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Infants learn a rule predicated on the relation same but fail to simultaneously learn a rule predicated on the relation different

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A R T I C L E I N F O

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A B S T R A C T

In two experiments, we assessed whether infants are able to learn rules predicated on two abstract relations linked by negation: *same* and *different* (*not same*). In an anticipatory looking paradigm, the relation between successive colored geometrical shapes predicted the location where a puppet would appear next. In Experiment 1, 7-month-olds learned and generalized a rule predicated on the relation *same*, but not a rule predicated on the relation *different*. Similarly, in Experiment 2, 12-month-olds learned a rule predicated on the relation *same-shape*, but not a rule predicated on the relation *different-shape*. Comparing our data with that from previous experiments in the speech domain, we found no effect of age, modality or rule complexity. We conclude that, in the first year of life, infants already possess a representation of the abstract relation same, which serves as input to a rule. In contrast, we find no evidence that they represent the relation different.

1. Introduction

The adult human mind is unique in its productivity, which sets us apart from other animals. We can produce and comprehend an indefinite number of sentences – many sentences of this paper have never been written before – and think an indefinite number of thoughts (Chomsky, 1957; Fodor, 1975; von von von Humboldt, 1836). As a result, our species could invent new concepts such as *atom, oxygen atom, engine* and *autism* and represent propositions such as "All men are created equal." Nothing remotely comparable has ever been observed in non-human animals, and the phylogenetic origin of these abilities is unclear. Parallel questions arise in the case of ontogenesis. Is infant cognition productive in this way as well? Or does productivity await the development of other capacities such as syntax and/or the lexicon?

Here, we investigate abstract combinatorial representations in infancy through a case study of infants' concepts *same* and *different*. As has been recognized at least since Premack's (1983) seminal work, three considerations have led these concepts to be taken as a good case study for this purpose (see, for example, Penn, Holyoak, & Povinelli, 2008). First, they are abstract relational concepts; their content cannot be captured in terms of perceptual features of individuals or sets of individuals (in contrast to concepts like *green* for instance). Second, they are at the core of analogical reasoning (Gentner, Holyoak, & Kokinov, 2001; Premack, 1983), and constitute what William James famously called *the very keel and backbone of our thinking* (James, 1890/1950, p. 459). Third, *same* and *different* are linked by negation, so that one of these concepts can be defined in terms of the negation of the other; i.e., *same* is *not different* and *different* is *not same*. *Same* and *different* therefore exemplify productivity, as it is likely that the representation of one of these relations is a constituent of the representation of the other (most likely, for adults, *different* is *not same*; see Clark, 1974; Hochmann, Mody, & Carey, 2016; Hochmann, Zhu, & Carey, in preparation).

Many studies suggest that a wide variety of animal species, from bees to chimps, can condition behaviors on sameness and difference (e.g., Giurfa, Zhang, Jenett, Menzel, & Srinivasan, 2001; Harley, Putman, & Roitblat, 2003; Mumby, 2001; Thompson & Oden, 1996; Wright, Cook, Rivera, Sands, & Delius, 1988), and young infants, years before they learn the words "same" and different", also appear to have these capacities (Addyman & Mareschal, 2010; Diamond, 2006; Ferry, Hespos, & Gentner, 2015; Hochmann et al., 2016; Kovács, 2014; Tyrell, Stauffer, & Snowman, 1991; Tyrell, Zingaro, & Minard, 1993; Walker & Gopnik, 2014). However, for each behavior that might reflect representations of same and/or different, one must identify what representation the animal or infant actually uses to pass the task. Is there a plausible account that does not involve the representation of an abstract relation? Are both relations, same and different, represented or only one of them? What is the format of these representations? It is

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obvious upon reflection, but easy to lose sight of, that the fact that the experimenter designed the study to probe representations of sameness and difference does not guarantee that representations of these relations actually underlie successful performance.

The earliest data that were taken as evidence for representations of both same and different derived from the capacity of animals and infants to solve the match-to-sample and the non-match-to-sample tasks (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; human infants: Diamond, 2006; Hochmann et al., 2016). In the match-to-sample (MTS) task, participants must learn to choose between two possible choices the stimulus that is the same as the sample (e.g., between a square and a triangle, if the sample is a square choose the other square) and generalize the rule to novel stimuli. In the non-match to sample task (NMTS), the rule is to choose the stimulus that is different from the sample (i.e., in the above example, if the sample is the square, choose the triangle). Because the rule learned generalizes freely to novel stimuli, it is likely that some representations of same and/or different underlie success. With respect to what these representations may be like, Zentall, Edwards, Moore, and Hogan (1981) and Hochmann et al. (2016) provide evidence that performance on *both* MTS and NMTS relies on the representation *same* alone. Briefly, after having learned the MTS rule, if given partial information in a test trial (e.g., the sample is X and the potential known choice is X, whereas the other choice is unknown), infants successfully choose X, for they have seen the input to the rule "choose same." But after having learned the NMTS rule and given partial information (i.e., the sample is Y, and the potential known choice is X, whereas the other choice is unknown), infants *choose at chance*, even though they have seen input that instantiates the rule "choose different." Rather, they *succeed* if they have seen the sample X and the potential choice X, whereas the other choice is unknown: they choose the alternative unknown choice, as if the rule they are following is "avoid same." Importantly, these results are consistent with the absence of a representation *different*, or *not same*, that can be the input to a decision (choice or avoidance).

Moreover, Hochmann et al. (2016) suggest that the representation *same* implicated in MTS and NMTS may be entirely implicit, carried by a match computation. It is important to emphasize that the capacity for match and mismatch computations is not in doubt—either for non-human animals or young infants. Match and mismatch computations play a role in the processes underlying recognition, categorization and habituation/dishabituation, and are part of the computational repertoire of even very simple organisms. Rather, what is debated is whether representations of the relations same and/or different are available as input into learned generalizations or learned rules that can be held in working memory and guide behavior. Hochmann et al. (2016) suggest that the procedure infants and animals may be using in MTS could be: place representation of sample in working memory: *x*; subsequently, if encounter *x*, select *x*, whereas in NMTS, the procedure might be: place representation of sample in working memory: *x*; subsequently, if encounter *x*, avoid *x*. The abstractness in these procedures is carried by lack of constraints on the content of the variable *x*. The representation is considered "implicit" with respect to the content *same* as there is no mental symbol for the relation same in this procedure.

One paradigm taken to provide unequivocal evidence that creatures represent the relations same and different with symbols that can articulate rules that can be held in working memory is the relational match-to-sample (RMTS). Initially developed by Premack (1983), 2-item RMTS has proved extremely difficult for non-human animals and human children younger than 5 years (Hochmann et al., 2017; Premack, 1983; Thompson & Oden, 1996; Wasserman & Young, 2010). In 2-item RMTS, participants must learn to match two pairs of stimuli depending on the relations that define each pair; i.e. matching AA to BB and CD to EF. In animals as well as in children, this task appears hard to solve without resorting to summary explicit symbols for the relations same and different such as the words "same" and "different", or symbols that previously acquired those meanings (Hochmann et al., 2017; Premack, 1983; Thompson, Oden & Boysen, 1997; see also Christie & Gentner, 2014).

Are word-like symbols necessary for representing the abstract relations same and/or different? Another paradigm used with success in the animal literature, the conditional same-different discrimination task suggests that this may not be the case. Two versions of this task exist. In one version, animals are simultaneously presented with one array of same stimuli and one array of different stimuli, and must select the *same* array or the *different* array depending on a contextual cue (e.g., the color of the background; Castro, Kennedy, & Wasserman, 2010; Flemming, 2011; Flemming, Beran, & Washburn, 2007; Russel & Burke, 2016; Thomas & Crosby, 1977; Thomas & Kerr, 1976). In another version of the task, animals are trained to respond in one way to a set of same stimuli (e.g., searching under the left stimulus) and in another way to a set of different stimuli (e.g., searching under the right stimulus; Burdyn & Thomas, 1984; Czerny & Thomas, 1975; Flemming et al., 2007). Success in this second version of the task very likely requires the representation of two rules, with the content *if same choose left* and *if different choose right*. However, whatever representations underlie success on this task, they do not allow all the computations that the human adult representations allow, as these animals still largely fail the RMTS task (Flemming et al., 2007; though see Obozova, Smirnova, Zorina, & Wasserman, 2015; Smirnova, Zorina, Obozova, & Wasserman, 2015; Thompson et al., 1997). Moreover, it is possible that animal successes in the conditional same-different discrimination or on RMTS could be explained by responses conditioned to symmetry vs. asymmetry or high vs. low entropy (Wasserman & Young, 2010).

A handful of studies have examined infant performance in a conditional same/different discrimination procedure. Kovács (2014) taught 7- and 12-month-old infants that pairs of same syllables (e.g. *la la*, *di di*) predicted that a toy would appear in one location, whereas pairs of different syllables (e.g., *bo mu*, *to na*) predicted that a toy would appear in another location. Infants learned and generalized to novel pairs the rule formulated over the relation same, suggesting the availability of some sort of symbol for same that can be the antecedent to a learned rule. However, they failed to learn the rule formulated over the relations different. Similarly, Hochmann, Benavides-Varela, Nespor, and Mehler (2011) and Hochmann, Benavides-Varela, Fló, Nespor, and Mehler (2018) found, using this paradigm, that 7- and 12-month-old infants could learn that pairs of syllables with the same vowel (e.g., *la da*, *gi bi*) predicted that a toy would appear in one location, while failing to learn that pairs of syllables with different vowels (e.g., *bo mu*, *to na*) predicted a toy would appear in another location. Spatial symmetry cannot be a basis of success on this task. Thus, these results suggest that some kind of symbol for same is available to articulate rules held in working memory at least by 7 months of age under circumstances in which infants fail to demonstrate any representation of the relation different.

However, these investigations are so far limited to speech stimuli, raising questions about the generalizability of the results. Reduplication is used in the morphology of many languages, marking plural or expressing the frequentative or distributive meaning of verbs (Broselow & McCarthy, 1983; Marantz, 1982). For instance, Walpiri, an aboriginal language in Australia, forms the plural of certain nouns by total reduplication (cited in Marantz, 1982):

Singular	Plural	Meaning
kurdu	kurdukurdu	"child/children"
kamina	kaminakamina	"girl/girls"
mardukuja	mardukujamardukuja	"woman/women"

Similarly, Samoan forms plurals of verbs by duplicating one syllable (cited in Broselow & McCarthy, 1983):

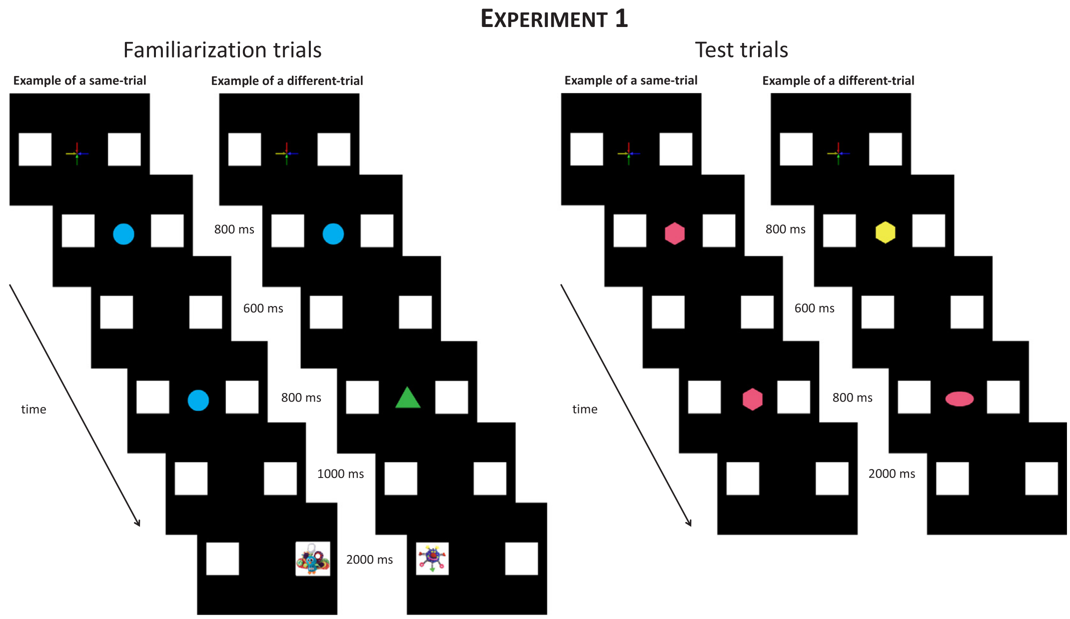

Fig. 1. Paradigm of Experiment 1 (same/different rules).

Singular	Plural	Meaning
taa	*ta*taa	(he) "strikes"/(they) "strike"
moe	*mo*moe	(he) "sleeps"/(they) "sleep"
alofa	a*lo*lofa	(he) "loves"/(they) "love"

Moreover, the case of vowel repetition may be related to the phenomenon of vowel harmony, whereby in many languages (e.g., Turkish, Hebrew), vowels within a word systematically exhibit similarity (van der Hulst & van de Weijer, 1995).

In sum, it is possible that the pattern of results reported by Kovács (2014) and Hochmann et al. (2011), Hochmann et al. (2018), namely that infants generalize syllable and vowel repetition patterns, in the face of insensitivity to syllable or vowel non-repetition patterns, reflects domain specific (i.e., specific to speech/linguistic stimuli) representations of the relations same word/syllable/vowel (see also Berent, Bat-El, & Vaknin-Nusbaum, 2017). Alternatively, these phenomena may reflect a domain-general representation of the relation same, applicable both to speech and non-speech stimuli.

In the two experiments presented below, we employed the same-different discrimination paradigm developed by Kovács and Hochmann, but instead of pairs of speech sounds instantiating the relations same and different, the stimuli were pairs of colored geometrical figures presented sequentially in the center of the screen. Sequential presentation rules out spatial symmetry as a basis for response. In Experiment 1, 7-month-olds were taught that the predictive relations were *same* (in shape and color) and *different* (in shape and color). In Experiment 2, 12-month-olds were taught that the predictive relations were *same-shape* and *different-shape,* as colors always varied. Infants were tested on their ability to generalize these predictive rules to entirely novel stimuli (i.e., novel shapes and novel colors). Success with the relation same would suggest that infants easily learn rules formulated in terms of a representation of that relation (e.g., *if same, the toy will appear in the right box*). Success with both relations would provide the first strong evidence that infants have symbolic representations both of the relations same and different. Alternatively, we might observe success with the relation same in the face of failure with the relation different, as in the studies of Hochmann et al. (2011), Hochmann et al. (2018) and Kovács (2014) with speech stimuli.

2. Experiment 1 – same vs. different

2.1. Material and methods

2.1.1. Participants

Eighteen infants were included in the final analysis; age range: 6 months 19 days – 7 months 12 days; mean age: 7 months 0 day. Seven-month-olds were chosen because this is the earliest age for which there is evidence that infants can learn a rule predicated on a representation of "same" (i.e., "same syllable predicts left", Kovács, 2014 or "same vowel predicts right", Hochmann et al., 2018). The sample size was chosen following the reference paper by Kovács (2014), who tested 7-month-olds with the relation same implemented on syllables. A power analysis showed that the sample size (N = 16) adopted in that study yielded adequate power (> 0.8). Twenty-five infants were initially scheduled to reach a sample size of at least 16 after exclusion. There were two no-shows. Five infants participated in the study but were excluded due to fussiness (i.e., refusing to sit facing the screen or crying leading to not finishing the experiment), leaving 18.

2.1.2. Stimuli

Visual cues to the location of toys' appearances consisted in the repeated presentation of colorful shapes. In Experiment 1, three shapes (disk, triangle and square) and three colors (green, blue and orange) were used in the familiarization. Two different shapes (ellipse and hexagon) and two different colors (pink and yellow) were used in the test phase. Each visual stimulus occupied a 4 × 4 cm square. Twelve pairs of colorful shapes were created for the familiarization. Six pairs consisted in two colorful shapes sharing the same shape and same color (blue disk – blue disk; green triangle – green triangle; blue square – blue square; orange triangle – orange triangle; orange square – orange square; green disk – green disk), and six pairs consisted in two colorful shapes with different shapes and colors (blue disk – green triangle; blue square – orange triangle; orange square – green disk; orange triangle – blue disk; green triangle – orange square; green disk – blue square). Four additional pairs were created for the test. Two pairs consisted in two colorful shapes sharing the same shape and same color (yellow hexagon – yellow hexagon; pink ellipse – pink ellipse), and two pairs consisted in two colorful shapes with different shapes and colors (pink ellipse – yellow hexagon; yellow hexagon – pink ellipse). Colored geometrical shapes were synthesized with Adobe Photoshop CS version

8.0 on a computer running Mac OS X, version 10.5.7.

2.1.3. Procedure

The procedure was adapted from the work of Kovács & Mehler (2009; see also Hochmann et al., 2011; Hochmann et al., 2018; Kovács, 2014). Experiment 1 consisted in a Familiarization phase and a Test phase (Fig. 1). Infants were seated on their caregiver's lap, in a darkened room, facing a Tobii Eye-tracker T1750. Caregivers were asked to close their eyes for the duration of the experiment. The presentation of stimuli was controlled by PsyScope X (http://www.psy.cns.sissa.it/). A camera hidden behind the eye-tracker allowed the experimenter to see the participant and her caregiver and decide when to start each trial.

The Familiarization phase consisted of 32 Familiarization trials presented in a pseudo-random order, with the constraint that no more than three trials of the same type (same trials or different trials) could follow each other. Trial order was separately randomized for each child. Familiarization trials were separated by the display of two white squares on the sides and a central attention-grabber. When the infant looked at the attention-grabber, the experimenter pressed a key to begin a new trial. The central attention-grabber disappeared and two colorful shapes appeared sequentially for 800 ms each, separated by 600 ms. The two colorful shapes could be identical or differ in both shape and color. Meaningless attractive sounds lasting 500 ms were played in synchrony with the appearance of each colorful shape. The same two sounds were used overall. Each consisted in two tones played by a synthetized instrument, respectively F3 E4 and F3 C4. For every pair, the first sound was presented with the first figure, the second sound with the second figure.

One second after the visual cue disappeared, a toy appeared in one of the squares, contingent on the visual cue: the same relation predicted the toy's appearance in one of the squares, while the different relation predicted the toy's appearance in the other square. The pairing of the visual cues with toy-locations was counterbalanced across participants.

During test, infants were exposed to 8 trials in a pseudo-random order, avoiding more than two trials of the same type following each other. Again trial order was separately randomized for each child. Test trials were similar to the familiarization trials, except that infants saw novel visual cues, which consisted in pairs of two identical novel objects or two different novel objects, and no toy ever appeared in the test trials. Two seconds after the visual cue disappeared, the next trial started.

2.1.4. Analysis

For each test trial, we first coded whether the infant looked to *either* square (scored trials), and then coded infants' first fixation (at least 100 ms) as correct or incorrect and computed the cumulative looking time to the correct and incorrect squares. For each of these two measures, we computed a difference score: (#correct trials - #incorrect trials)/(#scored trials); (Looking Time correct – Looking Time incorrect)/(total Looking Time).

2.2. Results

In the test phase, 58% of the same trials and 57% of the different trials were scored trials: i.e., on these trials infants fixated at least once either the left square or the right square. Two infants did not look either left or right for any of the same trials, and two infants did not look either left or right for any of the different trials, so that 16 infants were included in the analysis of each type of trials and 14 in the comparison between the two types of trials. The results, presented in Fig. 2, show that infants learned the rule predicated on *same* but not that predicated on *different*.

Considering first fixations, infants' performance was marginally different from chance for same pairs; M = 0.36; t(15) = 2.07; *P* = .056. In contrast, infants' performance was at chance for the different pairs; M = −0.12; t(15) = −0.64; *P* = .53. However, in contrast to the findings of Hochmann et al. (2011), Hochmann et al. (2018) and Kovács (2014), performance on same pairs did not differ significantly from the performance with different pairs; t(13) = 1.62; *P* = .13. Considering cumulative looking time, infants' performance was significantly different from chance for same pairs, M = 0.40; t(15) = 2.53; *P* = .02; and again, performance was at chance for the different pairs; M = −0.15; t(15) = −0.84; *P* = .41. In spite of at chance performance on different pairs and above chance performance on same pairs, performance on the two types of trials did not different significantly from each other; t(13) = 1.66; *P* = .12.

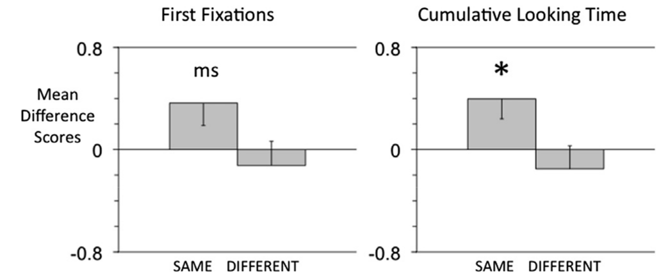

Fig. 2. Results of Experiment 1. Error bars represent standard errors. ms: p < .1, 2-tailed; *: p < .05, 2-tailed.

Please dwell on the striking failure on the different trials. Infants clearly distinguished the pairs of different stimuli from those of same stimuli, for they succeeded on the same trials (e.g., looked to the left square on test trials, if during familiarization pairs of cue figures that were the same in shape and color predicted that the toy would appear in the left) but were at chance in different trials. They did not merely learn a rule to always look to one side. The failure on different trials is striking: all infants needed to learn was "if same, look left; if not same, look right," but instead they learned, "if same, look left," and were flummoxed when the stimuli were not the same.

These results extend to the visual modality previous results from our lab in the speech modality (Hochmann et al., 2011; Hochmann et al., 2018; Kovács, 2014). Kovács found the same pattern of results at 7 months and 12 months with sameness of whole syllables as the basis of prediction, and Hochmann et al. (2011), Hochmann et al. (2018) found the same pattern of results at 7 and 12 months when same vowels (in the context of different consonants) were the input to the rule. Experiment 2 examines whether infants can learn a rule predicated on same shape (in the context of different colors), analogous to the Hochmann et al. results. In Experiment 1 we tested only 7-month-olds, because we wanted to match the earliest age for which same-different discrimination learning by human infants has been observed. In Experiment 2, we tested only 12-month-olds on the possibly more difficult "same shape predicts left" rule, for our concern here is not the absence of developmental differences between 7- and 12-month olds, but rather the replication (or not) of the pattern of success in learning a rule predicated on relation same implemented on one dimension only, and the replication (or not) of failure with the relation different. We thus chose the older age to maximize the chance of success on this intuitively harder task.

Experiment 2 will further help disentangle between two alternative interpretations of the results of Experiment 1, corresponding to two meanings of the word "same". In trials where two identical figures appear sequentially, infants may either interpret these as two numerically different figures with the same properties, or as a unique figure appearing twice. In Experiment 2, implementing the relation same on shape only, while always varying colors, allows only the former interpretation—numerically distinct figures that match or differ in shape.

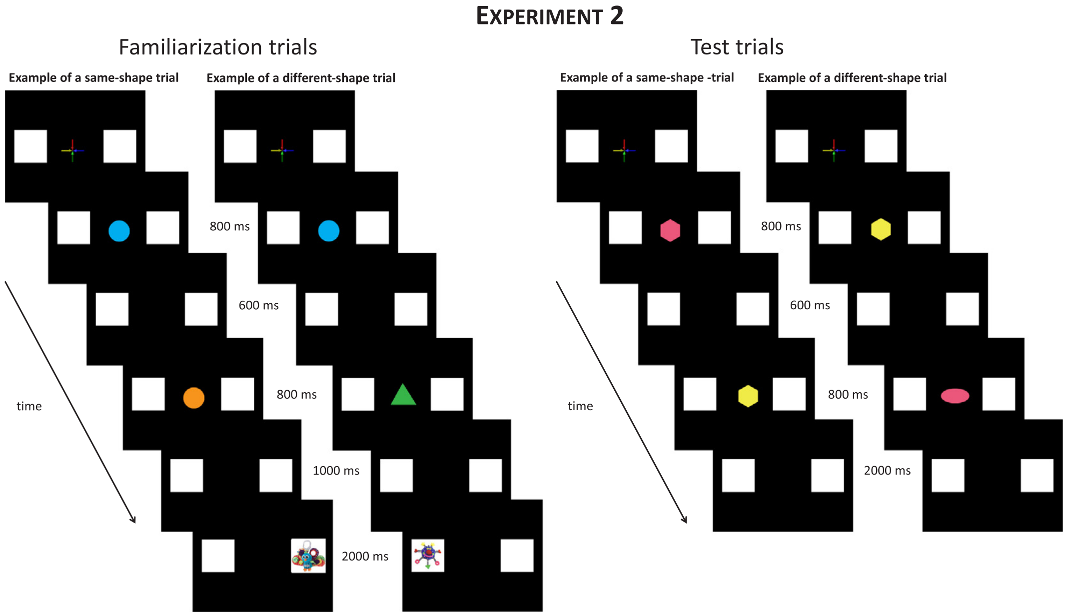

Fig. 3. Paradigm of Experiment 2 (same-shape/different-shape rules).

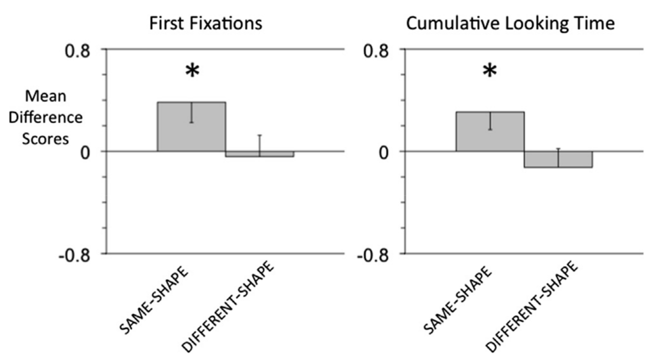

Fig. 4. Results of Experiment 2. Error bars represent standard errors. *: $p < .05$, 2-tailed.

3. Experiment 2 – same-shape vs. different-shape

3.1. Material and methods

3.1.1. Participants

The sample size was chosen following the reference paper by Hochmann et al. (2011), who tested 12-month-olds with the relation same implemented on vowels only. A power analysis showed that the sample size (N = 24) adopted in that study yielded adequate power (> 0.8). Thirty-three infants were scheduled to match the sample size of 24. Eight infants participated in the study but were excluded due to fussiness (refusing to sit facing the screen or crying and not finishing the experiment), leaving 25 in the final analysis; age range 11 month 15 days to 12 month 15 days.

3.1.2. Procedure and stimuli

The Procedure was the same as in Experiment 1, except for the stimuli (Fig. 3). One location of the toy's appearance was predicted by the cue of a pair with the same shape; the other location was predicted by the cue of a pair with a different shape. There were eight *same-shape* pairs consisting of two colorful shapes sharing the same shape but different colors (Familiarization: green disk – blue disk; blue disk – orange disk; blue triangle – orange triangle; orange triangle – green triangle; green square – blue square; orange square – green square; Test: yellow ellipse – pink ellipse; pink hexagon – yellow hexagon). There were also eight *different-shape pairs* consisting of two colorful shapes with different shapes and colors (Familiarization: blue disk – green triangle; blue square – orange triangle; orange square – green disk; orange triangle – blue disk; green triangle – orange square; green disk – blue square; Test: pink ellipse – yellow hexagon; yellow hexagon – pink ellipse). In all other respects, the design of the study (familiarization and test phases, timing and counterbalancing of trials) was identical to that of Study 1.

3.2. Results

In Experiment 2, 61% of the same-shape test trials and 50% of the different-shape test trials were scored; on the remaining trials infants looked at neither the left or the right square during the trial. Two infants did not look either left or right for any of the same-shape trials, and one infant did not look either left or right for any of the different-shape trials, so that 23 infants were included in the analysis of the same-shape trials, 24 in the analysis of the different-shape trials, and 22 in the comparison between the two types of trials. The results presented in Fig. 4 show that infants learned the rule predicated on *same-shape* but not that predicated on *different-shape*.

Considering first fixations, infants' performance was significantly better than chance for the same-shape pairs, $M = 0.38$; $t(22) = 2.40$; $P = .025$, whereas infants' performance did not differ from chance for different-shape pairs; $M = -0.04$; $t(23) = -0.25$; $P = .80$. Again, performance on the two types of trials did not differ significantly from each other, $t(21) = 1.13$; $P = .27$. The same pattern of results was observed on the cumulative looking time dependent measure. Infants' performance was significantly better than chance for the same-shape pairs, $M = 0.31$; $t(22) = 2.23$; $P = .036$, at chance for different-shape pairs; $M = -0.12$; $t(23) = -0.86$; $P = .40$, but performance on the two types of trials did not differ significantly, $t(21) = 1.35$; $P = .19$.

These data provide the first evidence in the visual modality that preverbal infants can abstract a relevant dimension from stimuli that vary in two dimensions (i.e., in this case shape, from shape and color) and learn a rule formulated over sameness in that dimension (*same shape predicts left*).

4. Effects of relation type, age, modality and saliency on first fixations

Experiments 1–2 show that 7- and 12-month-old infants can learn a rule predicated on the relation same. Furthermore, just as both 7- and 12-month-olds failed to learn rules predicated on “different syllables” or “different vowels” in the speech domain, so too they failed to learn rules predicted on “different figure” (Experiment 1) or “different shape” (Experiment 2) when the stimuli were sequentially presented visual figures.

In each of the present experiments, however, the comparison of the performance with *same* pairs and *different* pairs was not statistically significant, in contrast to the results of previous similar experiments in the speech domain (Hochmann et al., 2011; Hochmann et al., 2018; Kovács, 2014). Are these apparent differences between modalities meaningful?

To explore this possibility, we merged the data from Experiments 1–2 with the data from four experiments exploring infants’ ability to learn a rule predicated on the relation between syllables (Kovács, 2014) or vowels (Hochmann et al., 2011; Hochmann et al., 2018). Merging all these data further allowed us to compare the generalization of the relation of complete identity (same figure; same syllable) with the generalization of the potentially less salient and more complex relation of identity along one dimension only (same shape; same vowels). We ran a repeated measure ANOVA to explore the effect of Age (7 months; 12 months), Modality (Visual; Speech) and Saliency/Complexity (Strict identity; One dimension only), and Relation Type (same vs different) on our measure of success at predicting where the toy will appear (for first fixations: # fixations to correct side - # fixations to incorrect side/total fixations). We analyzed only first fixations as the dependent variable because cumulative looking time data were not available for the Kovács (2014) study (but see footnote [1] below for a parallel analysis looking at Modality, Saliency/Complexity, Trial Type and Age on the cumulative looking time dependent variable from the other four studies).

In the above studies, infants performed above chance on the relation same and at chance on the relations different. The aim of this analysis is twofold. First, we ask whether the performance in learning a rule predicated on the relation same is impacted by the modality of the stimuli, the age of participants and the saliency/complexity of the relation same. We thus only included experiments with at least one significant effect, excluding one experiment where infants apparently learned nothing (Experiment 2 in Hochmann et al., 2018, where infants failed to learn rules predicated on same vowels or same consonants). Six experimental groups were included (see Table 1). Second, we ask whether there are any significant effects of these variables on the difference of performance with same and different pairs. Thus, for each experiment, we only considered infants with data for both types of pairs, leading to the inclusion of 135 infants and the exclusion of 12 infants.

4.1. Results

The first fixation data from all 6 experiments are plotted in Fig. 5. A repeated-measure ANOVA examined the effects of the within-subject factor Pair Type (Same, Different) and the between-subject factors of Age (7 months, 12 months), Modality (Visual, Speech) and Saliency/Complexity (Strict identity; One dimension only) as between-subject factors on the first fixation difference score. The ANOVA showed a main effect of Pair Type; $F(1,129) = 22.38$; $P < .001$, $\eta^2 = 0.15$. Infants performed better with same pairs ($M = 0.42$) than with different pairs ($M = -0.13$). No additional main effect or interaction was observed, all $Ps > .29$.

As is clear from Fig. 5 and confirmed in the above ANOVA, the pattern of results is the same across all 6 studies. The fact that there was no interaction between the large effect of trial type (same vs. different, effect size 0.15) and any other variable, shows that the differentiation of the same from the different trials in the visual domain does not differ

Table 1
Summary of the data included in the analysis.

Modality	Age	Saliency	N	Paper	Experiment #
Visual	7 months	Identity	14	Present paper	Experiment 1
Visual	12 months	Shape only	22	Present paper	Experiment 2
Speech	7 months	Identity	16	Kovács (2014)	Experiment 1
Speech	12 months	Identity	16	Kovács (2014)	Experiment 1
Speech	7 months	Vowels only	45	Hochmann et al. (2018)	Experiment 3
Speech	12 months	Vowels only	22	Hochmann et al. (2011)	Experiment 2

statistically from that in the auditory domain. The lack of any significant effects of Age shows that some representation of same is available to articulate rules with the content “if same, look right” already by 7-months of age *to the same degree* as at 12-months of age, and that the failure with different in this context is also stable across this age range. The lack of any effects of Modality rules out that the success with same in the speech domain (same syllable, same vowel) is due to domain specific linguistic representations alone. The lack of any effects of Saliency/Complexity (sameness across all dimensions, sameness in one dimension only) shows that at least some variation in the complexity of the relation same does not affect success on this task.

In sum, as in all of the experiments from the speech domain listed in Table 1, infants tested in the visual modality in Experiments 1 and 2 performed better than chance on the same pairs, and at chance on the different pairs. And even though the difference between the same trials and the different trials did not reach significance in any of the analyses of the data from Experiments 1 and 2, the degree of differentiation of the same pair trials from the different pair trials did not differ statistically from that in the experiments in the speech domain (Fig. 5), both for first fixations and cumulative looking time.[1] Both 7- to 12-month-old infants are better at learning a rule predicated on same than a rule predicated on different, irrespective of the modality (Speech or Visual) in which that rule is implemented and irrespective of relation saliency (strict identity vs. sameness on just one dimension).

5. General discussion

Two experiments investigated infants’ ability to represent pairs of geometrical figures as the same (Experiment 1: same in shape and color, Experiment 2: same in shape) or as different in both shape and color. We found clear evidence that 7- and 12-month-olds could represent the abstract relation same. Seven-month-olds learned that pairs of identical geometrical figures predicted the location where a toy would appear and 12-month-olds learned that pairs of geometrical figures that were the same in shape (but different in color) predicted where a toy would appear. Importantly, in both experiments, infants generalized the rule to novel stimuli (i.e., to figures with shapes and colors never seen during familiarization), requiring an abstract representation of the relations same figure and same shape.

Although infants learned, for example, “same predicts left,” they failed to learn “different predicts right.” This means infants differentiated the pairs of different figures from the pairs of figures that were identical or that had the same shape; they knew that the different pairs did not predict the location of the toy that the pairs that were the same did. Nonetheless, they were at chance at anticipating the location of the toy when cued by the pairs of different stimuli. In sum, these studies

[1] Cumulative looking times were not available for the data reported in Kovács (2014). An ANOVA examined the effects of Age, Modality, Complexity/Salience, and Relation Type on the cumulative looking dependent variable for the remaining 4 studies in Table 1. The pattern is exactly the same as in the first fixation analysis. There was a main effect of Relation Type; $F(1,99) = 24.33$; $P < .001$. Infants performed better with same pairs ($M = 0.36$) than with different pairs ($M = -0.18$). There were no main effects or interactions involving Age, Modality or Complexity/Salience, all $Ps > .35$.

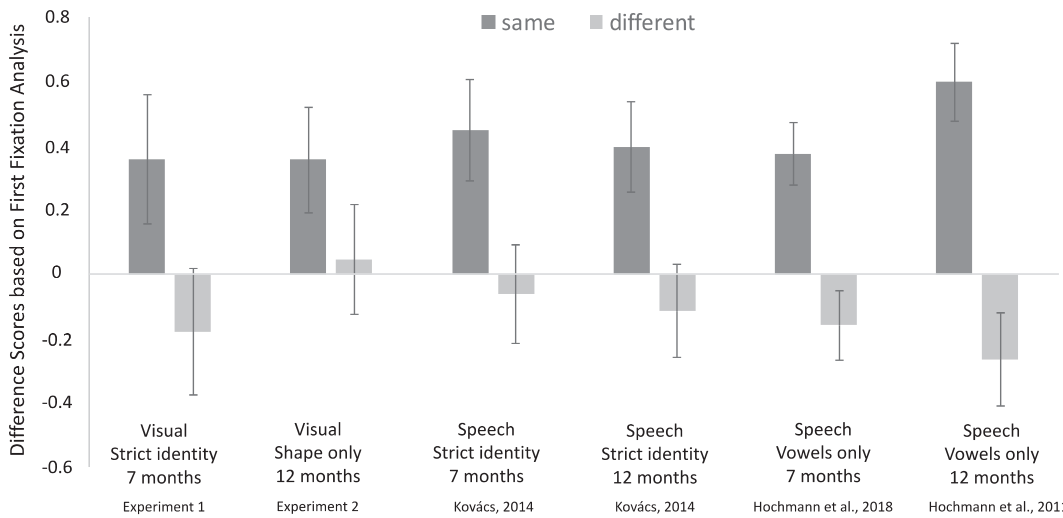

Fig. 5. Summary of the data used to evaluate the effects of Age, Modality and Saliency in the generalization of rules predicated on same and different.

provide no evidence that infants could represent the relation different as the input to an arbitrary predictive rule. They also show that having learned a rule with the content *same predicts right*, they could not easily learn the additional rule, *not same predicts left*.

These results generalize to the visual modality previous results obtained in the speech modality (Hochmann et al., 2011; Hochmann et al., 2018; Kovács, 2014), and are consistent with the data from the simple match- and non-match-to-sample paradigms in Hochmann et al. (2016) in finding behavior in infancy conditioned on the relation same in the absence of evidence for behavior conditioned on the relation different or not same. Altogether, this body of studies suggests that the relative ease of learning rules predicated on the relation same and the difficulty or impossibility of learning rules predicated on the relation different are not limited to a particular modality or task, but rather constitute a hallmark of the infants' representations of the abstract relations same and different.

5.1. Absence or complexity of the representation of different?

We take the above results to provide unequivocal evidence for some form of symbolic representation with the content *same* that can be input to further computations. In contrast, the *absence of evidence* for a mental representation of the relation different is not sufficient to establish the *absence of the capacity* to represent that relation. Infants may be able to represent the relation different, but fail to exhibit that ability in our paradigm.

The present paradigm presents infants with the formidable task (for babies) of learning two rules in parallel: *if same, look right; if different look left*. Even children may not be able to learn and remember two (non-conflicting) rules in a single context before they are 3 years old (Zelazo et al., 2003). Several dozens of experiments that have been run in our labs suggest that infants tend to learn only one rule in our anticipation paradigm, the rule predicated on the simpler representation (Benavides-Varela & Mehler, 2015; Hochmann et al., 2011; Hochmann et al., 2018; Kovács, 2014; Kovács & Mehler, 2009). For example, Kovács and Mehler (2009) taught infants that the structure of a sequence of three syllables predicted where a toy would appear. The structure XXY (e.g., *pu pu ki, le le ma,* etc.) predicted the toy's appearance in one location and the structure XYX (e.g., *pu ki pu, le ma le,* etc.) predicted the toy's appearance in another location. An adjacent repetition being a simpler structure to represent than a non-adjacent repetition, infants learned the first rule but not the second one. Importantly, a number of findings show that infants, despite their failure to learn the rule with XYX as its antecedent in that context, are able to do so in other contexts. For example, infants learn the rule *XYX predicts right*, when that rule is opposed to a rule predicated on a more complex structure: *XYZ predicts left* (Kovács & Mehler, 2009). Notice (relevant to the current investigation) that the greater complexity of XYZ than XYX derives from each one of the individual syllables in XYZ being different from both of the others. Nonetheless, just as the failure to learn a rule conditioned on the pattern XYX is not evidence for the inability to represent that pattern in any circumstance, the failure of infants to learn the rule *different predicts left* remains compatible with their being able to represent the relation different in other circumstances.

Still, even if infants have the capacity for symbolic representations of different, the results of Experiments 1–2, as well as the studies involving same syllable or same vowel in the speech domain, clearly show that such representations are more complex and/or less salient than representations of same. For adults as well, representations of different are more complex than those of same; different is not same, (Clark, 1974; Hochmann et al., 2016; Hochmann et al., submitted for publication). Thus, even for adults, the representation of different is not only more complex than that of same, it also requires more contextual support to be encoded, as does any representation involving negation (Wason, 1965).

Several results in the infant literature are taken to establish that young infants can represent the relation different. However, these results so far actually fail to provide conclusive evidence for representations of the relation different. For example, habituation studies (Addyman & Mareschal, 2010; Ferry et al., 2015; Tyrell et al., 1991) find that infants habituate to pairs of same objects or to pairs of different objects equally easily, and later regain attention to pairs instantiating the other relation. While consistent with the conclusion that they are habituating to the relation *different* in the different condition, these results could be explained by a representation of same only. That is, when habituated to pairs of same objects, infants may represent the relation same, and dishabituate when that relation is no longer respected. In contrast, when habituated to pairs of different objects, infants may not represent the relation different and simply habituate to a pair of objects (i.e., to twoness). The first time a pair of same objects is presented, their attention is drawn, because sameness is salient and draws attention. Imaging studies with neonates give weight to this hypothesis, showing that pairs of same stimuli elicit a systematic pattern of brain activation, while series of different stimuli elicit no systematic pattern (Gervain, Berent, & Werker, 2012; Gervain, Macagno, Cogoi, Peña, & Mehler, 2008).

Parallel reanalyses are possible for other infant results taken to show representations of different. For example, Walker and colleagues (Walker, Bridgers, & Gopnik, 2016; Walker & Gopnik, 2014; Walker & Gopnik, 2017) have shown that in the *blicket detector* task used to explore causal reasoning (Gopnik & Wellman, 2012), 18-month-old toddlers can equally easily learn that pairs of objects that are the same will activate a device when placed on top of it or that pairs of different objects will do so. As in the case of NMTS discussed above (Hochmann et al., 2016), because toddlers are always tested in a forced choice between a pair of same objects and a pair of different objects, the rule toddlers learned in the latter situation may be instantiated over a representation of same: "avoid the pair of same objects", rather than on a representation of different: "choose the pair of different objects". In sum, conclusive evidence for representations of the relation different in infancy have remained elusive.

A high priority for further research is to establish whether symbolic representations of different that are part of a rule that can be held in working memory are absent in infants 12-months or younger or simply more complex or less salient than representations of same. Absence would suggest limitations of the symbolic combinatorial machinery in infancy. Hochmann et al. (submitted for publication) provides strong evidence that, for adults, *different* is represented as *not same* (see also Clark, 1974; Hochmann et al., 2016). The absence of a representation of different could thus follow from the impossibility to combine negation and the representation of same (maybe because the relation same is not represented in a format that allows such combination), or from the absence of a representation of negation. Hochmann et al. (2016) detail several proposals for how same might be represented in such a way that it might not easily compose with not; e.g., if same is not represented by an explicit unitary symbol, but rather as a repeated variable (*x x*). Furthermore, Feiman and colleagues report findings consistent with the possibility that symbolic representations of negation that can articulate rules held in working memory are absent in young infants (Feiman, Carey, & Cushman, 2015; Feiman, Mody, Sanborn, & Carey, 2017; Mody, Feiman, & Carey, in preparation). Our present findings motivate more work on the development of a representation of negation and how it may combine with other representations.

5.2. How the present study relates to animal studies

Contrary to the present study with infants, a number of animal studies have found successful learning of two conditional rules predicated on the relations same and different (e.g., *if the stimuli are the same, search under the right stimulus; if the stimuli are different, search under the left stimulus*; Czerny & Thomas, 1975; see also Burdyn & Thomas, 1984; Flemming et al., 2007). These findings are consistent with the conclusion that animals must be able to deploy a representation of different. However, in almost all of the animal studies, pictures (or objects) are presented simultaneously in a fixed horizontal or vertical arrangement. Many animal species are sensitive to symmetry (Delius & Nowak, 1982; Giurfa, Eichmann, & Menzel, 1996; Schluessel, Beil, Weber, & Bleckmann, 2014), thus leaving open the possibility that animals solve some conditional discrimination tasks designed to explore representations of sameness and difference by learning rules about symmetry/asymmetry instead.

On the other hand, most of the animal studies also provide much more pragmatic support for representing both sameness and difference in these paradigms. Animals are usually first familiarized with the experimental apparatus and often go through an extended training of several hundreds or thousands of trials, whereas our infant participants are naïve and are provided only 32 familiarization trials from which to learn both rules (16 same trials and 16 different trials) before the test trials. In some cases, animals are taught the two rules sequentially, first reaching criterion on "if same, choose right" or "if same, choose red" before beginning to learn, "if different choose left" or "if different choose green." Thus, the animal paradigms provide even more pragmatic support for tokening a representation such as *not same* than does our current paradigm. Nonetheless, if these results reflect representations of rules articulated in terms of concepts of both sameness and difference (rather than symmetry and asymmetry), this would suggest that such representations are in the repertoire of at least some nonhuman animals, and thus do not require linguistic symbols. More training for infants might similarly lead to success, consistent with the conclusion that the infants' failures to learn rules formulated over different in any of the experiments summarized on Fig. 5 derives from the greater saliency of sameness of a pair of objects than difference between two objects, and perhaps also the greater complexity of representations of difference than those of sameness.

Clearly, much more research is needed before we conclude that infants are able or unable to represent the relation different in a format that can be held in working memory and can condition choices or inferences.

6. Conclusion

The human adult mind appears unique in its capacity to represent abstract and combinatorial concepts. Here, we showed that previous findings that infants can represent the relation same as part of a rule held in working memory were not limited to domain specific sensitivity to reduplication in language. Infants are already able to represent the abstract relation *same* by 7-months, and can learn a rule predicated on this relation. Furthermore, we showed that 12-month-olds can represent the relation *same* implemented on a single dimension of the stimuli (i.e., shape). Analyzing all the data from the speech and visual domains together showed no modality effects, no age effects and no rule complexity effects on success with same. In contrast, we found no evidence that infants can form representations with the content *different* or *not same*. These results remain compatible with two interpretations: either different is not represented at all, or it is a complex representation requiring a form of negation. A high priority for further research is the development of new paradigms that could constrain proposals for how the concepts same and/or different might be represented in prelexical (and equally in animal) thought, and might provide convincing evidence that representations of different are available in prelexical thought.

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