, there is no evidence that infants represent the constraint that W cannot take the value of V. Even showing that infants discriminate the patterns AAB and AAA would not be sufficient; infants could discriminate these two patterns on the basis of the number of repetitions of the variable V: {V V _} vs. {V V V}, or *the first 2 elements are the same* vs. *the three elements are the same* (Bijeljac-Babic, Bertoncini & Mehler, 1993). However, although infants can discriminate between 2 and 3 elements, their working memory capacity is not sufficient to distinguish 3 from 4 elements (e.g., Feigenson, Carey & Hauser, 2002). Thus, to assess whether infants are capable of representing such a constraint on W, one should show that infants can discriminate between AAAB and AAAA, assuming that {V V V _} and {V V V V} are not discriminable on the basis of the number of repetitions of V. Experiments in our lab are currently testing this possibility.

General lessons about infant and adult cognition

Our results bring us to a general comment about infant cognition. The recent discoveries that infants represent the goals (Woodward, 1998; Gergely & Csibra, 2003) and maybe even beliefs (Onishi & Baillargeon, 2005; Kovács, Téglás & Endress, 2010) of agents, understand social relations such as dominance (Thomsen et al., 2011; Mascaro & Csibra, 2012), and can compute elementary additions and subtractions (McCrink & Wynn, 2004; Wynn, 1992) and even probabilities (Denison, Reed & Xu, 2013; Téglás et al., 2007; 2011; Xu & Denison, 2009; Xu & Garcia, 2008) should not hide the limitations of infant cognition. In fact, despite the many striking similarities between infant and adult cognition, there may be interesting and important differences as well.

With respect to same and different, adults clearly have representations of both of these two abstract relations: the semantic content underlying the words “same” and “different”. They perform at ceiling in our version of the MTS and NMTS tasks. Moreover, adults appear to translate an instructed rule about different (*seek different*) into a rule relying on same (*avoid same*). These results suggest that sameness is primary for adults and that they represent different as the negation of same, rather than same as the negation of different.

Infants also represent the abstract relation same, allowing them to solve tasks such as MTS and NMTS, but, as argued above, there is no evidence that young infants represent the abstract relation different. Why is that so? Maybe the relation same is special, as others have argued (e.g., Endress, Nespor & Mehler, 2009). Moreover, infants may lack the cognitive tools to build the relation different as the negation of same. It is possible that the relation same is not represented in a format that can combine with logical negation, or that infants lack a logical negation operator. In fact, even though it is far too early to draw conclusions on this matter, our results are certainly compatible with the view that the infant’s mind is not equipped with a combinatorial language of thought, in which abstract relations are represented by unitary symbols that can compose with logical operators.

Conclusion

By studying the case of the abstract relations same and different, we have begun investigating the ontogeny of abstract combinatorial representations that are necessary for human higher cognition faculties such as language and reasoning. In two experiments, we showed that human infants have an abstract representation of the relation same, two years before they acquire the words “same” and “different”. In contrast, we found no evidence that infants represent the abstract relation different or not same. The exact nature of infants’ representations of the relation same remains to be explicated.

Acknowledgments

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Highlights

- We investigated the representations that underlie infants' (14-month-olds) and adults' success at match-to-sample (MTS) and non-match-to-sample (NMTS) tasks.
- Infants learned abstract rules.
- Infants tested in MTS learned to *seek* the stimulus that is the same as the sample.
- Infants tested in NMTS did not learn to *seek* the stimulus that is different from the sample.
- Infants tested in NMTS learned to *avoid* the stimulus that is the same as the sample.
- Adults also rely on a representation of sameness in both MTS and NMTS.

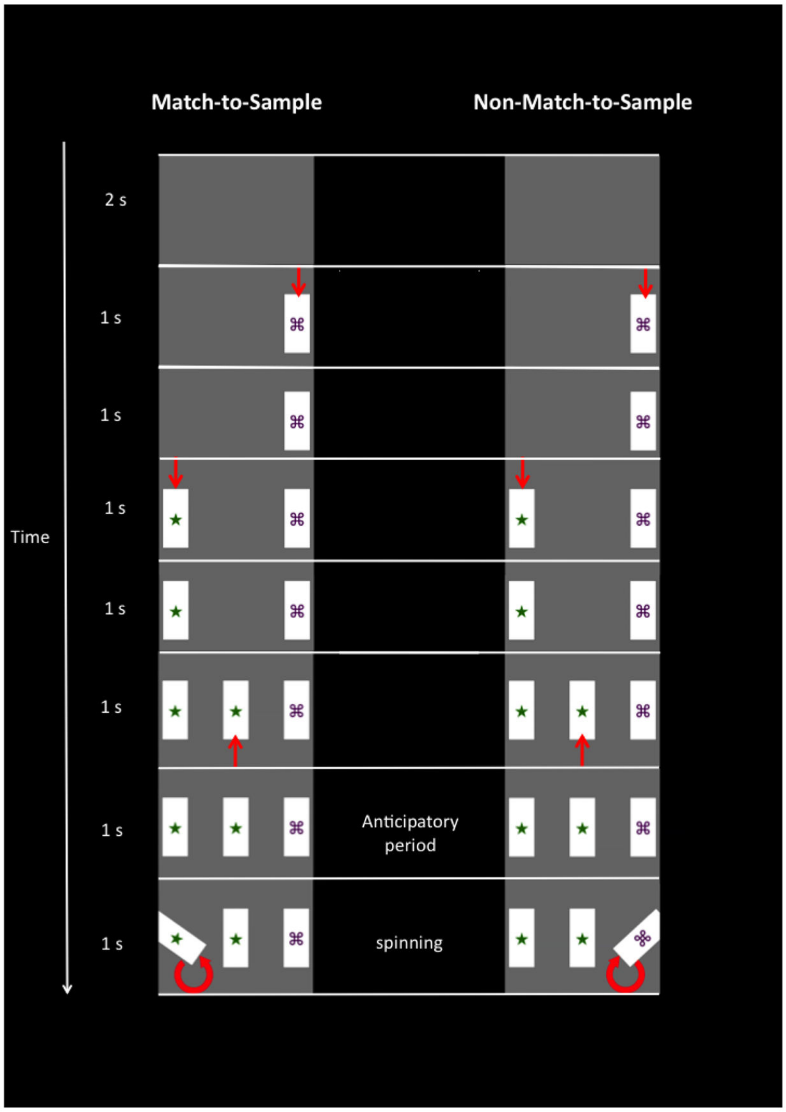

Figure 1.

Structure of a trial in the MTS condition (left) and the NMTS condition (right) in Experiment 1. Animations are depicted by red arrows.

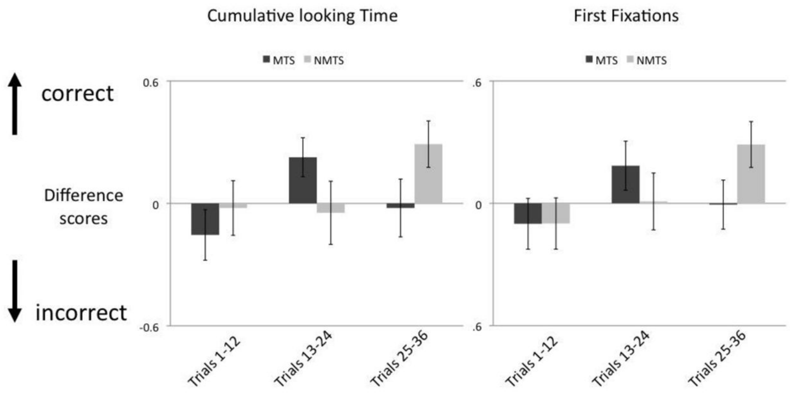

Figure 2.

Experiment 1 - Difference scores for the Cumulative looking time Analysis (left) and First Fixation Analysis (right) for infants tested in match-to-sample (MTS; dark grey bars) and non-match-to-sample (NMTS; light grey bars). Error bars represent standard errors from the mean.

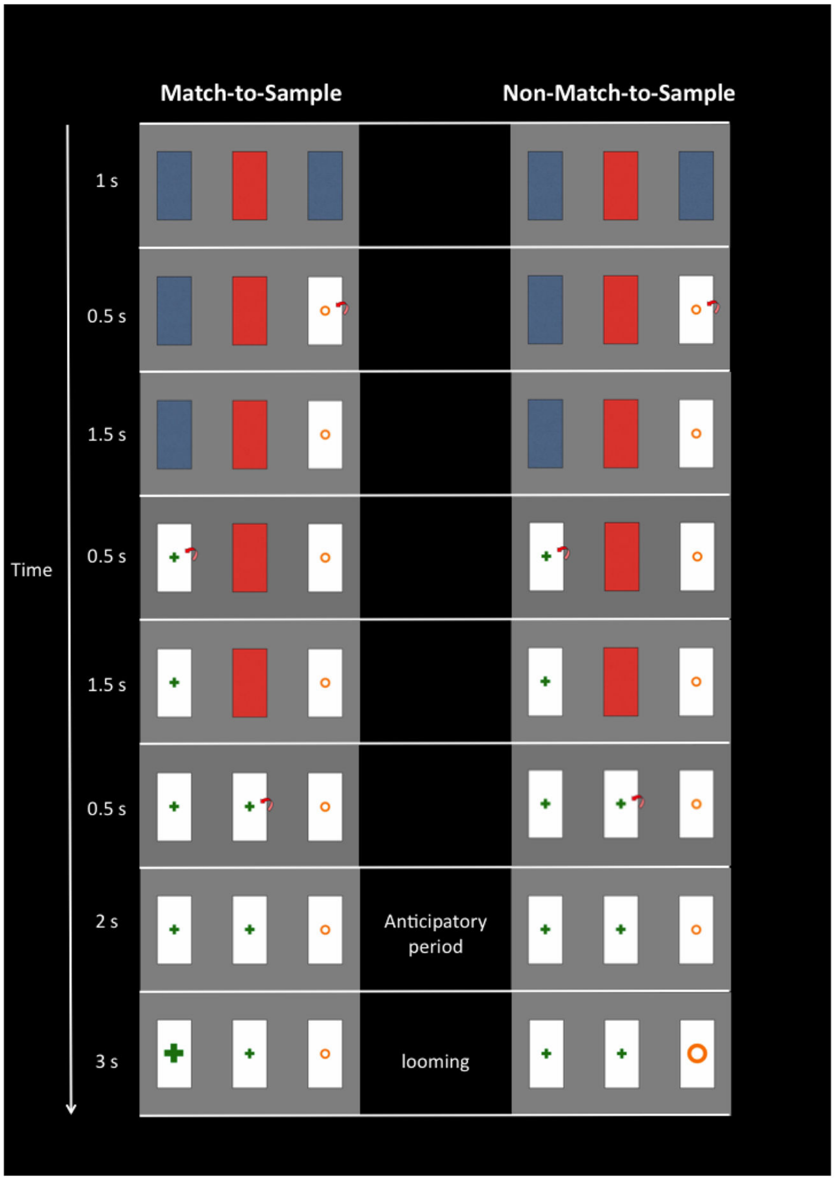

Figure 3.
Structure of Familiarization trials in the MTS condition (left) and NMTS condition (right) of Experiments 2. Animations are depicted by red arrows.

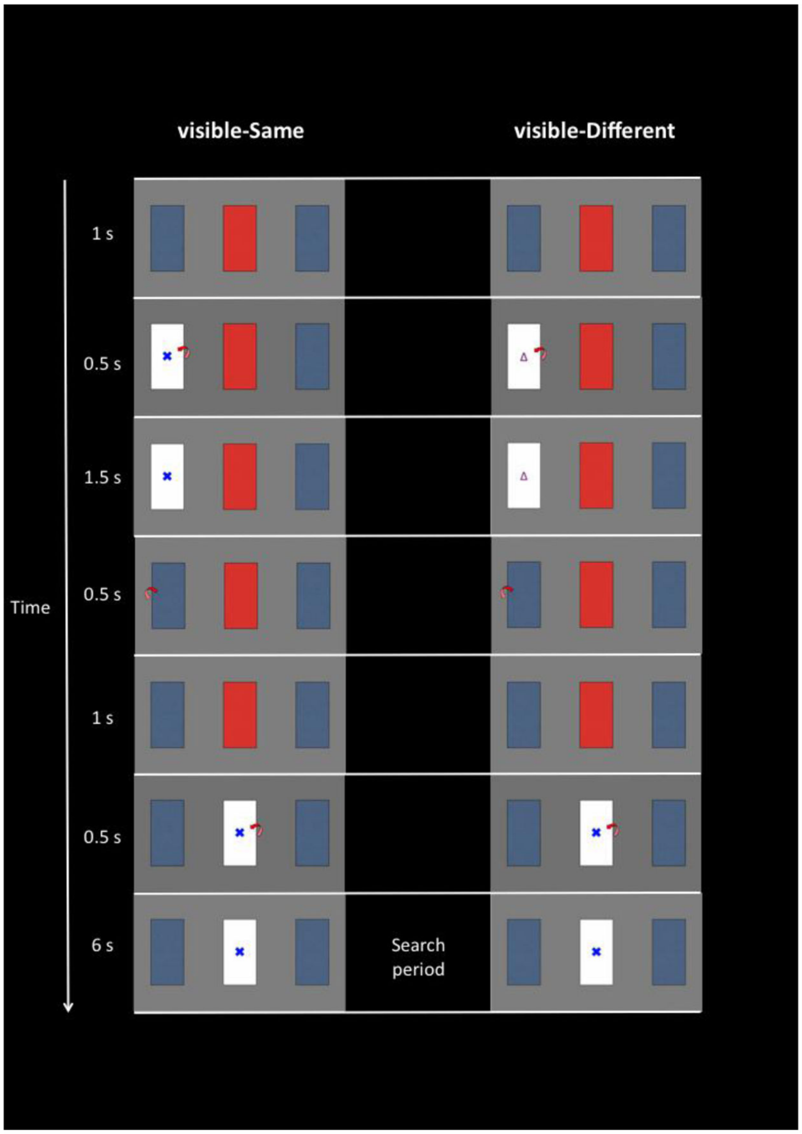

Figure 4.

Structure of Test trials in Experiments 2. Animations are depicted by red arrows.

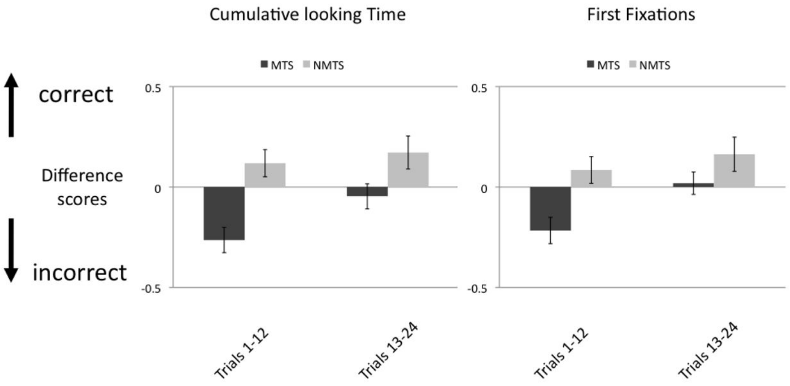

Figure 5.

Familiarization trials of Experiment 2: Difference scores for the Cumulative looking time Analysis (left) and First fixation Analysis (right) in familiarization for infants tested in match-to-sample (MTS; dark grey bar) and non-match-to-sample (NMTS; light grey bar). Error bars represent standard errors from the mean.

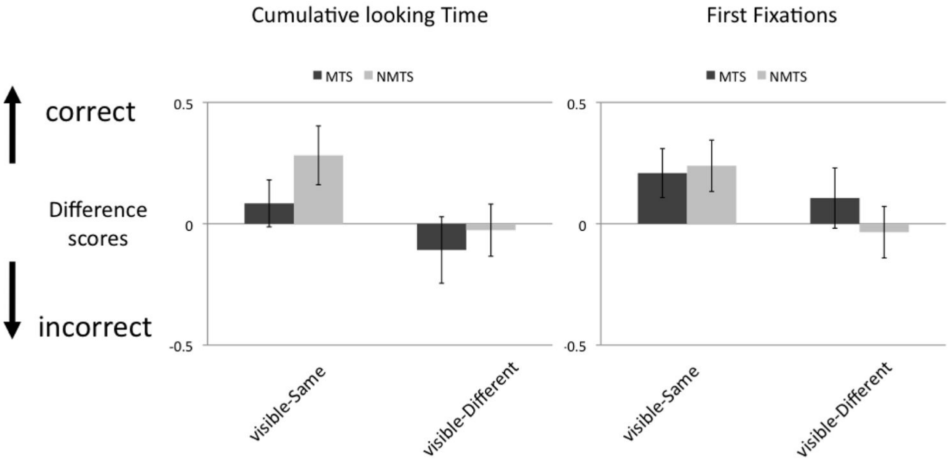

Figure 6.

Test trials of Experiment 2: Difference scores for the Cumulative looking time Analysis (left) and First Fixation Analysis (right) in test for infants tested in match-to-sample (MTS; dark grey bar) and non-math-to-sample (NMTS; light grey bar) in visible-Same and visible-Different trials. Error bars represent standard errors from the mean.

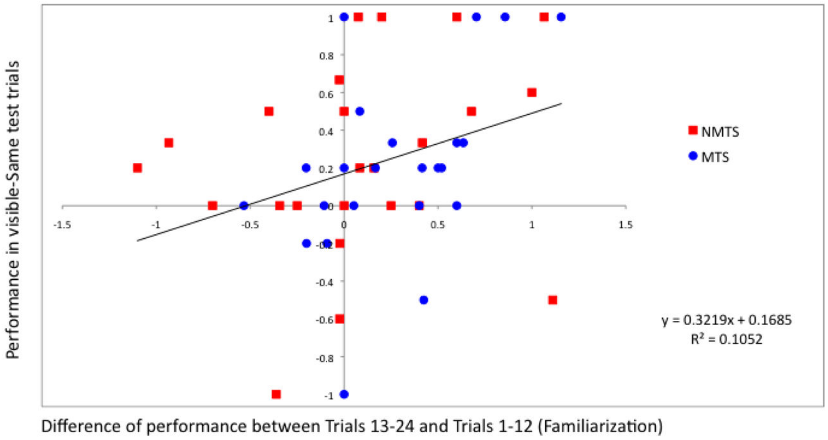

Figure 7.

Variation of infants' performance in the visible-Same test trials with respect to the improvement of their performance in the Familiarization (difference between the performance in Trials 13–24 and the performance in Trials 1–12)

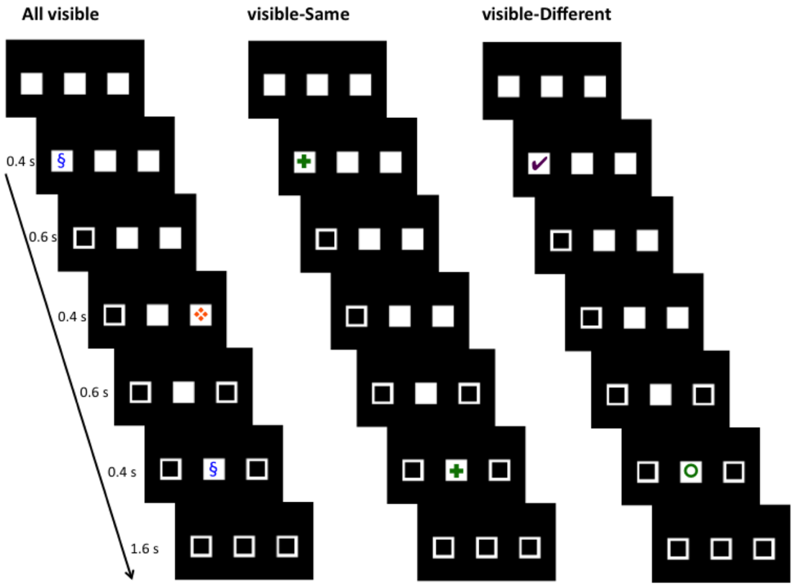

Figure 8.

Structure of each type of trials in Experiment 3.

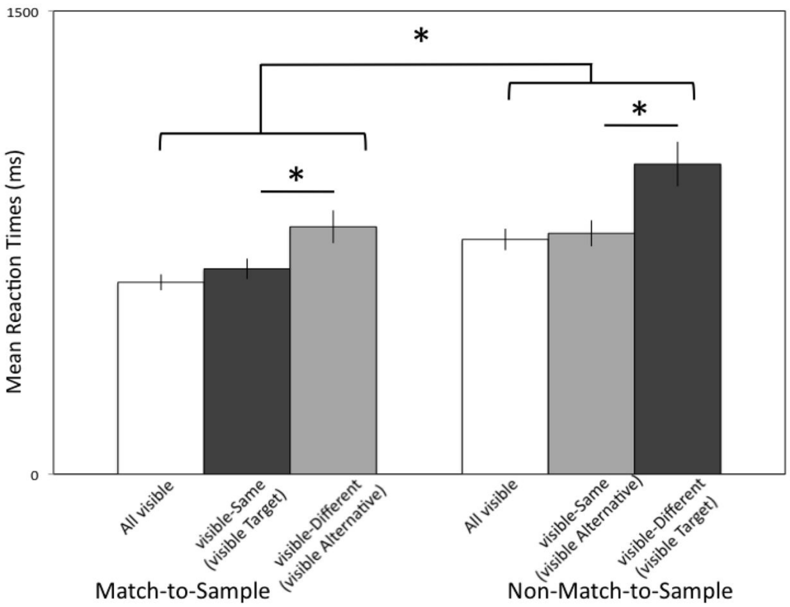

Figure 9.

Reaction times for adult participants in Experiment 3. Error bars represent standard errors from the mean.

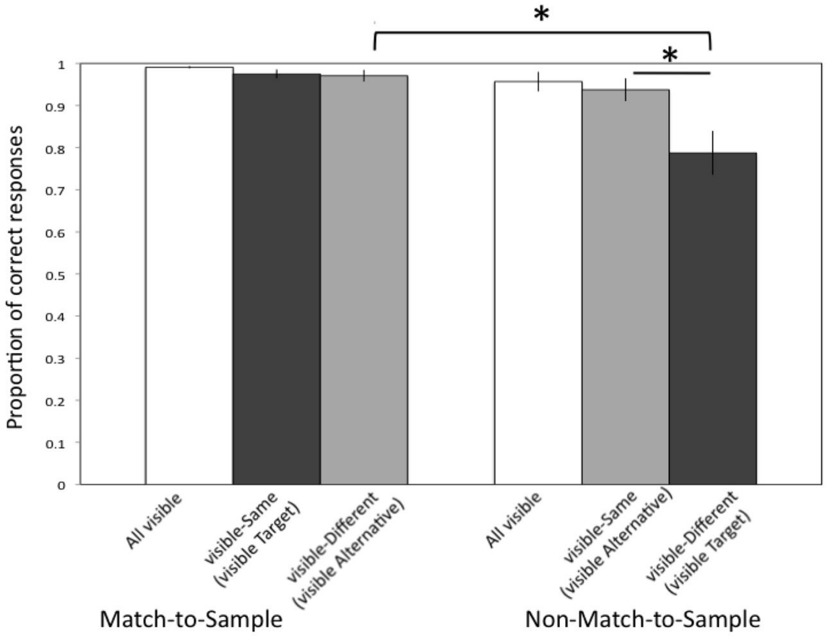

Figure 10.

Accuracy results for adult participants in Experiment 3. Error bars represent standard errors from the mean.