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The perceptual origins of the abstract same/different concept in human infants

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1 **The perceptual origins of the abstract Same/Different**
2 **concept in human infants.**

3 **Caspar Addyman · Denis Mareschal**

4

5 Received: date / Accepted: date

6 **Abstract** Very few experiments have studied the two item Same/Different
7 relation in young human infants. This contrasts with an extensive animal lit-
8 erature. We tested young infants with two novel tasks designed specifically to
9 provide convergent comparative measures. Each infant completed both tasks
10 allowing an assessment of their understanding of the abstract concept rather
11 than task-specific abilities. In a looking time task with photographic stimuli
12 we found that 8-month-olds are sensitive to the relation but 4-month-olds are
13 not. The second task used an anticipatory eye movement paradigm with simple
14 geometric stimuli. On each trial, two colored shapes appear and moved up-
15 wards behind an occluder. They reappeared on either the upper left or right
16 depending on the relation between them. Infants at both ages learned and
17 generalized the dependency but only for the different relation. These results

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18 show that human infants can learn the Same/Different concept but that, in
19 strong continuity with animal results, their abilities are firmly grounded in
20 perception.

21 (164 words)

22

23 **Keywords** Same/Different · Human Infants · Concept Learning

24 **1 Introduction**

25 A fundamental characteristic of human cognition is the ability to make use
26 of abstract concepts and perceive similar relations between otherwise unre-
27 lated items. These can take a very wide variety of forms including judgements
28 of numerosity and of comparative quantity and size (*e.g.*, *largest*, *smallest*),
29 relations expressed by spatial prepositions (*e.g.*, *above*, *behind*, *between*) and
30 numerous others. One of the simplest examples is the two item same/different
31 (S/D) distinction. Consider the set of 9 distinct items A to I and the pairs AA,
32 BB, CC, DE, FG, HI. The first three pairs share the relationship of sameness
33 and (by contrast) the last three have the common property of difference. These
34 relationships hold at an abstract level, irrespective of the actual items used
35 and it is this abstraction that defines the relationship. Despite the apparent
36 simplicity from an adult perspective, it has been difficult to demonstrate con-
37 clusively with species other than higher mammals and largely ignored in the
38 human infancy literature. Developmental and comparative approaches both
39 have a lot to reveal about adult human concepts (Mareschal et al., 2010).

40 Therefore, we sought to investigate S/D concept learning in infants, taking
41 into account the extensive animal learning literature.

42 Until recently the received wisdom was that humans find S/D tasks very
43 easy and animals find them very difficult. For humans the S/D distinction
44 would be expected to be a sharp, definite qualitative difference whereas for
45 animals, if they succeed at all, the difference would always be graded, uncertain
46 and quantitative. The difference between animals and humans is portrayed as
47 the contrast between a perceptual, stimulus-driven process and a genuinely
48 abstract concept ability. For example, Penn et al. (2008) present the S/D
49 concept as an example of a qualitative difference between animal and adult
50 human cognitive abilities. In contrast, Wasserman and colleagues suggests that
51 human and animal abilities exist on a continuum that takes account of the
52 number of items to be judged as same or different and the similarity between
53 them (see Wasserman and Young, 2010 for a recent review).

54 Evidence from studies with the human adults is equivocal. Smith et al.
55 (2008) find a sharp divide between humans and rhesus monkeys on a task that
56 systematically manipulated the similarity of pairs of random polygons. Using
57 signal detection theory, they found that humans assigned a strict, rule-like
58 criteria for Sameness whilst the monkeys performance was more graded. Mak-
59 ing the instructions slightly more vague to reduce the influence of language
60 made human performance slightly less certain but still apparently concep-
61 tual. Whereas, a series of studies by Wasserman and colleagues (Young and
62 Wasserman, 2001, 2002b; Castro et al., 2006) show that adult humans some-

63 times respond to multiple item redundancy and between-item similarity as if it
64 were a continuously changing value, similarly to pigeons' response to entropy
65 (Young and Wasserman, 2002a and see below). However, the majority of hu-
66 man participants those studies responded in a categorical fashion suggesting
67 there may be a special human concept of S/D over and above the perceptual
68 regularities that animals appear to exploit. Therefore the gap between adults
69 and animals remains large. . It is therefore instructive to consider the devel-
70 opment these abilities in human infants. This may bridge the gap between
71 animals and humans. By testing infants with paradigms comparable to the
72 animal literature, we may reveal the sudden appearance or innate presence of
73 a uniquely human concept or we may find evidence that human perceptual
74 skills sharpen and mature. Additionally, the animal literature makes it clear
75 that it is important how the question is asked. The abilities of animals are
76 highly task dependent and different tasks can be reveal different distinctions
77 between species. These contrasts are often overlooked when abstract concepts
78 are ascribed to young infants and suggest that multiple paradigms should be
79 used to establish a genuinely abstract ability. We begin by surveying the an-
80 imal literature before considering any existing work with human infants that
81 bears on this question.

82 1.1 Same/Different learning in animal subjects

83 For a long time, animal researchers had difficulty demonstrating S/D discrim-
84 ination in pigeons or rats. Zentall and Hogan and colleagues (Zentall and

85 Hogan, 1974, 1976; Zentall et al., 1981) demonstrated that pigeons could use
86 aspects of stimulus similarity and difference in a match-to-sample task. For
87 example, in Zentall and Hogan (1974) birds were trained on the color match
88 or mismatch between cue and target stimuli (e.g., a red or green cuing lamp
89 matched/mismatched to red or green target lamps) and were tested for their
90 ability to transfer this to new stimuli (e.g. blue and yellow lamps). Speeded
91 transfer was found when the second task was congruent to the first. However,
92 Premack (1983) pointed that the match-to-sample technique does not nec-
93 essarily provide a good test of animals ability to use the abstract relational
94 properties of the stimuli because they may simply be responding to the items
95 they have seen before. Indeed, even honey bees have been shown to succeed
96 on S/D with a delayed match to sample technique (Giurfa et al., 2001).

97 Premack (1983) proposed that generalization in the two (or more) item S/D
98 task is better suited to testing genuinely abstract S/D concept learning. This
99 has proved difficult with animals. Pearce (1991) found that with very extensive
100 training pigeons could learn to discriminate when relation was of equality or
101 difference in the height of two bars. However, pigeons had failed on an earlier
102 version of the task (Pearce, 1988), leading him to believe the pigeons were
103 simply memorizing all the possible configurations. This conflict between item-
104 specific learning and acquiring a generalized response is a common problem in
105 pigeon categorization experiments (Wright, 1997) The pigeons' behavior will
106 always be some trade off between the two. Therefore the crucial measure of
107 performance will be the response to completely novel stimuli.

108 Blaisdell and Cook (2005) reported a successful demonstration of two item
109 S/D learning in pigeons where the learning stimuli were colored geometric
110 shapes and the pigeons were tested on transfer to novel colored shapes. The
111 training stimuli were taken from a set of six shapes in six different colors. On a
112 single training trial a same pair (e.g., two red squares) and a different pair (e.g.
113 a purple chevron and a green star) were displayed on either side of computer
114 monitor and half the pigeons were reinforced to peck the same pair and half to
115 peck different pair. Six out of six pigeons reached an 80% criterion within 28
116 training sessions. Pigeons were then tested on transfer to either novel shapes,
117 novel colors or both novel. Transfer occurred in all conditions but was weakest
118 in the novel color condition and strongest when both cues were changed. This
119 provides strong evidence that pigeons can transfer in both dimensions, though
120 performance was driven primarily by color and the dimensions seemed to be
121 treated independently. Thus it seems that although pigeons can make some
122 abstraction based on the S/D relation this seems to be tied to individual
123 dimensions rather than taking place at a more 'conceptual' level.

124 Further evidence in support of a relatively low-level perceptual account of
125 pigeons abilities comes from Young and Wasserman (2002a). In their exper-
126 iment, pigeons responded to a 16 item array of computer icons that varied
127 in entropy from low (all same) to high (all different), responding was mea-
128 sured in a go/no-go task where arrays with higher or lower entropy were selec-
129 tively reinforced. Pigeons trained to respond positively to high entropy arrays
130 showed better discrimination. Young and Wasserman provided an analysis

131 which supported the interpretation that the pigeons multi-item S/D judge-
132 ments followed a logarithmic (rather than linear) entropy function, suggesting
133 that same-difference could be considered a dimensional rather than a categor-
134 ical distinction in certain cases. However, that does not prevent there from
135 also being an abstract concept particularly for pairwise S/D. Flemming et al.
136 (2007) demonstrated not only that a larger array (higher entropy) facilitated
137 learning of S/D relations in rhesus monkeys. But also that they could sub-
138 sequently succeed on a previously failed 2-item relation utilising a colour cue
139 to label represent the 'concept' of S/D. Interestingly, these same monkeys
140 then went on to fail a slightly higher order task assessing 'relations between
141 relations' (Exp. 3, Flemming et al., 2007).

142 Recently, Wright and Katz (2006) ran a comparative study with pigeons,
143 rhesus monkeys and capuchin monkeys using sets of photographic stimuli
144 which provided strong evidence of learning and generalization in all species.
145 Rhesus and capuchin monkeys learned at comparable rates while pigeons
146 learned more slowly. The animals were required to give one response if the pic-
147 tures matched and another if they were different. Correct responses resulted
148 in a food reward. All species reached a criterion of 80% with a training set of
149 just 8 items (giving 8 same item pairs and 56 different item pairs). However,
150 no animals initially learned to transfer this to novel test items. Increasing the
151 size of the training in stages lead to full generalization (when accuracy with
152 novel items reached equivalent accuracy as baseline) at 128 items for the mon-
153 key species and 256 items for pigeons. Thus there were quantitative but no

154 qualitative differences between species and a strong criterion for abstractness
155 (equivalent performance with novel material) was met. Wright and Katz spec-
156 ulated (based on human similarity ratings) that this continuity would extend
157 to higher mammals. This appears to be supported by Mercado et al.'s (2000)
158 demonstration of S/D learning in two bottlenose dolphins, albeit using a very
159 different paradigm.

160 Likewise, in a widely cited study, Oden et al. (1990) tested 11 month old
161 infant chimpanzees with several two item S/D tests. In one experiment, the
162 chimpanzees were given five minute sessions with pairs of toys to physically
163 examine. The two toys could either be the same or different from each other
164 (e.g. AA or CD). Immediately afterwards the chimpanzees were given a novel
165 pair of toys that maintained or changed the relationship. They looked longer to
166 the novel relationship. However, in another experiment the chimpanzees failed
167 on a physical matching to sample task where they were required to match
168 by hand a pair of items to another pair demonstrating a similar relationship.
169 In initial training, the chimpanzees succeeded in reaching a 10/12 criterion
170 but they could not transfer this to novel test sets. This contrasts with the
171 monkeys and pigeons in Wright and Katz (2006). Oden et al. speculate that it
172 was the instrumental aspect of the task that led to the failure with the infant
173 chimpanzees unable to integrate perceptual awareness with motor planning.

174 Many of these comparative results are of interest from a human devel-
175 opmental perspective. The success of a wide range of species at generalizing
176 the S/D concept suggests that human infants ought to be able both to per-

177 ceive and act on the abstract relational information and that, at least in the
178 case of perception, there is no reason to suspect this ability will be present
179 early on. Furthermore, infants might be expected to perceive the S/D relation
180 when tested with either rich photographic (Wright and Katz, 2006) or im-
181 poverished geometric stimuli (Blaisdell and Cook, 2005). However, Young and
182 Wasserman's (2002) study shows that care must be taken in giving too rich
183 a conceptual interpretation to S/D discrimination. Blaisdell and Cook (2005)
184 are careful to emphasize the importance of generalization as a measure of a
185 genuinely abstract concept. While chimpanzee's failure to perform physical
186 matching (Oden et al., 1990) emphasizes the difference between perceptual
187 awareness and instrumental knowledge. It suggests that lack of integration
188 between developing systems may lead to failures on certain tasks. The overall
189 message from the comparative literature is that one might expect infants to
190 succeed on a range of S/D tasks and demonstrate genuine abstract S/D con-
191 cept providing care was taken with the design and demands of the task. The
192 next section looks at previous relevant studies with children and infants.

193 1.2 Same/Different learning in human infants

194 Only two studies (Tyrrell et al., 1991, 1993) have directly investigated the
195 S/D concept with human infants. An earlier study (Caron and Caron, 1981)
196 found that infants habituated to matching pairs of items dishabituated to
197 non-matching pairs. However that study was not designed specifically to look
198 at S/D concept learning and because infants were only ever habituated to

199 sameness, non-conceptual explanations could not be ruled out, such as the
200 infants responding to the greater complexity or the broken symmetry of the
201 novel Different display.

202 Tyrrell et al. (1991) designed their study to address this problem. Using
203 a similar design to Experiment 2 of Oden et al. (1990), Tyrrell et al. tested
204 29 week old infants using a novelty preference test. Each infant took part in
205 two familiarization/novelty preference tests, one concrete and one abstract. In
206 the concrete test, the infants were familiarized with pairs of small toys affixed
207 to a board, infants in the Same condition had two 20s exposures to a pair of
208 matching toys (AA) and infants in the Different condition saw two dissimilar
209 toys (BC). All infants then saw pairs AA and BC next to each other and in
210 both groups they preferred the unfamiliar pair. In the second abstract phase
211 of the experiment, the infants in the two groups were familiarized to a new
212 pair of items with appropriate relation (DD or EF respectively) and tested for
213 preference for new items GG vs HI. Infants in both groups looked significantly
214 longer at the pair that had a novel relation relative to familiarization. There
215 were no interactions between conditions, although there was a main effect that
216 infants in the Same condition looked longer overall. The fact that infants in
217 both conditions responded to the novel relation in the abstract test suggests
218 that they are responding at a conceptual level. However, the very limited
219 familiarization phase showing just one pair of items in each case and using
220 'toys' constructed out of a common set of parts increase the likelihood that

221 the response was to some concrete similarity across conditions than through
222 the use of a completely abstract S/D concept.

223 Tyrrell et al. (1993) used a conditioned head-turn paradigm with a pair of
224 matching toys on one side and a pair of mismatching toys on the other. Turning
225 to the correct side caused a recording of a children's story to start playing.
226 Infants were assigned to one of four conditions and were reinforced over three
227 separate blocks of four, four and eight trials respectively, with a new set
228 of objects on each block. Infants in one condition were always reinforced for
229 looking at the same pair, whilst in another condition were always reinforced for
230 looking at the different pair. Infants in the two other conditions were reinforced
231 in the same way for blocks 1 and 2 but were then switched to for the final block
232 to be reinforced for the opposite relation. The results supported the hypothesis
233 that the infants were learning the concept rather than simple association to
234 particular items. All groups increased their looking to the correct side over
235 the first 2 blocks but the infants in the switch conditions were impaired at
236 the start of the 3rd block. Tyrrell et al. (1993) argued that this pattern of
237 results mirrors the reversal shifts found in discrimination learning and fits
238 the predictions of the House et al. (1974) model of discrimination learning.
239 They also consider the conditioned head turn paradigm to be an instance of
240 instrumental learning and so drew a contrast between the success of human
241 infants in their task and the failure of the infant chimpanzees in Oden et al.
242 (1990), although they acknowledge that the different task demands render it
243 impossible to make a direct comparison.

244 An awareness of similarity and difference relations between items is a nec-
245 essary pre-requisite for success in the artificial grammar tasks of Marcus et al.
246 (1999) In their Experiments 1 and 2 it is also a sufficient condition. Here
247 7.5-month-olds were habituated to an artificial grammar of syllables of syn-
248 thesized speech. Infants who had been exposed to several minutes of an ABB
249 tri-syllabic pattern showed a preference for ABA patterns over ABB patterns
250 when tested with completely novel syllables. An awareness of the presence of
251 a reduplicated syllable would be sufficient to discriminate between the two
252 types of grammar. In Marcus et al. (1999) Experiment 3, the contrast was
253 between an AAB and ABB pattern and a simple S/D discrimination would
254 no longer be sufficient. Equally informative are Marcus et al. (2007) where
255 the AAB/ABA/ABB discrimination was not learned directly with non-speech
256 stimuli but could be transferred from speech stimuli, and Johnson et al. (2009),
257 where 8- and 11-month-olds were tested with looming geometric shapes and
258 more easily learned grammars with late item repetition (ABB) than early rep-
259 etition (AAB) or non-adjacent repetition (ABA). These studies suggest that
260 S/D discrimination in human infants might be a graded phenomenon just as
261 it is in other animals.

262 Saffran et al. (2007) replicated the Marcus et al. (1999) auditory findings in
263 the visual domain using a task analogue of that task using pictures of dogs and
264 cats arranged in triplets of dog-dog-cat, etc. Saffran et al. contrasted infants
265 success with pictures of dogs and cats to their failures with simple geometric
266 shapes and musical tones (Marcus et al., 2007, Experiment 1) and speculated

267 that the stimuli must themselves form familiar categories before infants are
268 able to map relations from one case to another. It is an open question as to
269 the extent to which S/D discrimination is a more general process or relies on
270 pre-existing categorical knowledge.

271 The existing human infant literature has only investigated the abstract
272 S/D concept superficially and indirectly. Yet S/D is the simplest example of
273 a genuinely abstract relation and it is, therefore, of substantial interest to
274 know the limits and origins of infants abilities on this task. For example, no
275 research has looked for asymmetries between Same and Different highlighted
276 by Smith et al. (2008). Moreover, it is notable that no studies report any *fail-*
277 *ures* of younger infants to respond to S/D relations. Extensive research within
278 category learning (e.g. Eimas and Quinn, 1994) and spatial perception (e.g.
279 Quinn, 2003) has shown that these abilities become increasingly sophisticated
280 with age. It would of interest to know more about the development of infants'
281 abilities with more abstract relations, such as S/D.

282 The present study has several aims. The primary objective is to test pre-
283 linguistic human infants using convergent experimental designs that probe the
284 robustness of infants' abstract S/D conceptual knowledge to the same strin-
285 gent level as is required of other species. In particular, it is hoped the infants
286 will meet Blaisdell and Cook's (2005) criteria of equal performance with un-
287 familiar materials. An additional aim is to demonstrate continuity with the
288 animal literature using tasks that have some common elements (allowing for
289 necessary differences in experimental design required for testing such different

290 populations.) Thus, the experiments will use both rich photographic stimuli
291 and simplified colored, geometric shapes. The design will include a perceptual
292 and an instrumental task to explore the differences that were observed in Oden
293 et al. (1990) but which were not found in the work of Tyrrell and colleagues.
294 Additionally, the study aims to address the questions raised by Saffran et al.
295 (2007) about whether pre-existing category knowledge and/or domain speci-
296 ficity are important for S/D learning in human infants. Finally, as ought to be
297 the case with any infancy study, we are interested in the development of these
298 abilities. How early do competencies arise and how do they change over time?

299 Taking all these factors into consideration, two complimentary tasks are
300 presented that look at S/D learning. One task is a simple habituation/dishabituation
301 paradigm using photographic stimuli (see Mareschal and Quinn, 2001). The
302 items are unrelated to each other, not forming an particular category and
303 infants will be familiarized with either a same or a different condition as a be-
304 tween subjects variable. A second task adapts McMurray and Aslin's (2004)
305 anticipatory eye movement paradigm to assess infants' learning of associations
306 between Sameness leading to one outcome (e.g., an occluded pair of objects
307 reappears on the left) and Difference leading to another outcome (e.g., objects
308 reappear on the right). Here, the stimuli will be simple geometric shapes and
309 both learning and generalization will be assessed. The requirement for the in-
310 fant to actively anticipate the correct side makes this a task that investigates
311 instrumental learning. The same infants are tested on both tasks. This pro-

312 vides a measure of the robustness of the abstract S/D concept at the level of
313 the individual.

314 **2 Experiment 1 - S/D Discrimination using Photographic Stimuli** 315 **in a Looking Time Task**

316 Experiment 1 uses a standard habituation/dishabituation paradigm to test for
317 sensitivity to the abstract S/D relation in four and eight month old human
318 infants. The success of 7.5-month-olds in the related tasks of Tyrrell et al.
319 (1991) and Marcus et al. (1999) suggests that by 8 months infants should
320 succeed on a direct test of S/D discrimination. An obvious question is if these
321 abilities are present in younger infants. Caron and Caron (1981) found that
322 infants as young as 12 weeks old dishabituated to *Different* items after being
323 familiarized to items showing the *Same* relationship. However by not running
324 the converse condition, that experiment could not rule out explanations in
325 terms of symmetry or complexity. Therefore, a group of four month olds were
326 also tested.

327 A set of unrelated photographic stimuli is chosen to give a comparison
328 to the work of Wright and Katz (2006) whilst being able to address Saffran
329 et al.'s (2007) hypothesis that infants will not succeed on such tasks unless
330 the objects come from a familiar or coherent category.

331 2.1 Method

332 *2.1.1 Participants*

333 A total of 30 full-term human infants provided data, half were around 8 months
334 old (M= 249 days, range 232-259 days, 6 female, 9 male) and half were
335 around 4 months old (M= 124 days, range 117-129 days, 9 female, 6 male).
336 A further seven infants were tested but were excluded due to fussiness (5) or
337 experimental error (2).

338 Infants were recruited via the centre's participant database. Parents were
339 not paid for their infants' participation but infants were given a small present
340 and travel expenses were reimbursed. All infants took part in both Exper-
341 iment 1 and Experiment 2 in a single visit. The order of experiments was
342 counterbalanced.

343 *2.1.2 Apparatus*

344 A Macintosh G4 computer running MATLAB R2006a with the PsychToolBox
345 (Brainard, 1997; Pelli, 1997) controlled display of the stimuli and monitored
346 the habituation criterion, using experiment control routines written by the
347 authors. The stimuli were displayed on a Samsung 42" plasma screen and
348 infants reactions were filmed and recorded using an infrared DV camera for
349 later offline coding.

350 2.1.3 Stimuli

351 The stimuli were drawn from a set of 25 colored photographs of inanimate ob-
352 jects. All the pictures were scaled to be approximately the same size (300x300
353 pixels). Pairs of items were displayed on a uniform mid-grey background at
354 a screen resolution of 768 x 1080 pixels with their centers 520 pixels apart,
355 which equated to a visual angle of around 10° per item at a separation of
356 around 32° .

357 2.1.4 Procedure

358 Infants were seated on their care-giver's lap approximately 1.3m in front of
359 the monitor with the middle of the monitor at eye-level. The care-giver was
360 instructed not to interact with their infant during the experiment. The experi-
361 menter was seated at a control desk in the same room as the infant but hidden
362 behind a heavy curtain. The lighting was kept low and quiet classical music
363 was played in the background throughout the experiment. When the infant
364 was settled, the familiarization phase began.

365 The screen started as a blank grey slide and each trial began with a 'boing'
366 sound effect (approx. 74dB). Figure 1 gives a schematic representation of the
367 procedure. Pairs of items then appeared on the screen and remained there
368 whilst the infant continued to look at them. A trial finished if infants looked
369 away for a single 500ms period, if they accumulated 1000ms of glances away,
370 or if a maximum of 20s had elapsed. Looking behavior was coded on-line by
371 an experimenter holding a key down on the computer whenever the infant

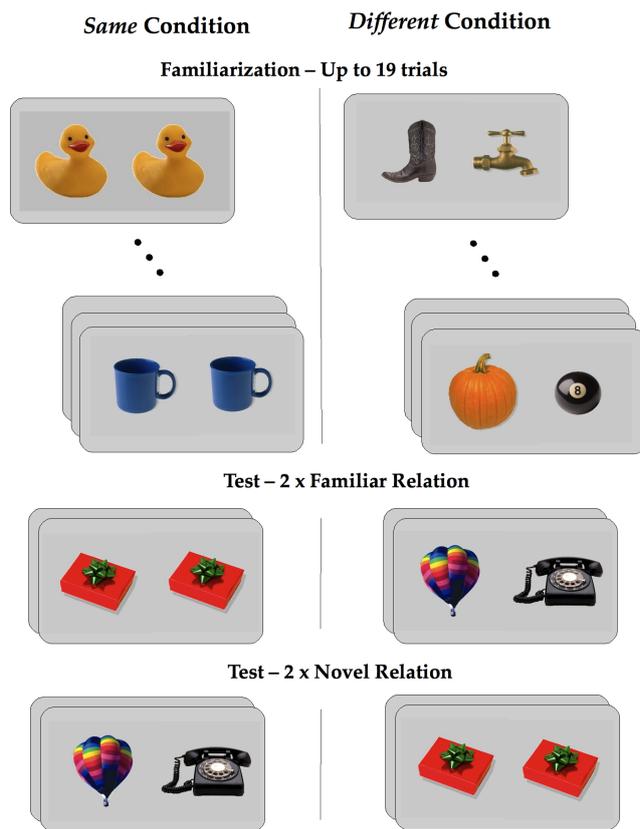


Fig. 1: Procedure for Experiment 1. Infants were assigned to either the *Same* or *Different* condition. They were familiarized to pairs of items demonstrating the relevant relation and then shown four novel test trials. The first two had the familiarized relation while the last two had the opposite relation. A yoked design ensured that pairs of infants in each condition saw the same test images but in opposite orders.

372 was watching the screen. The control software determined when a look away
 373 criterion or a maximum time was reached. The familiarization phase ended
 374 if the average length of last two trials was 50% less than the average of the
 375 first two trials. Otherwise, there were a maximum of 19 familiarization trials.
 376 These were followed by 4 test trials.

377 The stimuli displayed depended on the experimental condition. Infants
378 were randomly assigned to either the *Same* or the *Different* condition. For
379 infants in both conditions, each trial featured a novel pair of items. The order
380 and selection of items determined by a pseudo-random permutation and care
381 was taken that infants in the different condition did not see more images
382 overall. The experiment employed a 'yoked' design, so that the same sets of
383 items for one member of each group. A random subset of 19 items were used
384 in the familiarization trials. For infants in the *Same* condition each stimulus
385 consisted of an item from this set paired with itself. For infants in the *Different*
386 condition the item on the left was always paired with different item on the
387 right. The item that appeared left position on the n-th trial would re-appear
388 on the right position on trial $n+7$ (modulo 19). For each infant, the remaining
389 6 pictures were used to produce the test items, two *Same* test pairs and two
390 *Different* test pairs. An infant in the *Same* condition would see the *Same*
391 test items first then the *Different* test items, a yoked infant in the *Different*
392 condition would see the identical test images but in the opposite order.

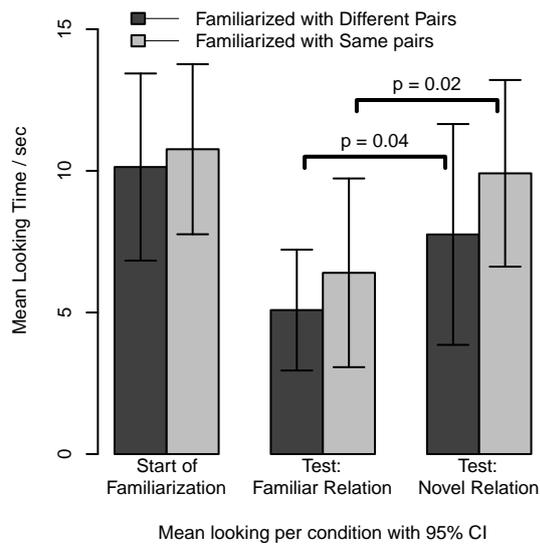
393 2.2 Results

394 Looking time scores were calculated by off-line coding of the video recordings.
395 A second experimenter, blind to the experimental hypothesis, double coded
396 the videos of a randomly selected 20% of the infants. A Pearson correlation
397 on the two sets of data gave a high degree of inter-rater reliability, $r = 0.96$,
398 $p = 0.001$. The mean looking times grouped by age are summarized in Figure

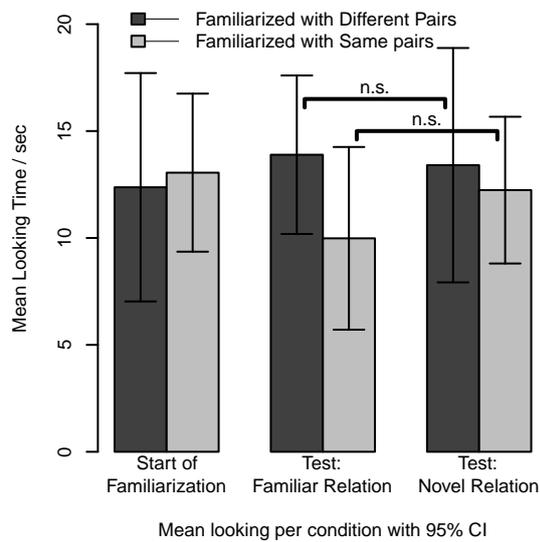
399 2. For each infant the average of their looking times for first two familiarization
400 trials (Start of familiarization) was compared to the average for the two test
401 trials with the same relation as in familiarization (Test: Familiar Relation) and
402 for the two novel relation trials (Test: Novel Relation), with the comparison
403 between the two test conditions giving an indication of discrimination of the
404 relation.

405 It was notable that very few infants habituated. Only 4 out of 15 of the
406 8-month-olds and 5 out of 15 of the 4-month-olds met the habituation crite-
407 rion of a 50% drop in looking. The 8-month-olds saw an average of 18.5 trials
408 during familiarization and 4-month-olds saw an average of 18.3. For this rea-
409 son, habituation was not included as a factor for analysis and we looked at
410 all infants together. The experiment was concerned with whether there were
411 age differences in response pattern and whether infants significantly increased
412 their looking to the test trials showing the novel abstract relation.

413 Therefore, a mixed 3x2x2 ANOVA was conducted with trial type as the
414 within subject variable (*Start of Familiarization, Test: Familiar Relation,*
415 *Test: Novel Relation*), and condition (*Same or Different*) and age (*8 months*
416 *old or 4 months old*) as the between subject variables. This revealed a main
417 effect of age, $F_{1,26} = 7.96$, $p = 0.009$, indicating a difference in patterns of
418 responses between 4- and 8-month-olds. As expected, there was a main effect
419 of trial type, $F_{2,52} = 0.046$, which was explored with planned comparisons
420 (see below). Crucially, there was no main effect of condition, $F \ll 1$, nor



(a) 8-month-olds



(b) 4-month-olds

Fig. 2: Mean looking times in Experiment 1. The light and dark bars indicate infants in the *Same* and *Different* conditions respectively. The leftmost set of bars show average looking at the start of familiarization, while the middle and rightmost bars show responses to familiar and novel test conditions. Planned comparisons and 95% confidence intervals are shown.

421 were there any interactions all F 's < 1 , indicating that infants were responding
422 equivalently in both the *Same* and *Different* conditions.

423 Planned comparisons investigated the infants response to the S/D relation.
424 At 8 months old, infants did show a significant decrease in looking to the
425 familiar relation, $t_{14} = 3.51$, $p = 0.003$, and a subsequent increase in looking to
426 the novel relation, $t_{14} = 3.56$, $p = 0.003$. This was found for both conditions.
427 Eight month old infants who had been familiarized with Same pairs looked
428 longer at the Different test items compared to the Same test items, $t_7 = 2.78$, p
429 $= 0.02$. While 8-month-olds who saw Different pairs initially looked relatively
430 longer at test pairs with two Same items, $t_6 = 2.08$, $p = 0.04$. However, the
431 4-month-olds showed no overall decrease, $t_{14} = 0.44$, $p = 0.33$, no recovery
432 $t_{14} = 0.65$, $p = 0.26$ nor any decrease or recovery within condition, all t 's < 1 .

433 2.3 Discussion

434 These results provide strong evidence that 8 month old human infants are
435 sensitive to the abstract relation of *S/D*. Infants who had been familiarized
436 to pairs of same or different objects showed a significant increase in looking
437 when shown pairs of new objects with a novel relation. This supports previous
438 findings that 7.5-month-olds succeed on artificial grammar tasks (Marcus et al.,
439 1999; Saffran et al., 2007) and that 7-month-olds can perform some simple S/D
440 discriminations (Tyrrell et al., 1991, 1993). The study also provides continuity
441 with the findings of Wright and Katz (2006) showing that human infants
442 are also able to make a S/D discrimination using photographic stimuli. This

443 continuity with the animal results and the strength of the effect in the older
444 infants suggests that the mechanism is more general than previously believed.

445 Saffran et al. (2007) speculate that an awareness of category membership
446 was a pre-requisite for noticing higher level commonalities in infants. But
447 in this case there was no specific perceptual or conceptual category that all
448 objects belonged to. Yet the infants were nevertheless sensitive to the S/D
449 relation. Furthermore, this experiment provides stronger evidence than the
450 experiments of Tyrrell and colleagues where in each case there were only a
451 very small set of items, making it unclear that a genuinely abstract relation
452 was being detected.

453 Finally, it should be emphasized that there was no differences between the
454 conditions in terms of either overall looking time or in decline and recovery
455 of looking during the test phase. It might be expected that slides with two
456 different objects are intrinsically more interesting than slides with two identical
457 objects and that therefore infants in the *Different* condition would look longer,
458 especially at the start of the experiment. In fact, no such differences were
459 found. This is strong evidence that the 8 month old infants were responding
460 on an abstract level to the S/D relation.

461 In contrast, the 4 month old infants did not show a significant decline in
462 looking over familiarization and consequentially did not show the recovery or
463 discrimination at test. They did not look longer at pairs of items exhibiting
464 a novel S/D relationship relative to that which they had been familiarized
465 with. One possibility is that the infants were potentially capable of making

466 the discrimination but because they had not habituated they were not liable
467 to show a novelty preference at test. In practical terms it may be very difficult
468 to test this hypothesis. The infants in this experiment, saw an average of
469 over 18 habit trials each of up to 20 seconds and did not habituate. Either
470 increasing the number of familiarization trials or increasing the maximum
471 length of individual trials might give the infants more time to process the
472 stimuli but just as likely is that the experiment would then be too long and
473 lose the participants completely.

474 **3 Experiment 2 - S/D Learning and Generalization using** 475 **Anticipatory Eye Movement**

476 This experiment adapts the anticipatory eye movement (AEM) paradigm de-
477 veloped by McMurray and Aslin (2004), building on the method of their Ex-
478 periment 3. A pair of geometric shapes moved together behind an inverted T-
479 shaped occluder and reappeared on either one side or the other. If the shapes
480 were the same as each other they moved in one direction, if they were differ-
481 ent they moved to the other direction. The experiment sought to determine
482 if human infants would learn this dependency and correctly anticipate the
483 reappearance of the shapes. A final phase tested if they could generalize this
484 learning to the novel shapes.

485 The current experiment makes several methodological changes to the Mc-
486 Murray and Aslin paradigm. First, we reduced the speed with which the stimuli
487 moved across the screen. In the original experiment stimuli were fully occluded

488 for only 750ms and infants appeared to be equally likely to expect the stimuli
489 to appear along a linear trajectory directly above the occluder as they were
490 to have looked either left or right, consistent with the actual paths the stim-
491 uli took. It is possible infants have a pre-potent expectation of linear motion
492 (see von Hofsten et al., 2000) and so increasing the length of the occlusion
493 allows time for the infants to overcome any such bias and search in the correct
494 location. Therefore, in the current experiment the stimuli move more slowly.
495 In particular, they remain occluded for 3000ms, with the whole animated se-
496 quence lasting approximately 6000ms. An additional benefit is that slower
497 moving stimuli that remain on the screen for longer allow more opportunity
498 for the infants to encode the items that are presented (Day and Burnham,
499 1981). A further problem of the original study was that infants missed some
500 trials because they were not looking in the right direction. For the infant
501 to learn the dependencies it is essential that they are attending to the screen.
502 Therefore, in the present experiment, the software only started each trial when
503 it determined that the infant was looking at the appropriate lower middle third
504 of the screen. Finally, the number of learning trials is increased to give infants
505 the fullest opportunity to learn the relation. The full procedure is explained
506 below.

507 3.1 Method

508 *3.1.1 Participants*

509 The same infants who took part in Experiment 1 also took part in Experiment
510 2. Seventeen 8-months-olds were tested but only 10 infants ($M = 252$ days,
511 range 243-259 days,) provided data suitable for group analysis. There were
512 eyetracker timing and synchronization problems with data from 3 other infants
513 and the remaining 4 provided insufficient data due to fussiness. A group of 9
514 four month old infants also provided data ($M = 123$ days, range 117-128 days,
515 6 female). A further 8 were tested but were excluded due to fussiness (3),
516 synchronization problems in the eye-tracking data (3) or very sparse data due
517 to poor calibration (2).

518 *3.1.2 Apparatus*

519 The experiment used a Tobii 1750 eye-tracking camera with integrated 17”
520 LCD monitor. It was connected to a Dell PC running Windows XP and
521 Exbuilder control software. A digital video camera placed directly above the
522 monitor also recorded the infants reactions.

523 *3.1.3 Stimuli*

524 The stimuli are shown in Figure 3 and were seen by all the infants. An in-
525 verted T-shaped red occluder on a black background was present on the screen
526 throughout each block. The occluder was approximately 23.3cm across and

527 11.6cm high at its maximum, subtending a visual angle of 21.9° by 11° when
528 viewed at 60cm. For the learning phase the paired stimuli were a yellow circle
529 and a light blue square. For the generalization phase, test shapes included a
530 maroon cross, an orange heart, a pink diamond and a green triangle. Each was
531 about 2.5cm across, making a visual angle of approximately 2.4° .

532 3.1.4 Procedure

533 The infant was seated on the caregiver's lap in front of the Tobii 1750 at
534 60cm from the screen. A preliminary eye-tracking calibration was performed
535 in which a small looming circle appeared at centre of the screen and moved
536 sequentially to each corner. The experiment itself then immediately began. It
537 was divided into four blocks, each of sixteen trials. The first three blocks were
538 learning trials and featured only two of the stimulus shapes in all four possible
539 pairings; two yellow circles or two blue squares, a circle and a square, or a
540 square and a circle. Each pairing occurred four times in each block of sixteen
541 learning trials with a randomized ordering for each infant and each block. In
542 the generalization phase, eight novel pairings were introduced, four of which
543 featured a maroon cross and orange heart in all possible pairings and four with
544 a pink diamond and a green triangle. These were randomly mixed with eight
545 trials that featured the circle and square from the learning phase. For half the
546 infants all *Same* pairs would always go to the left and all *Different* pairs go to
547 the right. This dependency was reversed for the other infants.

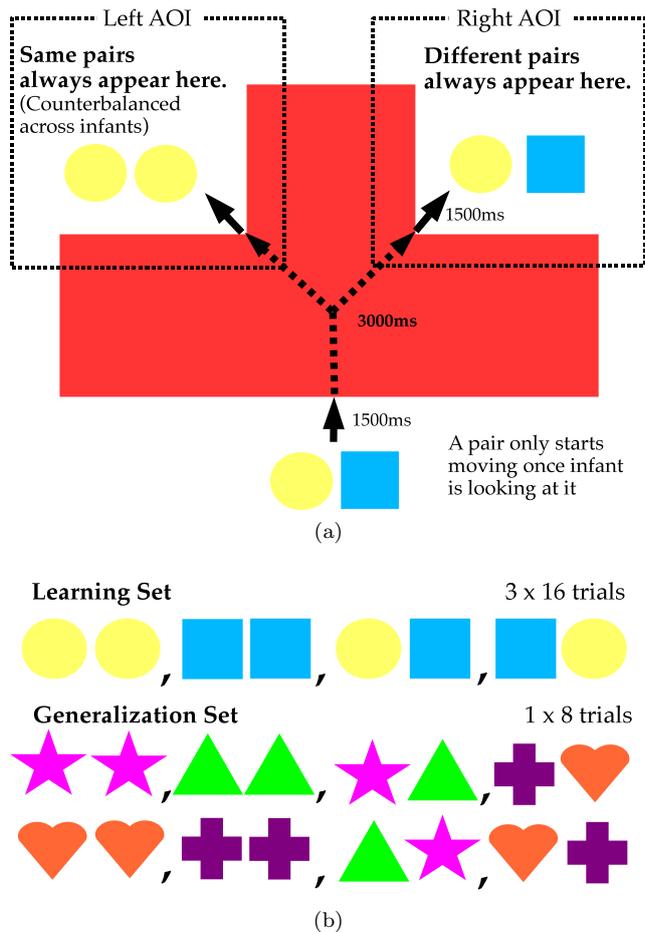


Fig. 3: (a) A schematic representation of the AEM task. On each trial two items would appear together at the bottom of the screen, move up and behind the inverted T-shaped occluder before reappearing on either the left or right depending on the S/D relation. The arrows and dotted squares were not visible but represent the path of the objects and the areas of interest used in the analysis respectively. (b) The pairs of shapes presented during the learning and generalization phases.

548 The procedure is illustrated in Figure 3. A bell sound effect marked the
 549 beginning of each trial when the two objects first appeared at the lower mid-
 550 dle part of the screen. Once the eye-tracker detected the infant was attending
 551 to that part of the screen the objects would begin to move. Otherwise the

552 objects remained in place and loomed smaller and larger at a rate of about
553 one full cycle per second until they captured the infants attention. The bell
554 was then sounded again and objects began to move. In the first phase of each
555 trial the objects moved together vertically upwards and behind the occluder,
556 a transition which took approximately 1500ms. The objects then continued
557 to move at the same rate following one leg of a Y-shaped trajectory behind
558 the occluder and emerging on either the left or the right. The occlusion was
559 accompanied by the sound of harp cascade. The objects were completely oc-
560 cluded for 3000ms. Finally the two objects moved to a resting position in
561 the upper left or right when a final sound effect was played and the objects
562 disappeared, either shrinking away to a point for all objects on one side or
563 shrinking and spinning for all objects on the other side. This took a further
564 1500ms. The sound effects had an average intensity of around 73dB. To help
565 the infants understand the task, on the very first four trials the occluder was
566 semi-transparent so the infant could see the objects moving behind it. The oc-
567 culder became gradually less transparent, so that from the fifth trial onwards
568 it was completely opaque.

569 The experimenter attempted to get the infant to complete all 64 trials but
570 this was rarely possible. Several steps were taken to increase the attentiveness
571 of the infants. If necessary the experimenter could reorient the infant by caus-
572 ing randomly moving cartoon figures to appear on the screen between trials.
573 Furthermore, in the third learning block the parents were instructed to talk to
574 their children, making a 'peek-a-boo' style game out of the occlusion sequence.

575 They were encouraged to use phrases like “Where is it?”, “There it is!” that
576 would maintain the infant’s engagement but without giving the infant any in-
577 formation about the trial outcomes. Caregivers were silent at all other times.
578 Finally, if the experimenter felt the infant was still becoming fussy or other-
579 wise disinterested during the final block of the learning phase, the experiment
580 was moved directly into the generalization phase.

581 3.2 Results

582 In general the infants were engaged with the task. The 8-month-olds sat
583 through an average of 43.2 out of 48 learning trials and 5.2 out of 8 gen-
584 eralization trials, the 4-month-olds saw an average of 37.7 learning trials and
585 4.9 test trials. Furthermore, there was no relation between the order in which
586 experiments 1 and 2 were carried out and likelihood of a baby not completing
587 the experiment [chi-squared: $\chi_1^2 = 1.83$, $p = 0.18$].

588 To compensate for the variation in the amount and quality of data collected
589 only relative measures of performance were considered. Two equally sized areas
590 of interest (AOI) were defined in the top left and top right and the analysis
591 compared fixations to the correct AOI relative to those to the incorrect AOI.
592 The two relative measures investigated were; (1) the proportion of fixation time
593 during occlusion that was spent looking to the correct AOI and (2) whether the
594 first fixation after occlusion was to the correct AOI. For the proportion score
595 on each trial the cumulative fixation times to the correct AOI were divided by
596 the total fixation to both AOI’s during the occlusion phase. For the first look

597 correct measure, each trial is scored as a success if during occlusion there was
598 a fixation in the correct AOI *and* there was no prior fixation in the incorrect
599 area, conversely if the first recorded look was to the incorrect AOI that trial is
600 scored as a failure and otherwise the trial is marked as possessing insufficient
601 data. All measures were calculated directly from the raw fixation data provided
602 by the Tobii 1750.

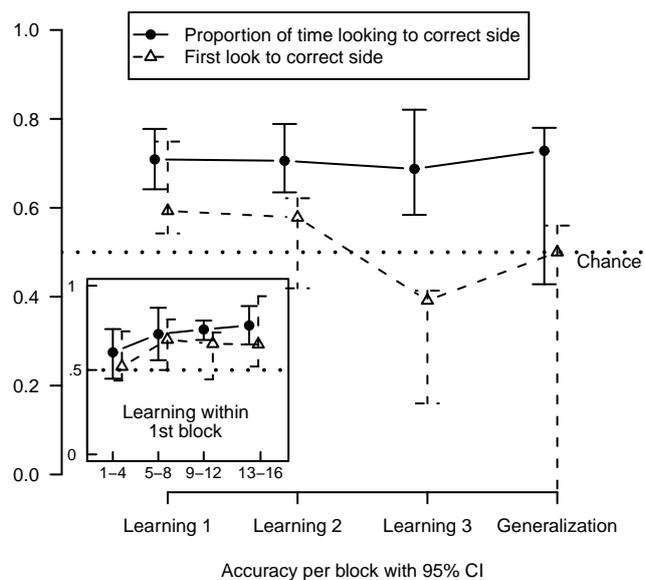
603 The sparseness of the data meant that not all participants had equal
604 amounts of data per condition. Therefore, we opted to use weighted averages:

$$\mu^* = \frac{\sum_i w_i \bar{x}_i}{\sum_i w_i}$$

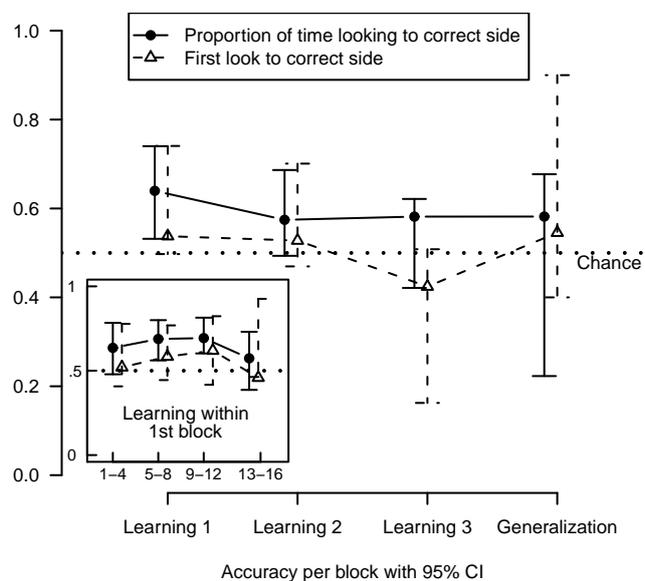
605 where, for a given participant in a given block, \bar{x}_i is their average score
606 and w_i is the number of data points collected for that participant. In this way,
607 infants with more data-points contribute proportionally more to the estimate
608 of the group mean but their individual (co)variance is ignored so that each
609 participant is treated as an independent sample. However, using this measure
610 means that standard parametric statistics should not be used. Instead, we
611 used the bootstrap method of Efron (Efron and Tibshirani, 1997; Davison and
612 Hinkley, 1997) to work out the 95% confidence intervals for each condition.¹

613 The results organized by block are summarised in Tables 1 and 2 and
614 shown in Figures 4(a) and 4(b). For the 8-month-olds, their relative looking
615 to the correct area was significantly better than the chance level of 0.5 on

¹ Parametric analyses yielded similar results. Only results from bootstrapping are reported here.



(a) 8-month-olds



(b) 4-month-olds

Fig. 4: Accuracy scores for all participants in Experiment 2 averaged by block. The solid line represents the relative proportion of looking to the correct area of interest (AOI) during the occluded period. The dashed line represents the proportion of occlusions on which there was a fixation to the correct AOI *before* there was one to the incorrect AOI. The insets show learning within the first block. The error bars are 95% confidence intervals from the bootstrap analysis.

| | Relative proportion looking to correct AOI | | First look to correct AOI | |
|---|--|-------------------------|---------------------------|-------------------------|
| | Weighted Mean | 95% Confidence Interval | Weighted Mean | 95% Confidence Interval |
| Learning 1 | 0.71 | 0.64 – 0.78 | 0.59 | 0.55 – 0.75 |
| Learning 2 | 0.71 | 0.64 – 0.80 | 0.58 | 0.42 – 0.63 |
| Learning 3 | 0.69 | 0.59 – 0.82 | 0.39 | 0.16 – 0.41 |
| Generalization | 0.73 | 0.44 – 0.78 | 0.50 | 0.00 – 0.56 |
| Performance within the first learning block | | | | |
| Trials 1–4 | 0.60 | 0.46 – 0.75 | 0.52 | 0.43 – 0.73 |
| Trials 5–8 | 0.71 | 0.56 – 0.87 | 0.68 | 0.50 – 0.80 |
| Trials 9–12 | 0.74 | 0.68 – 0.79 | 0.66 | 0.44 – 0.72 |
| Trials 13–16 | 0.76 | 0.65 – 0.88 | 0.65 | 0.52 – 0.92 |

Table 1: Experiment 2 - Accuracy scores for 8 month old infants

| | Relative proportion looking to correct AOI | | First look to correct AOI | |
|---|--|-------------------------|---------------------------|-------------------------|
| | Weighted Mean | 95% Confidence Interval | Weighted Mean | 95% Confidence Interval |
| Learning 1 | 0.64 | 0.53 – 0.74 | 0.54 | 0.49 – 0.73 |
| Learning 2 | 0.57 | 0.50 – 0.69 | 0.53 | 0.47 – 0.71 |
| Learning 3 | 0.58 | 0.42 – 0.62 | 0.42 | 0.15 – 0.51 |
| Generalization | 0.58 | 0.21 v 0.68 | 0.55 | 0.40 – 0.90 |
| Performance within the first learning block | | | | |
| Trials 1–4 | 0.64 | 0.48 – 0.79 | 0.52 | 0.43 – 0.78 |
| Trials 5–8 | 0.69 | 0.55 – 0.80 | 0.58 | 0.45 – 0.77 |
| Trials 9–12 | 0.69 | 0.60 – 0.82 | 0.62 | 0.40 – 0.82 |
| Trials 13–16 | 0.57 | 0.41 – 0.73 | 0.46 | 0.46 – 0.91 |

Table 2: Experiment 2 - Accuracy scores for 4 month old infants

616 all three learning blocks. They maintained a similar level of accuracy in the
617 generalization phase, although this was not significant. This may be a power
618 issue as a consequence of there being less generalization data; an average of 5.3
619 points per participant compared to 16, 15.5 and 11.7 points in three learning
620 blocks. Eight month old infants appear to have learned from the within the
621 first block to associate the training stimuli with the sides they would reappear.
622 Likewise, in the first block the infants would on average look first to the correct
623 side significantly more often than chance. But this decreased over time and in

624 third learning block infants were looking more to the other side. This finding
625 may reflect infants learning the time structure of the events. Objects always
626 reappeared 3000ms after they were occluded so there is no need to look towards
627 the AOI before that point and consequentially infants may learn to cast their
628 first looks elsewhere. Although the 4-month-olds showed a qualitatively similar
629 pattern of response. The 4-month were only significantly above chance in the
630 relative looking for the first block. But, as before this may be an issue of power,
631 as there was much less data for the age group. with 12.6, 10.6, 5.2 and 2.9 data
632 points per participant for each of the three learning blocks and the test block
633 respectively.

634 It is notable that at both ages learning happened very quickly. Even if
635 we discount the first 4 trials where the occluder is partially transparent and
636 infants could potentially see the path of the pairs. In order to establish that
637 infants really are learning the task, we performed another analysis looking at
638 the time course of learning in the first block. We divided it into 4 sub-blocks
639 and calculated the weighted average for each group of 4 trials. We also ran
640 another set of bootstrap analyses. The results are shown in the lower halves of
641 Table 1 and 2 and in the inset boxes in Figures 4(a) and 4(b). These analyses
642 clearly indicate that the infants at both ages are learning something about the
643 task very early on.

644 One further analysis investigated if infants learn differently between the
645 Same and the Different trial types. The trials were classified accordingly and
646 another set of weighted averages and bootstrapped confidence intervals were

| | Same pair trials | | Different pair trials | |
|----------------|------------------|-------------------------|-----------------------|-------------------------|
| | Weighted Mean | 95% Confidence Interval | Weighted Mean | 95% Confidence Interval |
| Learning 1 | 0.57 | 0.45 – 0.68 | 0.85 | 0.74 – 1.00 |
| Learning 2 | 0.52 | 0.39 – 0.66 | 0.80 | 0.71 – 0.90 |
| Learning 3 | 0.41 | 0.20 – 0.65 | 0.87 | 0.76 – 0.97 |
| Generalization | 0.56 | 0.36 – 0.82 | 0.80 | 0.45 – 0.97 |

Table 3: Experiment 2 - Same versus different accuracy for 8 month olds

| | Same pair trials | | Different pair trials | |
|----------------|------------------|-------------------------|-----------------------|-------------------------|
| | Weighted Mean | 95% Confidence Interval | Weighted Mean | 95% Confidence Interval |
| Learning 1 | 0.49 | 0.28 – 0.69 | 0.76 | 0.64 – 0.87 |
| Learning 2 | 0.54 | 0.40 – 0.80 | 0.58 | 0.42 – 0.78 |
| Learning 3 | 0.46 | 0.33 – 0.52 | 0.67 | 0.52 – 0.77 |
| Generalization | 0.34 | 0.02 – 0.62 | 0.81 | 0.55 – 0.99 |

Table 4: Experiment 2 - Same versus different accuracy for 4 month olds

647 calculated. For this analysis we only looked at the more reliable proportion
648 score. The results are presented in tables 3 and 4 and plotted in Figures 5(a)
649 and 5(b).. The infants appear to learn to predict where the pairs of different
650 items will reappear but are at chance when the items are the same as each
651 other. To attempt to confirm this we ran a conventional analysis of variance
652 on the combined learning data from the 4- and 8-month-olds using standard
653 arithmetic means as the dependent variable, with age as a between subject
654 variable and pair relation (same versus different) as a within subject variable.
655 This revealed a main effect of age $F_{1,17} = 5.76$, $p = 0.03$ and a main effect of
656 the S/D relation $F_{1,17} = 12.28$, $p = 0.003$ but no other effects or interactions.
657 This indicates that, although the effect was stronger with the 8-month-olds,
658 both groups showed the same pattern of learning in only the different case.

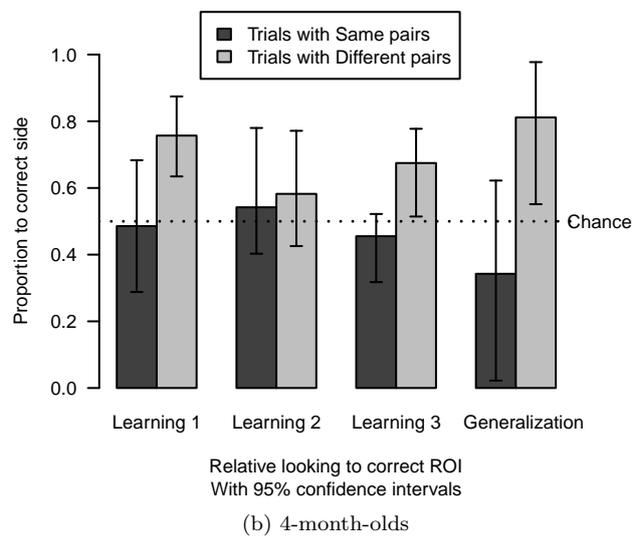
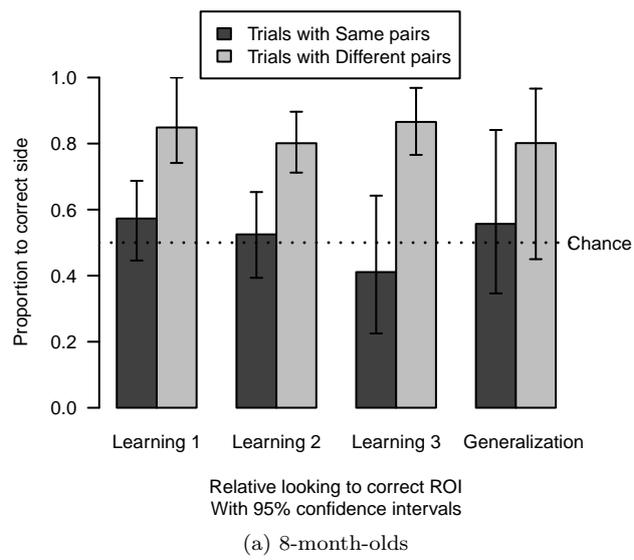


Fig. 5: Graph showing the accuracy for same or different trials in the learning and generalization phases for Experiment 1b. Error bars show the 95% confidence intervals.

659 3.2.1 Comparing Experiments 1 and 2

660 Finally, we were interested in if there was any consistency in responses across
661 the two experiments. As a measure of performance on the looking time study,
662 we took the ratio of the two test conditions. A higher value indicates a stronger
663 S/D response, namely a greater relative looking to the novel relation. For
664 the AEM task we considered two measures, the average accuracy rate across
665 the whole learning phase and accuracy in the generalization block as these
666 may index different aspects of the ability. Since we were looking for evidence
667 of common causation between the tasks we include both age groups in one
668 analysis. This gave N=18 (10 eight-month-olds). The analysis showed that
669 better performance in the looking time task did not correlate with performance
670 in the AEM task, measured against learning (Spearman's rank correlation
671 $\rho = 0.02$, $p = 0.95$) or generalization (Spearman's rank correlation $\rho = 0.19$,
672 $p = 0.50$).

673 3.3 Discussion

674 The results of this experiment suggest that 8 month old human infants are
675 able to use at least some aspect of S/D distinction on an instrumental learning
676 task with simple geometric stimuli. It appears that these infants rapidly learn
677 which side the different pairs will reappear and look longer to this location.
678 The infants can generalize the rule they have learned, performing as well with 8
679 stimulus pairs with novel colors and shapes in the test phase. The infants' first

680 look after occlusion is initially predictive of where the objects will reappear
681 but as they learn the timing of the reappearance they stop looking directly
682 to the correct location. The fact that each trial had the same sequence of
683 sound effects could also provide scaffolding for the infants to anticipate the
684 point at which the objects reappeared. However, the fact that infants only
685 appear to learn to predict the *Different* trials was unexpected and suggests
686 that their performance may not be directly attributable to ability to perceive
687 the abstract S/D relation, but may be due to a more low level interpretation.

688 The fact that infants only learned the dependency for *Different* trials but
689 were at chance with *Same* pairings indicates that infants are responding to
690 something other than a truly abstract S/D concept which in theory would
691 lead to equal accuracy on both types of trials. From an adult perspective it is
692 obvious that *Same* and *Different* are 'opposites' and so might be expected to
693 be associated with different outcomes but this is a highly conceptual interpre-
694 tation. The infants mixed performance makes it apparent that the task is not
695 quite as simple as adults see it. In fact there are two separate contingencies
696 to be learned. Infants must learn that non-matching pairs will always reap-
697 pear on one side and, independently, that matching pairs always reappear on
698 the other. In fact, as both Young and Wasserman (2002a) and Smith et al.
699 (2008) make clear, there is a great deal of asymmetry between the two cases.
700 Like the pigeons in Blaisdell and Cook (2005), infants could be responding to
701 lower level aspects of the stimuli, symmetry, contrast, etc. that are present in
702 the *Different* stimuli but not in the *Same* pairs. However, unlike Young and

703 Wasserman (2002a) the infants appear to have learned better with the more
704 complex exemplars. This might be precisely because the *Different* stimuli are
705 more complex and are therefore more engaging for the infants prompting them
706 to learn. Alternatively, as suggested by Smith et al. (2008), the asymmetry may
707 arise from the fact that a *Same* category is narrow and precisely delineated
708 while *Different* is more broad. Hence *Different* is potentially easier for the
709 infants to learn.

710 Interestingly, learning was very rapid. Infants were already above chance
711 in the first block of 16 trials. Learning appeared faster than in Experiment 3 of
712 McMurray and Aslin (2004), which used a very similar AEM design. In their
713 learning phase infants received just 16 learning trials and averaged only 53%
714 accuracy. Three factors might account for this improved learning (1) infants
715 in our experiment were older (8 months vs 6 months), (2) each trial only
716 started when the infant was looking towards the lower middle of the screen
717 ensuring that all infants saw (at least part of) all the training trials, and (3)
718 the stimuli moved more slowly across the screen giving infants more time per
719 trial on being and included being fully occluded for 3000ms (vs 750ms) giving
720 them more time to direct their attention to the correct location. This rapid
721 learning can be found in other studies, with an alternative anticipatory eye
722 movement design. For example, Sobel and Kirkham (2006, 2007) found that 8
723 and 5 month old infants were able to learn a spatial dependency after just 4
724 exposures to the critical training event.

725 The 4 month old infants in Experiment 2 did not show learning to the
726 same extent as the 8 month old infants had done. However, they do seem to
727 show a qualitatively similar pattern of responding. They learn the contingency
728 for *Different* pairs but not for *Same* pairs and they generalize this learning to
729 novel shapes. The fact that such young infants respond in this similar fashion
730 supports our finding with 8-month-olds. When considered in light of their
731 failure on the S/D looking time task, these results suggest that success in
732 this task may be mediated by something other than abstract same-different
733 concept learning. We return to this point in the general discussion below.

734 **4 General Discussion**

735 This study investigated the emergence of abstract concept learning in human
736 infants. The two item S/D relation was chosen as an example of a very sim-
737 ple abstract concept that had previously been extensively investigated in the
738 animal cognition literature but to a much lesser extent with human infants.
739 Infants were tested in a passive looking time task and an active anticipatory
740 eye movement (AEM) task with visual rich and simple stimuli respectively.
741 Two groups of infants, aged 4 and 8 months, were tested to provide a develop-
742 mental perspective. In the looking time task, it was found that 8-month-olds
743 but not 4-month-olds were sensitive to the S/D relationship. In the AEM task,
744 it was found that both 4- and 8-month-olds responded in a similar fashion;
745 learning to anticipate the re-emergence of occluded Different paired shaped but
746 performing at chance when the pair of shapes were the same as each other.

747 Additionally, both age groups transferred their learning in the Different case
748 to trials with novel colored shapes. This pattern of responding is not consis-
749 tent with with infants having a full awareness of an abstract concept of S/D
750 but is strongly suggestive that the S/D concept develops from sensitivity to
751 more perceptual regularities. Furthermore, no correlations were found between
752 performance on the two tasks suggesting multiple processes are involved.

753 4.1 Looking times with photographic stimuli

754 In Experiment 1 infants were familiarized with pairs of photographic images
755 of either matching or non-matching inanimate objects drawn from a set of
756 randomly chosen unrelated objects. They were then shown two further trials
757 in which novel objects with a novel relation were presented. The results were
758 very clear cut, with 8-month-olds succeeding and 4-month-olds failing at the
759 task. In both conditions, 8-month-olds dishabituated to pictures showing the
760 opposite relation to that which they had been familiarized with. There was no
761 effect of scene complexity, meaning that infants did not look longer at displays
762 with 2 dissimilar items relative to 2 identical items either during familiarization
763 or at test.

764 These results provides clear evidence that 8 month old infants are sensitive
765 to the abstract relation of S/D. This finding gives stronger support for infants'
766 S/D discrimination ability than previous research. It is more direct proof than
767 the indirect conclusions concerning S/D awareness than may be drawn from
768 7.5 month olds success on artificial grammar tasks (Marcus et al., 1999; Saffran

769 et al., 2007). It is a more robust finding than those of Tyrrell et al. (1991) and
770 Tyrrell et al. (1993) where only a small set of objects were used and paired
771 preference paradigms meant that Same and Different pairs were simultaneously
772 presented. In the present study infants saw a wide range of unrelated objects
773 whose only common feature was the S/D relationship between them and they
774 only saw a single pair of items at a time.

775 The design of this study also provides continuity with the findings of Wright
776 and Katz (2006) concerning S/D learning in monkeys and pigeons. These re-
777 sults show infants are also able to make a S/D discrimination using photo-
778 graphic stimuli, even more rapidly and with smaller example sets. This conti-
779 nuity with the animal findings and the strength of the effect in 8 month old
780 infants suggests the mechanism is more general than previously believed. Note
781 that the animal participants were rewarded for learning while human infants'
782 performance is a measure of spontaneous discrimination. Moreover, the fail-
783 ure of 4-month-olds suggests that this S/D discrimination is not an innate
784 response but is due to concept learning. Wright and Katz (2006) found that
785 increasing the number of exemplars improved performance of the pigeons and
786 monkeys so a similar manipulation may lead to better S/D discrimination in
787 the younger infants. However, the current design is probably at the limit for of
788 attention for the number of familiarization trials for such a young age group.
789 (Infants saw up to 19 familiarization trials each of up to 20 seconds, plus 4
790 test trials). An alternative approach might be to have many more shorter trials
791 and repetitions. Mareschal et al. (2005) found that a regime of rapid, repeated

792 presentation (each trial 2 seconds long seen multiple times) led 4-month-olds
793 to succeed in forming categories based on perceptual correlations that would
794 otherwise not be found before 7 months old. A similar design may reveal a
795 sensitivity of 4-month-olds to the S/D relation.

796 Seven month old infants can learn the AAB/ABA discrimination with syn-
797 thesized syllables (Marcus et al., 1999) and with pictures of dogs and cats
798 (Saffran et al., 2007) but do not learn directly with musical tones, timbres or
799 animal sounds (Marcus et al, 2007). Saffran et al. (2007) suggest that stimuli
800 must belong to a familiar category if infants are to notice the higher order
801 relations between them. But, in this experiment, the stimuli did not form a
802 single meaningful category and many of the individual stimuli were very likely
803 to be completely unfamiliar to the participants. Nevertheless, 8-month-olds
804 were sensitive to the higher order S/D relation between the items.

805 4.2 Anticipatory eye movement with colored geometric shapes

806 In Experiments 2 an AEM paradigm demonstrated that infants can rapidly
807 learn to anticipate where a pair of geometrical shapes would reappear but
808 only when the pair of objects were different from each other. Infants spent
809 longer looking to the correct area of the screen while the objects were oc-
810 cluded. The infants were also able to generalize their learning to novel shapes
811 that also shared the different relation. But their performance was always at
812 chance when the two objects were the same as each other. This was a surprising
813 finding and one that is difficult to explain fully without further investigation.

814 Nevertheless, the effect appears to be real since a very similar pattern of re-
815 sponding was found in both 4- and 8-month-olds. Moreover, the asymmetry is
816 strongly suggestive of a non-conceptual interpretation of infants abilities.

817 Unlike in Experiment 1, where infants must learn just one relation and
818 simply detect its violation, in Experiment 2 the task is more complex; infants
819 must simultaneously develop categories of *Sameness* and *Difference* and as-
820 sociate them with two possible outcomes. It appears that the infants, at both
821 ages, rapidly learn which side the different pairs will reappear and look longer
822 to this location. They can generalize this rule to novel pairs of shapes. But
823 they do not learn the *Same* relation. This may imply that *Difference* is a
824 simpler concept for infant than *Sameness*. One possible reason may be that
825 to establish *Sameness* one must check that *all* properties of two objects are
826 equivalent, whereas *any* single discrepancy establishes *Difference*, as suggested
827 by Smith et al. (2008). Hence, under the challenging conditions of the AEM
828 task, infants only manage to learn the simpler contingency. This difference be-
829 tween tasks and between *Sameness* and *Difference* within Experiment 2 shows
830 that infants do not have a single, unitary S/D concept directly equivalent to
831 that of adults.

832 One simpler explanation that has to be ruled out first is the possibility
833 that infants' performance could be accounted for because they were exhibiting
834 a systematic side bias, as was found in some infants in the experiments of Mc-
835 Murray and Aslin (2004). This can be discounted on two grounds. Firstly the
836 side to which the Same and Different pairings appeared was counterbalanced

837 across infants, for half the infants Different pairs would go to the left and Same
838 pairs would go to the right, whilst for the remaining infants this dependency
839 was reversed. Therefore, nothing in the geometry of the experimental set up
840 (e.g., the layout of the testing room) could systematically influence infant at-
841 tention to one side or another. Secondly, a side bias would lead to a below
842 chance performance on the unbiased side. Such a bias was never seen in the
843 data with performance on the Same trials being very close to the chance level
844 of 50% in all cases.

845 Instead, it may be due to the infants responding to lower level aspects of
846 the stimuli such as symmetry, contrast, complexity, etc.. When Blaisdell and
847 Cook (2005) demonstrated two item S/D learning with geometric shapes in
848 pigeons they were careful to chose a set of colors and shapes for their stimuli
849 that would be highly dissimilar so that it would not be possible to account
850 for transfer in terms of the similarity between stimuli. They also point to
851 converging evidence from other studies that supports the case for an abstract
852 S/D in the pigeons by ruling out any other common perceptual property across
853 experiments (e.g. Cook et al., 1997; Cook, 2002). However, in Experiments 2
854 an S/D interpretation is *not* appropriate since there is no learning of the Same
855 cases and so alternative mechanisms must be considered.

856 In Young and Wasserman (2002a), pigeons learned S/D discriminations
857 better with larger arrays of items that increased their awareness of the redun-
858 dancy / dissimilarity contrast. Although those findings do not bear directly on
859 the performance of the human infants in this experiment, one related expla-

860 nation might be that the Different stimuli are more complex with contrasting
861 colors and they were more engaging leading the infants to attend and learn
862 with these stimuli. Although this interpretation seems implausible from an
863 adult perspective, only further experiment could rule out such an explana-
864 tion of the infant behavior. It is even more surprising that neither group of
865 infants learned the Same dependency when the learning phase used only two
866 objects (the yellow circle and the blue square). With just four trial types in
867 the learning phase, it might be expected that infants could learn a direct as-
868 sociation between each pairing and its eventual reappearance. However, this
869 did not happen with either age group and the fact that the identical pattern
870 was found in the generalization phase suggest that performance must be ac-
871 counted for in terms of some kind of abstract feature of the stimuli. Future
872 studies could systematically vary the common and distinct properties of the
873 stimuli to investigate this. For example, using arrays of multiple objects or a
874 wider selection of objects in the learning trials or using photographic stimuli
875 to investigate the issue of the infants' engagement with the stimuli. Without
876 further studies, it is not possible to give a clear explanation for the surprising
877 findings of Experiments 2. Nevertheless, the identical pattern of responding
878 between ages and between learning and generalization makes it likely that
879 there is some abstract process underlying the infants behavior in this task.

880 4.3 Infants' understanding of Same/Different as an abstract concept?

881 While the results of these experiments show that 8-month-olds (but not 4-
882 month-olds) respond to the relation of Same and Different with photographic
883 stimuli and that both 4- and 8-month-olds learn and generalize some property
884 of Different geometric shapes, questions remains as to the extent to which these
885 abilities can be said to be *abstract* and the extent to which they can be said to
886 be *conceptual*. The two are not necessarily synonymous and the question is of
887 interest to developmentalists. Jean Mandler (Mandler, 2004) argues that there
888 is a fundamental difference between the perceptual and the conceptual. The
889 former referring to implicit perceptual sensorimotor knowledge while “concept
890 refers to declarative knowledge about object kinds and events that is poten-
891 tially accessible to conscious thought.” (p.4, Mandler, 2004). In particular she
892 claims that concepts are not just complex associations of percepts but are a
893 different mode of representation created from perceptual inputs and a core set
894 of innate *image-schemas* (see chapter 4, Mandler, 2004). By contrast, Quinn
895 and Eimas (2000) take a strongly empiricist perspective arguing for continuity
896 between percepts and concepts. Our results help clarify this debate.

897 From Mandler's perspective there can be two interpretations of S/D dis-
898 crimination abilities found in these experiments. Either these abilities are due
899 to the infants detecting perceptual regularities in the stimuli they encountered
900 or could be a consequence of their awareness of a concepts of Sameness and
901 Difference. Since, in Experiment 1, the stimuli are all unrelated, it is hard to
902 point to the perceptual features that the stimuli have in common and which

903 would contribute to a concept of sameness. Sameness appears to be a concept
904 but not a category. Here, the commonality between instances is of a different
905 kind to that found in object-based categories such as trees or dogs. Infants as
906 young as 3 months can form such categories (Eimas and Quinn, 1994) as can
907 pigeons (Herrnstein and Loveland, 1964). In such cases, although it may not be
908 possible to determine exactly which features define the category, it is clear that
909 they are perceptually grounded. Members of these categories share many sim-
910 ilarities in terms of texture, color, shape and spatial arrangement of features.
911 Whilst all the Same pairs do share a horizontal translational symmetry, this
912 is not a shared perceptual feature per se, but operates more like an abstract
913 rule applicable to those cases. Nevertheless, Sameness or object-identity with-
914 out being a concrete or abstract object-category is fundamentally a perceptual
915 property and may contrary to Mandler's view develop from perception alone.
916 A parallel can be found in Quinn's (2003) account of development of spatial
917 relation categories in infancy. Quinn reviews evidence that infants under 1
918 year do have non-object based concepts of spatial relations such as above, be-
919 low, between but that these develop in sophistication and abstraction over the
920 first year consistent with a perceptually grounded account, where innate core
921 concepts are not necessary. The failure of 4-month-olds to respond to the S/D
922 distinction with photographic stimuli indicates that this ability also develops.
923 Although this by itself does not necessarily support either position.

924 The results of Experiment 2 also support a perceptual interpretation. In-
925 fants are not applying an abstract S/D rule to the stimuli but are abstracting

926 some perceptual feature to identify the Different stimuli and to learn to pre-
927 dict where these stimuli reappear and generalize this learning to new Different
928 stimuli. This ability is largely unchanged across the two ages tested who show
929 a very similar pattern of response. Infants of both ages seeming to possess
930 the same ability to discriminate and generalize only with Different stimuli. A
931 surprising finding made more so when we compare this to the successes and
932 failures of the same group of infants on the looking time tasks. A result which
933 is problematic for Mandler's dual process account; if eight month old infants
934 possessed an abstract conceptual awareness of the S/D relation that allowed
935 them to succeed on the looking time task, why is this concept not accessible
936 in the AEM task? If the abilities are based on a perceptual analysis then this
937 difference between the tasks can be explained in terms of the substantial per-
938 ceptual differences between the stimuli used in the task. This interpretation
939 leads to the testable predictions that using simpler stimuli in the looking time
940 task might lead 4-month-olds to succeed on the S/D discrimination whilst us-
941 ing more complex stimuli in the AEM may induce the older infants to learn
942 the dependencies for the Same stimuli.

943 Of course, there is a further problem with a conceptual interpretation to
944 the looking time results with 8-month-olds in that monkeys and pigeons can
945 also make S/D discriminations with photographs (Wright and Katz, 2006).
946 Likewise, Blaisdell and Cook (2005) show that pigeons can discriminate S/D
947 relations with colored geometric shapes. In neither case would any researchers
948 be likely to attribute these successes to the animals possessing human-like

949 concepts but these results do prove problematic for Mandler’s account, where
950 perceptual meaning analysis is required to form and utilize abstract concepts.
951 Mandler (2004) is dismissive of Young and Wasserman’s (2002) results, claim-
952 ing that these are purely abstract perceptual abilities but does not address the
953 wider comparative literature where the accumulation of data across a range
954 of paradigms make clear that non-human animals can go beyond the purely
955 perceptual features of S/D stimuli. Penn et al. (2008) do look at a wider set
956 of animal studies but make their strong claims that human and non-human
957 S/D abilities are qualitatively different without considering how human infants
958 perform on these tasks. Our results bridge this gap and support the position of
959 Wasserman and Young (2010) that there are continuities between humans and
960 animals. We find that infants show asymmetries between *Same* and *Different*
961 and that, as in other species, their abilities depend upon the particulars of ex-
962 perimental set-up and perceptual features available in a given task. The S/D
963 concepts of both human infants and animals appear to be firmly grounded in
964 perception.

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970

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