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Making sense of infant familiarity and novelty responses to words at lexical onset

Rory A. DePaolis^{1*}, Tamar Keren-Portnoy², Marilyn M. Vihman²

¹Communication Sciences and Disorders, James Madison University, USA, ²Language and Linguistic Science, University of York, United Kingdom

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1 **1.1.1 Making sense of infant familiarity and novelty responses to words at lexical onset**

2 Rory A. DePaolis^{1*}, Tamar Keren-Portnoy², and Marilyn Vihman²

3 ¹Communication Sciences and Disorders, James Madison University, MSC #4304, Harrisonburg, VA
4 22807

5 tel: 001 540 568-3869

6 *corresponding author

7 ²Language and Linguistic Science, University of York, V/C/210, 2nd Floor, Block C, Vanbrugh
8 College, University of York, Heslington, York YO10 5DD

9 * **Correspondence: Rory DePaolis at depaolra@jmu.edu**

10 **Keywords:** Novelty, Familiarity, Early Word Learning, Headturn Preference Procedure, Infant
11 Speech Perception

12

13 **Abstract**

14 This study suggests that familiarity and novelty preferences in infant experimental tasks can in some
15 instances be interpreted together as a single indicator of language advance. We provide evidence to
16 support this idea based on our use of the auditory headturn preference paradigm to record responses
17 to words likely to be either familiar or unfamiliar to infants. Fifty-nine ten-month-old infants were
18 tested. The task elicited mixed preferences: familiarity (longer average looks to the words likely to be
19 familiar to the infants), novelty (longer average looks to the words likely to be unfamiliar) and no-
20 preference (similar-length of looks to both type of words). The infants who exhibited either a
21 familiarity or a novelty response were more advanced on independent indices of phonetic advance
22 than the infants who showed no preference. In addition, infants exhibiting novelty responses were
23 more lexically advanced than either the infants who exhibited familiarity or those who showed no-
24 preference. The results provide partial support for Hunter and Ames' (1988) developmental model of
25 attention in infancy and suggest caution when interpreting studies indexed to chronological age.

26 **2 Introduction**

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27 The auditory headturn preference paradigm (AHPP), which has been used since the 1980s
28 (Fernald, 1985; Kemler-Nelson, Jusczyk, Mandel, Myers, Turk, & Gerken, 1995), has been
29 instrumental in understanding infants' ability to process speech (for a partial review see Gerken &
30 Aslin, 2005). The success of the paradigm is based on the exploitation of two well-established types
31 of infant responses to stimuli, familiarity and novelty responses, expressed as enhanced attention to
32 either familiar or novel stimuli, respectively. A familiarity response can be thought of as involving
33 matching of stimuli to an existing partially-formed memory trace, while a novelty response would
34 occur at a more advanced stage, after the familiar stimuli have been more completely processed and
35 an infant's attention is free to turn to less well-represented stimuli (Roder, Bushnell, & Sasseville,
36 2000; Rose, Gottfried, Melloy-Carminar, & Bridger, 1982). Typically, in a single study either a
37 familiarity or a novelty response at the group level is taken to suggest that the infants have noticed
38 some aspect of the stimuli. But what does it mean when both novelty and familiarity are observed in
39 a single experiment? In this paper we argue that a mixture of familiarity and novelty responses can,
40 under some conditions, be interpreted together as indicating developmental advance.¹ In the process
41 we provide an empirical test of the Hunter and Ames (1988) model of the underlying mechanisms
42 that elicit familiarity and novelty responses, as it applies to words at the onset of a developing lexicon
43 (see below for a detailed description of the Hunter and Ames model).

44 Factors that affect novelty and familiarity responses in infants have been extensively studied
45 since the methodology was first developed (Dember & Earl, 1957; Fantz, 1958, 1964) and two
46 factors have emerged as the primary determinants of the type of response elicited from infants. The
47 first is the role of stimulus complexity in the progression of responses from familiarity to novelty
48 (Burnham & Dodd, 1998; Cornell, 1975; Hunter & Ames, 1988; Kaplan & Werner, 1986; Kinney &
49 Kagan, 1976; Martin, 1975; Roder et al., 2000). Very simple stimuli may lead to a novelty
50 preference, whereas more complex stimuli, which necessitate more elaborate processing, may lead to

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51 a familiarity preference. However, the relationship between preference and complexity is, in a word,
52 complex. For example, Kidd, Piantadosi and Aslin (2012) familiarized infants to visual stimuli that
53 varied from high- to low-predictability events. These investigators found that the infants looked away
54 both from stimuli that were overly complex (low predictability) *and* from stimuli that were overly
55 simple (high predictability). At the same time, there is also an interaction between complexity and
56 development, since the same stimuli can elicit both a familiarity and a novelty pattern in infants of
57 different ages (Colombo & Bundy, 1983).

58 The second major factor that affects infant responses to familiar or novel stimuli is
59 familiarization time. Fantz (1964) found that infants fixated progressively less to familiar relative to
60 novel stimuli. Since that classic finding, familiarization has been studied in detail both across and
61 within ages (e.g., Burnham & Dodd, 1998; Bahrick & Pickens, 1995; Colombo & Bundy, 1981;
62 Martin, 1975; Roder et al., 2000; Rose et al., 1982). In a typical experiment an infant is familiarized
63 to a stimulus and the infant's attention is measured relative to a similar but novel stimulus (see Rose
64 et al., 1982, for an example). With brief familiarization time infants show a preference for the
65 familiarized pattern, but as exposure time in the habituation phase increases, the preference shifts to
66 the novel stimulus. What has emerged from many of these studies is a progression from familiarity to
67 novelty that, like the notion of complexity itself, is further complicated by development. For
68 example, Bahrick and Pickens (1995) found that, after a familiarization phase, infants showed a
69 novelty effect after delays of only one minute between familiarization and testing but a familiarity
70 response after a delay of one month. Intermediate-length delays – between one minute and one month
71 – elicited no preference from the infants. In addition, Colombo & Bundy (1983) found that the same
72 stimuli that elicited a familiarity response at 2 months elicited a novelty response at 4 months. Thus,
73 complexity and familiarization time interact with development in a complex manner.

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74 Interestingly, novelty and familiarity are often used in the same experiment to index the same
75 behaviour. For example, McMurray and Aslin (2005) exposed infants to one of two endpoints on the
76 voice onset time (VOT) continuum between a /b/ and a /p/. Upon analysing the results, they sub-
77 categorized the infants into those who responded with longer looking time to the familiarized stimuli
78 versus those who responded to the novel stimuli. They then used *both* the novelty and familiarity
79 infants to argue for infant sensitivity to within-phonetic-category differences. McMurray and Aslin
80 explicitly left open the question of why infants might respond differently in this experiment,
81 suggesting that “no consensus has emerged, and few studies make a priori predictions” as to why this
82 is the case (p. B20).

83 Thiessen, Hill, and Saffran (2005) suggest something similar. They familiarized infants with
84 twelve artificial-language sentences recorded with prosody that is consistent with either infant-
85 directed or adult-directed speech (IDS or ADS). Then all of the infants heard whole- and part-word
86 lists (part-words being syllable sequences from within the sentences that crossed word boundaries) in
87 ADS. Only the infants who had been familiarized with the sentences in IDS exhibited a preference
88 for the whole words (familiarity), suggesting that IDS facilitated word segmentation. Based on
89 models predicting infant novelty versus familiarity responses (Hunter & Ames, 1988; Wagner &
90 Sakovits 1986) the authors reasoned that an alternative explanation for their results could be that the
91 infants had segmented words under both IDS and ADS, but the infants exposed to ADS were faced
92 with an easier task, as they were matching like to like (ADS at familiarization to ADS at test). This,
93 the authors thought, may have led them to exhibit a mix of familiarity and novelty responses,
94 resulting in a group response of no preference. The infants exposed to IDS, however, showed a
95 familiarity preference for whole words due to the their task being more difficult, involving a
96 mismatch in speech style between the familiarization and the test stimuli. Essentially, the authors
97 argued that stimulus complexity might be driving the results. To explore this further they made the

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98 task easier by doubling the length of the familiarization and testing slightly older infants. In the
99 second experiment the infants in the ADS condition again showed no preference, whereas those in
100 the IDS condition showed a novelty preference for part-words over whole words. The authors saw
101 this as evidence that the infants in the ADS condition did not succeed in segmenting the words in
102 either experiment. The switch in the IDS group to novelty when the task become 'less complex',
103 partly due to an increase in processing time prior to testing and partly due to the increased age of the
104 infants, suggests that novelty and familiarity responses could be used to investigate developmental
105 differences in infants at a single age.

106 Others have found both novelty and familiarity in a single study (e.g. Gerken, Dawson,
107 Chatila & Tenenbaum, 2015), but the Thiessen et al. study highlights the importance of tracking the
108 characteristics of the stimuli (auditory, visual, complex, bright, colorful, soft, loud, simple,
109 ecologically relevant, etc.). It could be argued that each new type of stimulus requires a
110 methodological rethink as to how the parameters will affect infant responses. For example, although
111 words are often explored in novelty/familiarity paradigms either in isolation (e.g., Hallé & Boysson-
112 Bardies, 1994, 1996; Swingley, 2005; Vihman, Nakai, DePaolis & Hallé, 2004) or in passages of
113 sentences containing target words (e.g., Jusczyk & Aslin, 1995; Jusczyk, Houston & Newsome,
114 1999; Bortfeld, Morgan, Golinkoff & Rathburn, 2005; Singh, 2008; Singh, Reznick & Xuehua, 2012;
115 DePaolis, Vihman, & Keren-Portnoy, 2014), there are few methodological examinations of
116 familiarity and novelty as they apply specifically to the developing lexicon. One exception is a
117 computational model of factors affecting word segmentation in AHPP experiments (Bergmann,
118 Bosch, Fikkert, & Boves, 2013). Another is a study (DePaolis, Vihman & Nakai, 2013) that found
119 that 12-month-old infants' preference for non-words was linearly related to the number of consonants
120 each infant produced that were featured in the test stimuli; effectively, the infants showed either
121 familiarity or novelty, based upon the extent of their previous practice with the test stimuli (see

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122 DePaolis, Vihman, & Keren-Portnoy, 2011 and Majorano, Vihman, & DePaolis, 2014 for similar
123 differences in infant preference based upon their babbling patterns). The dearth of studies of novelty
124 and familiarity as they relate to word learning is surprising, however, since using words as stimuli
125 can introduce complex elements of associative memory that are typically not present with other
126 stimuli, such as consonants.

127 Untrained words may be expected to elicit novelty, familiarity, and no preference responses
128 from different infants of the same age but at different stages of lexical advance. Thus words should
129 be the ideal stimulus to investigate the phenomenon of developmental stage, rather than its proxy –
130 chronological age – since attentional responses to words will depend more upon lexical experience
131 than age. A series of studies in Dutch, English, and French contrasting familiar versus unfamiliar
132 word lists (Hallé & Boysson-Bardies, 1994, 1996; Swingley, 2005; Vihman et al., 2004) suggests a
133 paradigm well suited for this line of inquiry. Using the AHPP the experimenters determined that
134 infants have a stronger representations of word *forms* (independent of contextual cues for meaning,
135 such as seeing or playing with a ball while hearing the word *ball*) by 11 months than at 9 months of
136 age. The term ‘word form’ is used to indicate that this recognition need not imply understanding of
137 the word’s meaning or reference.

138 This task is very different from that of identifying (or segmenting) experimentally
139 familiarized words within running speech, a skill that may emerge as early as 7.5 months of age
140 (Jusczyk & Aslin, 1995; Jusczyk et al., 1999, but see Floccia et al., 2016). Segmentation immediately
141 after familiarization with a pair of words can be thought of as drawing upon short-term memory;
142 word form recognition or segmentation without experimental familiarization, as in the word-form
143 recognition task, must be based upon representation in long-term memory – essentially drawing upon
144 the lexicon that is just beginning to emerge. The emphasis in the word-form recognition task on a

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145 newly formed but unstable representation of often-heard words makes it likely that, at the onset of
146 lexical development, the task will elicit both familiarity and novelty responses, since the level of
147 lexical advance of individual infants can be expected to vary considerably.

148 This variability is just what was found when the word-form recognition experiments were
149 replicated in a cross-sectional design, at 9, 10, 11, and 12 months (Vihman, Thierry, Lum, Keren-
150 Portnoy & Martin, 2007). Of particular interest to the current study is that at 10 months of age
151 roughly half of the infants tested exhibited a familiarity response while the other half exhibited a
152 novelty response, with a gradient from weak to strong preferences in both directions. These results
153 show that testing infants at 10 months of age on isolated word-form recognition yields a high degree
154 of variability in response to the familiar words, as the test elicits both familiarity and novelty
155 responses; thus the word-form recognition paradigm is an ideal vehicle for exploring the nature of
156 novelty and familiarity responses in a single experiment. If the variability in responses is due to the
157 variability in the development of a lexicon, separate measures of lexical and/or phonetic advance
158 might be able to explain or predict the responses on the AHPP.

159 In this study we have adopted the AHPP paradigm and the Hunter and Ames (1988) model of
160 infant response to stimuli in formulating our initial hypothesis that no-preference, familiarity and
161 novelty responses can each reflect a different level of lexical advance at a single age. This type of
162 model suggests that ‘preferences for novelty and familiarity are not tied to particular ages but instead
163 can be found at any age, depending on the duration of previous familiarization and on task difficulty
164 relative to the age and experience of the infant.’ (Hunter & Ames, 1988, p. 70; for similar models see
165 Bahrck & Pickens, 1995; Kaplan & Werner, 1986; Rose et al., 1982; Wagner & Sakovits, 1986).
166 The core idea is that an infant’s attention to a stimulus is dictated by the stability of the representation
167 of the stimulus in memory. A hypothetical experiment supporting this type of model would

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168 familiarize an infant to a set of previously unknown words and then contrast these words with other
169 unknown and unfamiliarised words. If the familiarization phase is too short for the infant to begin to
170 form a tentative memory, infants will show no preference for either word list. Subsequent
171 presentations of these words would elicit longer looks due to the newly formed memory, and
172 continued presentation of these words would elicit a decrease in interest in the familiar words due to
173 the increasing stability of the representation of the word in memory, thus yielding a novelty response.

174 In the word-form recognition experiments described above (Hallé & Boysson-Bardies, 1994,
175 1996; Swingley, 2005; Vihman et al., 2004, 2007) the familiarised stimulus is the child's own
176 lexicon, since familiarisation, if it can be called that, occurs very gradually over the course of
177 everyday exposure to words in the period before the infant is brought to the lab. Figure 1 displays the
178 hypothesized development of three infants' familiarity and novelty responses to the stimuli in a
179 word-form recognition experiment based on the Hunter and Ames model. The figure has been
180 redrawn from Hunter and Ames (1988) to show the progression from familiarity through to novelty
181 as a function of length of exposure to familiar words. It tracks three hypothetical infants who begin at
182 different ages to represent word forms independent of context, an achievement which can signal the
183 onset of lexical representation (Swingley, 2009) .

184 The infant characterized by the solid line has not started forming lexical representations by
185 the time of the experiment, so that no memory trace has been formed that is strong enough to elicit
186 either a novelty or a familiarity response to the words heard during the test that were expected to be
187 familiar (i.e., words chosen from pooled parental reports for early vocabulary). This infant will thus
188 most likely exhibit no preference for either the familiar or unfamiliar words. The infants
189 characterized by the dashed lines are more lexically advanced; they have begun constructing the
190 knowledge and skills necessary for lexical representation at the time of the test. Depending upon the

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191 speed with which each infant processes the newly learned words, the comparison of the words heard
192 in the test to partially or well-formed memory traces of familiar words will lead to either familiarity
193 or novelty responses, respectively.

194 [Figure 1 about here]

195 It is also possible that the more advanced infants will fail to exhibit a preference (note the
196 transition through *No preference* for each infant in Figure 1), although Roder et al. (2000) found no
197 evidence that the transition from familiarity to novelty was mediated by a period of no preference. It
198 is likely that if, between the time in which a familiarity and a novelty response are elicited, there is a
199 period in which the infant displays equal interest in the stimuli, it is a very brief one, as can be seen
200 by the steep hypothesised slope of the line in the transition between these two responses in Figure 1.
201 It should also be noted, however, that there is some disagreement as to whether the Hunter and Ames
202 model holds in every case, especially insofar as it relates to a period of no preference during the shift
203 from familiarity to novelty (see Slater, 2004, for discussion). However, recall that the Hunter and
204 Ames model does hypothesize a longer, more stable no-preference period prior to the onset of any
205 learning.

206 Further complicating this picture is the potentially variable speed of progression from
207 familiarity to novelty, which again depends on the speed of processing for familiar words. In Figure 1
208 the three infants are plotted as having identical processing speeds, while the Roder et al. (2000)
209 experiments suggest that the pace would likely vary by infant. Crucially, from the perspective of this
210 study, the putative contraction or expansion of the progressions for different infants in any AHPP
211 experiment should make it even more likely that both familiarity and novelty would be elicited by the
212 same stimuli at the same age, since both reflect recognition of the familiar words, although probably
213 to differing degrees.

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214 Regardless of the processing timescale and the slope of the change in preference for familiar
215 words, if the model depicted in Figure 1 is sound, then some experiments should yield both a
216 familiarity and a novelty effect and these two effects should both signify recognition of familiar
217 words and signal that the onset of lexical representation has begun. The important point to note is that
218 in such cases it is expected that the most advanced infants will exhibit a novelty effect while the
219 infants who are the least advanced in terms of lexical representation will tend not to show a
220 preference (corresponding to the early No-preference period in the Hunter and Ames (1988) model).
221 The infants who exhibit a familiarity effect would be predicted to fall between these two groups in
222 terms of lexical representation. Recall that the experiments by McMurray and Aslin (2005) and
223 Thiessen et al. (2005) support this possibility.

224 To validate this interpretation of the mix of preference behaviours in the AHPP separate
225 measures of language advance are needed to justify an independent grouping of infants into more vs.
226 less advanced. This is the rationale behind the current study, which used additional measures of
227 phonetic and lexical advance to corroborate the division of the infants, based on their AHPP
228 responses, into three groups: two advanced groups showing a relatively strong familiarity or novelty
229 response and a less advanced group, showing no clear preference.

230 The variable chosen to estimate phonetic advance was the age of attainment of two vocal
231 motor schemes or VMS (measured by the repeated production of a specific consonant), which
232 indicates the degree to which an infant is using a consonant consistently and repeatedly in babble
233 (McCune & Vihman, 2001). Previous research has shown that attainment of one or more VMS,
234 beyond indexing phonetic advance, affects the infant's response to similar consonants in running
235 speech (DePaolis et al., 2011). Additional work has shown that acquisition of the second VMS is a
236 necessary step for referential word use (McCune & Vihman, 2001) or for word use in general (Keren-

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237 Portnoy, Vihman, & DePaolis, 2005; McGillion et al., in press). Each of these studies points to the
238 importance of VMS for forming stable lexical representations.

239 Our measure of lexical advance was the number of words that the infant is able to
240 comprehend according to parental report, using the Oxford adaptation of the MacArthur
241 Communicative Developmental Inventory (CDI: Hamilton, Plunkett & Schafer, 2001), a widely used
242 measure of vocabulary development. Receptive vocabulary size, as reported by parents, is also an
243 estimate of the infant's level of lexical representation, although it presumably includes meaning in
244 addition to word form recognition. Interestingly, CDI estimates of lexicon size between 12 and 24
245 months have been shown to be correlated with performance on the AHPP (word segmentation) at 7-8
246 months of age (Singh et al., 2012), supporting the use of this measure to identify infants who are
247 likely to recognize word forms in this study.

248 In summary, the purpose of this study was to investigate the possibility that familiarity and
249 novelty responses both reflect the onset of lexical representation in 10-month-old infants. In order to
250 do this we used the AHPP to run word-form recognition experiments on 59 infants at 10 months of
251 age, a point at which we expected roughly half of the infants to recognize familiar words. At the
252 same time, we collected independent measures of phonetic and lexical advance for those same
253 infants. We hypothesized that these additional measures would agree with the categorisation of the
254 infants suggested by the AHPP response. Specifically, if Figure 1 is valid in its conceptualisation of
255 the interplay between familiarity and novelty, the infants who exhibit either a familiarity or a novelty
256 response should be more advanced in both phonetic and lexical ability than their peers who show no
257 preference for either type of stimulus. In addition, we hypothesize that there will be a progression of
258 lexical and phonetic advance, with the infants showing no preference being the least advanced,

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259 followed by those showing familiarity, and finally by those showing novelty responses, who would
260 be the most advanced.

261

Provisional

262 3 Methods

263 2.1 Participants

264 A total of 59 infants participated in a nine-month longitudinal study from which this data were taken.
265 Infants were recruited through ads in newspapers and in local shops and playgroups. None of the
266 participants had any known developmental or hearing problems (all infants had been screened by the
267 National Health Service). This study was approved by the Ethics Committees of both the University
268 of York. Written informed consent was obtained from all participating families.

269 2.2 Variables

270 **2.2.1 Phonetic advance.** Age at two VMS was assessed using half-hour weekly audio and video
271 recordings made in the home, starting at 9 months of age and continuing until the infant attained two
272 high-use VMS (defined as supraglottal consonants only, typically a labial, alveolar or velar stop or a
273 labial or alveolar nasal). The recordings were transcribed phonetically, and consonants used in
274 vocalizations (mostly babble, but in some cases words as well) were tallied. A consonant was
275 considered to have reached VMS status if it fulfilled one of two criteria: (1) A minimum of ten
276 tokens of the given consonant were produced in each of at least three out of four consecutive half-
277 hour sessions (McCune & Vihman, 2001) or (2) a total of 50 or more tokens of the given consonant
278 were produced in one to three successive recording sessions (DePaolis et al., 2011). We dated the
279 emergence of a VMS to the first of these criterial sessions. Age of attainment of the second VMS was
280 dated to the first criterial session for the child's second VMS.

281 2.2.2 Lexical advance.

282 Receptive lexicon size estimates were based upon the Oxford CDI (Hamilton et al., 2001), completed
283 by parents when the infants were 9 months old and then monthly thereafter, although not every

284 parent completed the questionnaire every month. An average of 2.5 (SD=2.11) parental reports were
285 missing per child, out of the expected ten monthly CDIs.

286 **2.2.3 Auditory Headturn Preference Procedure (AHPP).**

287 The word-form recognition test was administered at 10 months. The stimuli were lists of words
288 produced in isolation. Half of the lists consisted of 12 words likely to be familiar to the infants
289 (Familiar words, based on CDI data from a previous study of 99 infants being raised in English in
290 North Wales, aged 9-11 months.) The other half consisted of 12 words unlikely to be familiar to
291 infants (Rare words, based on frequency counts of no more than 6 in 1,014,232 in Francis & Kučera,
292 1982). The Rare words were comparable to the Familiar words in terms of their segments (consonant
293 and vowels) and phonotactics. (See Table I for stimuli. We constructed two lists for each type of
294 stimulus, with half the infants being presented with list A and half with list B, for both Familiar and
295 Rare words.)

296 **2.3 Procedure**

297 **2.3.1 Naturalistic recordings.**

298 Infants were recorded at home in naturalistic play interactions with a caregiver, once a week. The
299 recordings were made using a Sony digital video camera recorder, either HDV 1080i HVR-A1E or
300 DSR-PDX10P. The recordings were then transferred digitally to a computer and transcribed
301 phonetically by one of three experienced transcribers, using ELAN Linguistic Annotator. Reliability
302 among transcribers was calculated based on four 3-minute sections randomly sampled from the 10-
303 month-old recording sessions. The average agreement between every two transcribers regarding the
304 frequency of use of each potential VMS consonant (/p,b/, /t,d/, /k,g/, m, n, ŋ, l, s) was 69% (range
305 65%-72%). Most disagreements had to do with the very infrequently used consonants, /l/ and /s/. The

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306 average agreement for all other consonants was 80% (range 76% to 89%). Given that the
307 transcription was of prelinguistic babble, this degree of agreement is consistent with similar previous
308 studies (e.g., Vihman, Macken, Miller, Simmons & Miller, 1985; Davis & MacNeilage, 1995;
309 McCune & Vihman, 2001).

310 2.3.2 AHPP

311 The stimuli were recorded using a female speaker with a Northern English dialect, speaking in an
312 infant-directed manner. All items were recorded in a sound-treated room (IAC Model 400) using a
313 Sennheiser ME 66 microphone (with K6 power module) connected to a Tascam DA-P1 digital
314 recorder sampling at 44.1 K Hz. The stimuli were transferred digitally onto a PC hard drive for
315 eventual output. A multivariate ANOVA comparing amplitude, duration and mean F0 across the four
316 word lists used in the familiar and rare conditions revealed no difference in any of these measures (p
317 values of .292 for amplitude, .512 for duration and .81 for mean F0).

318 The AHPP procedure used was similar to that described in Kemler-Nelson et al. (1995). Seated on
319 the caregiver's lap in a quiet darkened sound-treated room, the infants faced the central panel of a
320 three-sided test booth where a camera and red light were mounted. A blue light and speaker were
321 mounted on each side panel. A PC and video monitor were located in the adjoining room where the
322 experimenter controlled stimulus presentation and recorded infant looking times by pressing the left
323 and right mouse buttons. The computer initiated and terminated trials in response to signals from the
324 experimenter. In each trial, the infant's gaze was centered by the blinking red light. The experimenter
325 then initiated the computer run trial by activating a blinking blue light on the left or right of the
326 infant. When the infant was judged to orient to the blue light, a trial was presented from that speaker.
327 If the infant looked away from the speaker for more than two seconds of accumulated time, the trial
328 was terminated and another begun. Multi-talker babble created from the same speaker of the stimuli

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329 used in the experiment was delivered to the headphones worn by both experimenter and caregiver to
330 mask the actual test stimuli. The caregiver also wore foam-insert hearing protection. All stimuli were
331 presented at an average level of 65 dB (Tenma 72-6635 sound level meter).

332 Each experimental session consisted of an exposure and a test phase. In the exposure phase the
333 infant was presented with two lists of each of the two test conditions, Familiar and Rare,
334 counterbalanced for order such that half the infants heard Familiar first and half heard Rare. The
335 exposure trial lists consisted of a randomized presentation of the twelve words. This condition was
336 intended to expose the infant to the test procedures, since our previous experiments using the AHPP
337 paradigm have indicated that the initial trials lead to overly long looking times that do seem not to be
338 indexed to the type of stimuli presented. In both exposure and test phases the word type was
339 randomly assigned to either side.

340 The test phase of the experiment consisted of 12 trials, six each of the two test conditions. The
341 words in the test trial lists were pseudo-randomized such that each pair of words appeared first in one
342 trial. This ensured that each infant heard each of the 12 Familiar and 12 Rare words at least once,
343 even if trials were terminated early. The order of presentation in the test phase was designed to
344 ensure that the first four trials were counterbalanced across test conditions, such that they included
345 two trials of each test condition, in varying orders, counterbalanced across infants. The
346 counterbalancing at the beginning was designed to control for an anticipated decrease in looking
347 times, independent of the stimuli, over the course of the test trials (see Vihman et al., 2004, for an
348 analysis of looking time by trial). The final eight trials were pseudo-randomized such that no more
349 than two test trials of the same kind (Familiar or Rare) occurred in sequence. In both phases, the side
350 of presentation was pseudo-randomized such that no more than two successive presentations from

351 one side were allowed. The experiment lasted less than 10 minutes; the actual time was dependent
352 upon the infant's attention.

353 **3 Results**

354 **3.1 AHPP Participants**

355 Fifty-three of the infants tested on the AHPP completed the task. The results from six others were
356 discarded due to suspected otitis media (N=1), an eye condition which precluded judging direction of
357 look (N=1), experimenter error (N=2) and excessive fussiness leading to early termination of the test
358 (N=2). The mean age at test was 309 days (SD = 4 days). Mean Age at 2 VMS for the 53 infants who
359 completed the AHPP task was 313 days (SD= 41 days). The range was from 276 days to 457 days
360 (for infants who had not reached 2 VMS by the time of the AHPP, measuring continued after the
361 AHPP until the 2-VMS point was reached.)

362 **3.2 Receptive lexicon size**

363 The infants exhibited a steady growth in lexicon as measured by the CDI data (see Figure 3, below).
364 As an important check on the AHPP experiments we correlated the mean number of words on the
365 CDI that the infants were reported to know at 9 months (M=12.3, SD = 11.9) with the mean number
366 of stimulus words on the AHPP test that the infants were reported to know (M = 1.44, SD = 1.48).
367 The two lexical measures were strongly correlated: $r = .64$ ($p < .01$), indicating that the words used in
368 the AHPP provide a good sample of the first words comprehended.

369 **3.3 AHPP looking time analysis**

370 There was no difference between the Familiar (M=5.71s, SD=2.05) and Rare (M=5.68s, SD=1.86)
371 looking times; $t(52)=0.101$, $p=.92$, $d =.013$ (correcting for the correlation, see Dunlap, Cortina,
372 Vaslow, & Burke, 1996). To control for differences in individual infants' attention span we base

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373 further analyses not on differences in mean looking times (LT) but rather on the proportion of time
374 an infant looked towards Familiar stimuli out of total LT to both Familiar and Rare:

375
$$\text{Preference ratio} = \text{LT (Fam.)} / [\text{LT (Fam.)} + \text{LT (Rare)}]$$

376 A value equal or close to 0.5 signifies no preference, values over 0.5 signify longer looking towards
377 the Familiar stimuli (i.e., a familiarity preference) and values under 0.5 signify longer looking
378 towards the Rare stimuli (a novelty preference).

379 As can be seen in Figure 2, the preference ratio (p-ratio) distribution is normal (Kolmogorov-
380 Smirnov (53) = 0.107, $p = .185$), as expected: see discussion above. The distribution is centered on the
381 no-preference value of 0.5 and displays both extreme familiarity and extreme novelty responses. We
382 divided the p-ratios such that both ends of the scale, novelty and familiarity preference, would be
383 taken to signify 'success' in the task while the middle portion, no preference, would signify 'failure'.
384 The criterial point for distinguishing between 'Pass' and 'Fail' was chosen so as to create two
385 similar-sized groups, with sample sizes of 26 and 27, respectively. The half of the p-ratio scores
386 which were furthest away from 0.5 (in either direction) were considered a 'Pass', and the half which
387 were closest to 0.5 (in either direction) were considered a 'Fail'. The cutoff point for this binary scale
388 turned out to be a distance of .0501 from the 0.5 point on the p-ratio scale: P-ratio values above
389 0.5501 or under 0.4499 were classified as extreme ('Pass') and those between those two values were
390 classified as moderate ('Fail')² (see Figure 2).

391 [Figure 2 here]

392 In order to test whether this criterion for dividing the group into two is simply a proxy for age,
393 such that the extreme group is older than the moderate group, we compared the two groups on
394 average age. Recall that our hypothesis is that the infants showing either a novelty or a familiarity

395 preference are more linguistically advanced, not simply older. An independent t-test showed that the
396 mean ages for the two groups do not differ (M (Moderate) = 308.9 days, sd = 4.0, M (Extreme) =
397 309.9 days, sd = 4.1, $t(df = 51) = -.928, p=.36.$) and their ranges and standard deviations are very
398 similar.

399

400 **3.4 Testing the relationship between the AHPP and language advance**

401 **3.4.1 Performance on the AHPP and infants' receptive lexicon size.**

402 First we tested the relationship between the AHPP and lexicon (as measured on the CDI at 9 months).
403 Because the distribution of lexicon size by preference type is skewed, we assessed its goodness of fit
404 to both a Poisson and Negative binomial distribution. Only the Negative Binomial turned out to be a
405 good fit (Goodness of fit ratio (value/df) of 1.239, $p > .1$). Thus we ran a Generalized Linear Model
406 (GLM) using the Negative Binomial distribution with a log link, with the binary AHPP score as a
407 predictor and number of words on the CDI as a predicted variable. The mean number of words
408 known by the infants was $M=15.7$ for the Extreme group (novelty and familiarity grouped together)
409 and $M=8.9$ for the No-Preference group. The GLM was very close to being significant (Wald $\chi^2 =$
410 $2.690, df=1, p = .051, one-tailed, \eta^2=.79$, where η^2 is calculated assuming normality). Thus, the
411 infants who exhibited either a familiarity or a novelty preference tended to know more words than
412 those who showed no preference. We chose a one-tailed test since our original hypothesis was that
413 the infants with familiarity and novelty responses would have a larger lexicon. The alternative
414 possibility, that infants with no preference on the AHPP would have higher scores on the CDI, is not
415 consistent with the Hunter and Ames (1988) model or in fact with any model of infant response to
416 novel or familiar speech stimuli.

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417 One possible reason for the failure of the GLM to achieve statistical significance is the fact that
418 only 36 parents filled out the CDI at 9 months of age, which led to a reduction in the power of the
419 test. The large effect size ($\eta^2=.79$) supports this and suggests that the difference might be significant
420 with a larger sample. This limitation in sample size was also the reason that we ran the test as two
421 groups (Novelty/Familiarity versus No preference) instead of three (Novelty versus Familiarity
422 versus No preference), as our original hypothesis would suggest.

423 To begin to test our hypothesis directly (and in effect to test the Hunter and Ames model) we first
424 plotted lexical growth for each group (see Figure 3). Here we can see that the Novelty group
425 separates out from the Familiarity and No-preference groups, the latter two being indistinguishable.

426 [Figure 3 about here]

427 To test our hypothesis that the preference exhibited in the AHPP is indicative of lexical advance as
428 measured by the CDI we used a fixed effects model with a first order autoregressive covariance
429 structure that assumed the repeated measures (CDI across ten months) were correlated within each
430 infant but independent across infants. The results show both group ($F(2,107.8)=5.927$, $p=0.004$) and
431 age ($F(1,195.8)=265.894$, $p<.001$) to be significant, with no difference between the Familiarity and
432 No-preference groups and a significant difference between the Novelty and the No Preference group
433 (see Figure 3 and Table II).

434 3.4.2 Performance on the AHPP and infants' phonetic advance (age at two VMS).

435 Figure 4 plots the age at two VMS (in days) against p-ratios on the AHPP. The vertical line shows
436 the average age, around 10 months, at which the infants were tested on the AHPP. The points to the
437 left of the vertical line are the p-ratios of the infants who had attained two VMS by the day of their
438 AHPP and those to the right of the line are those of the infants who had not yet attained two VMS by

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439 the test date. As can be seen, the p-ratios of the infants whose production is more advanced at the
440 time of the test are much more widely dispersed than are those of their less advanced counterparts.
441 The difference in variance between the group of infants who had not attained two VMS vs. that of
442 those who had is significant (Levene's Test for Equality of Variances: $F = 5.059$, $p = .029$, $df = 51$).
443 The greater dispersion in the group with the more advanced production stems from their having more
444 extreme p-ratios than the infants who have not yet attained two VMS. Thus, the infants who are more
445 advanced phonetically are also more likely to show either a strong novelty or a strong familiarity
446 effect.

447 [Figure 4 about here]

448 **4 Discussion**

449 The findings of this study indicate that the infants who show either a strong novelty or a strong
450 familiarity response indeed make up the more linguistically advanced group: strong preference for
451 either type of stimulus was seen in the infants who attained two VMS earlier but not in those who
452 reach that level of phonetic mastery only later (figure 4). This figure is interesting from at least two
453 perspectives. First, it implies that phonetic advance in production is connected to success on the
454 AHPP in recognizing words. This is supported by three recent studies that have found a correlation
455 between vocal production and speech perception in prelinguistic infants (DePaolis et al., 2011, 2013;
456 Majorano et al., 2014) and another study that found that obstructing the tongue of prelinguistic
457 infants impaired their ability to discriminate phonemes whose production involves movement of the
458 obstructed tongue (Bruderer, Danielson, Kandhadai & Werker, 2015).

459 Second, it suggests that variability in this word recognition task changes developmentally, with
460 stability in responses decreasing as infants became more advanced phonetically and lexically.
461 Importantly, this advance is not necessarily tied to age but instead to each infant's individual

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462 developmental path. The variability in figure 4 is reminiscent of Thelen and Smith's (1994) claim
463 that transitions from one stable state (in this example, an inability to recognize word forms) to
464 another (the ability to recognize often-heard word forms) is characterized by instability. Thus, figure
465 4 indirectly supports a dynamic systems approach to early lexical development (see Vihman,
466 DePaolis, & Keren-Portnoy, 2015, where that approach is related to early phonological
467 development).

468 Finally, analysis of the CDI at 10 months of age (section 3.4.1), the age of the infants when tested on
469 the AHPP experiment, lent partial support to a Hunter-and-Ames-type model as the AHPP results
470 tend to differentiate the infants by lexical advance. This finding is presented with caution since a one-
471 tailed test just missed reaching significance *and* we could test only the no-preference group versus
472 the combined familiarity and novelty groups. We now take up AHPP and lexical advance in more
473 detail, and in the process, test the Hunter and Ames model more directly.

474 4.1 AHPP looking time analysis: The Distribution

475 As we expected, the distribution of preferences in the AHPP was normal around a p-ratio
476 of .5, reflecting equal interest in both the familiar and unfamiliar words. Interestingly, if we had not
477 collected independent indices of phonetic and lexical advance we might have reported this as a null
478 finding and concluded that 10-month-old infants show no sign of recognizing word forms. This in
479 fact is what Vihman et al. (2007) concluded when they used this paradigm with 10-month-olds.

480 There is growing evidence, however, that studies that are indexed to chronological age are
481 at risk of null findings when the data are actually masking developmental change. For example,
482 recent studies examining electrophysiological responses to VOT distinctions in English infants found
483 a similar null effect that turned out to be a mixture of different levels of advance, similar to what we

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484 found in this study. Rivera-Gaxiola and colleagues (Rivera-Gaxiola, Silva-Pereyra, & Kuhl, 2005b;
485 Rivera-Gaxiola, Klarman, Garcia-Sierra, & Kuhl, 2005a) examined the responses of 7- and 11-month
486 old infants to both native and non-native language differences in voice onset time (VOT). They found
487 that while 7-month-old infants' event related potentials (ERP) were discriminatory between native
488 and non-native VOT contrasts, there was no significant difference in the ERP patterns to the non-
489 native contrasts at 11 months of age. Upon closer examination of the results, however, two groups of
490 infants emerged: One group of 11-month old infants displayed a larger amplitude in the N250-550
491 response to *both* native and non-native contrasts. The other group displayed a differential response, a
492 larger amplitude N250-550, for the native contrasts only, along with a larger P150-250 response to
493 the non-native contrast. The authors interpreted this latter response as being more mature, possibly
494 suggesting that the infants experienced the non-native contrast as irrelevant, which allowed them to
495 disregard it. That this latter group was indeed more linguistically advanced is also supported by the
496 fact that its members had larger receptive vocabularies from 18 to 30 months of age.

497 Another ERP study by Kooijman, Junge, Johnson, Hagoort, & Cutler (2013) found that 7-
498 month-olds exhibited an overall positive right frontal and negative left posterior response to familiar
499 words when they were embedded in sentences. In this case the authors also found two subgroups of
500 infants: The majority showed a positive familiarity response on right frontal electrodes; a smaller
501 number exhibited a negative left frontal and posterior response at 7 months, similar to that
502 demonstrated by 10-month olds in a previous study (Kooijman, Hagoort, & Cutler, 2005). This
503 minority group also had significantly higher scores on word comprehension and on sentence and
504 word production at age three.

505 Thus, similar to the research by Rivera-Gaxiola and colleagues, and the current study,
506 Kooijman and colleagues found that two patterns of responses could be identified and explained once

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507 the results were referenced to other measures of linguistic advance. In all three of these studies,
508 without the additional measures of linguistic advance, the group results would have masked
509 important differences, highlighting that experiments conducted at a set chronological age are likely to
510 include subgroups of infants that cover a range of different developmental stages. In both
511 electrophysiological studies data clearly separate the infants into groups that differ in measures of
512 language advance when examined years later. Similarly, the infants who show a familiarity or
513 novelty response in the current experiment proved to be more advanced when we examine the AHPP
514 results closely in relation to the lexical growth data from the CDI. We now consider the clearest
515 evidence for this.

516 **4.2 Performance on the AHPP and infants' receptive lexicon size.**

517 The growth in receptive lexicon began earlier for the Novelty group (see figure 3) but there
518 was no difference between the Familiarity and No-preference groups. Hunter and Ames's (1988)
519 model predicts a difference in looking times between the Familiarity and the No-preference groups
520 but the actual difference between the two groups does not seem to translate here to lexical growth. So
521 why is the CDI growth rate of the No-preference and Familiarity infants the same? It may be that the
522 infants who are not showing a preference are on the cusp of this advance. The group effect of word
523 form recognition is robust at 11 months of age (Hallé & Boysson-Bardies, 1994, 1996; Swingley,
524 2005; Vihman et al., 2004; Vihman et al., 2007), only a month after the age at which the infants were
525 tested in this study. So, while the Novelty group may be truly advanced, the No-preference and
526 familiarity groups could be developmentally much more similar. In addition, if there truly is a
527 developmental shift from familiarity to novelty, it is possible that some of the infants, if tested while
528 in this transition period, will therefore exhibit no preference (but see the discussion in the
529 introduction, above).

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530 We suggest that another reason to suspect that a novelty response indicates a more
531 advanced level of language processing is the robustness of the representation of the word that is
532 required for an infant to exhibit such a response. A novelty or familiarity response indicates that the
533 infant has maintained a memory of the stimulus that has lasted from the time when the infant was last
534 presented with it until it is presented in the experiment (see the discussion in Civian, Teller, &
535 Palmer, 2005, regarding novelty responses to visual stimuli elicited from 16-week-old infants). In the
536 current study, the stimuli are words commonly heard in everyday situations, before the infant is
537 brought to the lab. For a novelty response, memory for the words must be robust enough to render
538 these familiar words too well established to warrant attention. Just the opposite effect underlies a
539 familiarity response; representations for these words are just beginning to form in memory and are
540 thus of interest in themselves (cf. Kidd et al., 2012, who showed that infants' attention to visual
541 stimuli is increased when the stimuli are neither too complex nor too simple). Thus, while the
542 familiarity responses indicate the beginning of word-form recognition, a novelty response suggests
543 that the infants have stable memory representations of words. It is possible that those infants are also
544 beginning to associate meaning with these words.

545 4.3 Summary

546 This paper presents a novel approach to the analysis and interpretation of group results on
547 the AHPP. Its implications are particularly pertinent for cases in which the responses to an AHPP are
548 distributed symmetrically around the no-preference value, resulting in a lack of preference for either
549 type of stimulus at the group level. Our findings show that such results may still be informative at the
550 subgroup level. Such a distribution may be indicative of a mixed group, containing both advanced
551 infants, who have successfully distinguished between the two types of stimuli, and less advanced
552 infants, who have not. Crucially, in order to interpret such results, additional measures of advance in

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553 a related cognitive domain must be independently obtained for the same infants. It should then be
554 possible to determine whether the lack of a group effect is due to individual infants not distinguishing
555 between the stimuli or to the ability of different infants to make such a distinction, as manifested in
556 different preferences. With regards to our initial question as to the suitability of the Hunter and Ames
557 Model for word learning, we have found evidence that, as regards word-form recognition, no-
558 preference, familiarity and novelty responses do seem to reflect different stages of advance in the
559 independent domains of vocal production and lexical comprehension. The familiarity subgroup
560 patterns with the more advanced novelty subgroup in vocal production but with the less advanced
561 moderate group in lexical advance. Our data therefore provide only partial support for a Hunter and
562 Ames model of word form recognition. Future studies, if they can achieve greater precision in
563 measuring infants' lexical knowledge, may be able to show clearer separation between the groups
564 exhibiting these three types of responses.

565 Footnotes:

566 ¹This idea was proposed fifteen years ago at the 12th Biennial International Conference on Infant
567 Studies (Aslin, 2000), and was recently advanced in a symposium at the 17th Biennial International
568 Conference on Infant Studies (Dawson and Kidd, 2010).

569 ²The distribution can also be divided differently, with p-ratios in both the lowest and the highest
570 quartiles being treated as success and those in the two middle quartiles as failure. The two methods of
571 categorization result in nearly identical groups, with only three infants (out of a total of 53) being
572 placed in different categories. It is worth noting that there are a number of ways to sort the infants
573 into three groups. For example, from a statistical standpoint it could be argued that it would be best to
574 create equal group sizes to increase the numbers in the novelty and familiarity groups, and thus
575 potentially increase the power of the test (as proposed by one reviewer). We did not use this option

576 since there is no reason to assume that a sample of 59 infants would include equal numbers of infants
577 exhibiting novelty and familiarity preferences. We chose instead to minimize the chances that infants
578 who have no preference for either word type would end up classified in the novelty or familiarity
579 group. This was accomplished by classifying only the most extreme 50% of the infants as exhibiting
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581

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719

720 **7 Tables and Figures**

721 Table I Word Stimuli for the AHPP experiment

722 List A		List B	
723 Familiar	Rare	Familiar	Rare
baby	pauper	birdie	beadle
biscuit	tendon	bottle	blotter
breakfast	brindle	clever	dapper
careful	geezer	dolly	gully
cuddle	dabble	gentle	tendrill
mummy	deacon	grandad	plunder
dinner	Berber	daddy	gecko
dirty	turbo	nappy	netter
dummy	tinny	naughty	doughty
granma	crofter	teddy	tatty
telly	demi	tickle	kindle
tired	mired	toothbrush	tangram

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728 Table II Fixed Effects Model Results.

729

730

731	<u>Parameter</u>	<u>Estimate</u>	<u>Std. Error</u>	<u>df</u>	<u>t</u>	<u>Significance</u>
732	Intercept	-182.56	16.00	183.44	-11.41	.000
733	Novelty	27.40	8.75	107.27	3.13	.002
734	Familiarity	-2.06	9.14	108.52	-0.23	.822
735	No Preference*	0	0			
736	Age	18.51	1.14	195.84	16.31	.000

737

738 *This parameter is set to zero since it is redundant.

739

740 Figure legends

741

742 Figure 1. Schematic predicted responses of three infants at different levels of lexical advance (all
743 three figures are redrawn from Hunter and Ames, 1988). The downward arrows indicate the onset of
744 lexical representation for each infant. The hypothesized curve for each infant represents his or her
745 response to lists of (untrained) familiar words contrasted with unfamiliar words. The shaded area
746 demonstrates that at specific testing points novelty and familiarity would both indicate the
747 recognition of word forms (dashed lines), while no preference would indicate a lack of sensitivity to
748 word forms (solid line). The vertical axis is the strength of the familiarity or novelty effect. The
749 horizontal axis represents the time for a novelty effect to shift to a familiarity effect. Each infant
750 would have their own individual time scale for beginning to recognize words in everyday life,
751 although for clarity the three infants depicted in this figure are treated as having identical time scales
752 for the shift in word-form recognition.

753 Figure 2. Distribution of p-ratios for the AHPP. Vertical lines show the cutoff points for the
754 categorization of a score as extreme or moderate. P-ratio scores to the left of the .45 line or to the

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755 right of the .55 line are 'extreme' and are classified as novelty and familiarity preferences
756 respectively.

757 Figure 3. The average growth of CDI by response on the AHPP (low, mid, and high preference ratio
758 infants).

759 Figure 4. Variability in p-ratios on the AHPP and VMS. This variability reflects differences between
760 infants who had vs. had not attained two VMS by the test date. The vertical line represents the AHPP
761 test date of 10 months. Infants to the left of the line had acquired two VMS by the AHPP test, while
762 those to the right had not.

763

Provisional

Figure 03.TIF

