

Accepted refereed manuscript of: O'Sullivan E, Bijvoet-van den Berg S & Caldwell CA (2018) Automatic imitation effects are influenced by experience of synchronous action in children, *Journal of Experimental Child Psychology*, 171, pp. 113-130.

DOI: [10.1016/j.jecp.2018.01.013](https://doi.org/10.1016/j.jecp.2018.01.013)

© 2018, Elsevier. Licensed under the Creative Commons Attribution-NonCommercial-NoDerivatives 4.0 International

<http://creativecommons.org/licenses/by-nc-nd/4.0/>

1

2

Accepted for publication in *Journal of Experimental Child Psychology* published by Elsevier.

3

Automatic imitation effects are influenced by experience of synchronous action in children

4

Word Count: 10,730

5

6

7 Eoin P. O’Sullivan ^{a, b}

8 Simone Bijvoet-van den Berg ^c

9 Christine A. Caldwell ^{a, b}

10

11 ^{a.} Behaviour and Evolution Research Group, Psychology Division, University of
12 Stirling, Stirling, UK.

13 ^{b.} Scottish Primate Research Group, University of Stirling, Stirling, UK.

14 ^{c.} Department of Psychology, University of Sheffield, Sheffield, UK.

15

16

17

18

19

Abstract

20 By their fourth year children are expert imitators but it is unclear how this ability develops.
21 One approach suggests that certain types of experience might forge associations between the
22 sensory and motor representations of an action that might facilitate imitation at a later time.
23 Sensorimotor experience of this sort may occur when an infant's action is imitated by a
24 caregiver or when socially synchronous action occurs. This learning approach therefore
25 predicts that the strength of sensory-motor associations should depend on the frequency and
26 quality of previous experience. Here, we tested this prediction by examining automatic
27 imitation; i.e., the tendency of an action stimulus to facilitate the performance of that action
28 and interfere with the performance of an incompatible action. We required children (aged
29 between 3:8 and 7:11) to respond to actions performed by an experimenter (e.g., two hands
30 clapping), with both compatible actions (i.e., two hands clapping) and incompatible actions
31 (i.e., two hands waving) at different stages in the experimental procedure. As predicted by a
32 learning account, actions thought to be performed in synchrony (i.e., clapping/waving)
33 produced stronger automatic imitation effects when compared to actions where previous
34 sensorimotor experience is likely to be more limited (e.g., pointing/hand closing). Furthermore,
35 these automatic imitation effects were not found to vary with age, as both compatible and
36 incompatible responses quickened with age. These findings suggest a role for sensorimotor
37 experience in the development of imitative ability.

38

39 *Keywords:* automatic imitation, synchrony, associative sequence learning, social learning,
40 sensorimotor experience.

41

42 Automatic imitation effects are influenced by experience of synchronous action in children

43 Copying the behavioral morphology of an action is often considered to be cognitively
44 demanding due to the correspondence problem (i.e., the sensory mismatch when observing
45 one's own actions and those of another, Nehaniv & Dautenhahn, 2002), and imitating actions
46 that in some cases are unobservable to the imitator (also, known as opaque actions; e.g., facial
47 expressions) requires a mechanism for transforming sensory information into a corresponding
48 matching action. It has been suggested that humans are born with an inter-modal representation
49 space where proprioceptive feedback from an action can be compared to a sensory
50 representation of the same action, facilitating action imitation (the active inter-modal mapping
51 hypothesis, AIM; Meltzoff & Moore, 1997). On the other hand, domain-general accounts
52 propose that associative learning links sensory and motor representations to overcome the
53 correspondence problem (e.g., Associative sequence learning approach, ASL, and the
54 ideomotor approach; Heyes & Ray, 2000; Brass & Heyes, 2005). However, while experience-
55 dependent approaches have been extensively studied in adults, few studies have tested their
56 predictions in children.

57 There is no consensus in the field of developmental psychology about when infants first
58 exhibit a capacity for imitation. However, researchers predominantly fall into one of two
59 camps. Some believe an imitative faculty is present from birth (Meltzoff & Moore, 1997; Nagy
60 et al., 2005; Simpson, Murray, Paukner, & Ferrari, 2014), while others believe imitative ability
61 develops throughout the first years of life (Jones, 2009; Ray & Heyes, 2011). The observation
62 that infants imitate facial gestures within hours of being born was first reported by Meltzoff
63 and Moore (1977) and there have been many attempts to replicate these findings, with mixed
64 results. Some studies report evidence of a number of actions being imitated from birth including
65 tongue protrusion, mouth opening, finger movement, and emotional expressions (Field,

66 Woodson, Greenberg, & Cohen, 1982; Meltzoff & Moore, 1977, 1983; Nagy et al., 2005;
67 Nagy, Pilling, Orvos, & Molnar, 2013), while others find either selective imitation of only
68 certain actions or no imitation at all (Anisfeld et al., 2001; Hayes & Watson, 1981; Heimann,
69 Nelson, & Schaller, 1989; Oostenbroek et al., 2016). Studies of nonhuman primates have
70 identified further evidence of neonatal imitation of mouth opening and tongue protrusion in
71 chimpanzees (*Pan troglodytes*, Bard, 2007; Myowa-Yamakoshi, Tomonaga, Tanaka, &
72 Matsuzawa, 2004), and evidence of lip-smacking and tongue protrusion imitation in three-day
73 old rhesus macaques (*Macaca mulatta*, Ferrari et al., 2006; however, note that there was no
74 evidence of neonatal imitation of these actions when infants were one, seven or 14 days old,
75 and no evidence was found of mouth opening or hand opening imitation). This evidence from
76 nonhuman primates lends some weight to the notion of an evolved and innate action matching
77 system that is at least sensitive to certain actions.

78 These empirical findings are granted different weight in reviews of the evidence, as
79 both early (Anisfeld, 1996; Meltzoff, 1996) and contemporary reviews (Lodder et al., 2014;
80 Ray & Heyes, 2011; Simpson et al., 2014) often draw conflicting conclusions about the
81 presence of an innate imitative ability. While a consensus answer to the neonatal imitation
82 question is not forthcoming some have suggested that overconfidence in neonatal imitation
83 may distract from the empirical study of how imitative ability develops throughout infancy
84 (Jones, 2007). Indeed, regardless of the presence or absence of innate imitative ability it is
85 important to consider both predispositions to imitation and also the influence of ontogenetic
86 processes.

87 An ability to imitate at birth does not preclude the involvement of learning processes
88 later in development. In fact, some argue that evidence of imitative ability diminishing over
89 the first few months (Ferrari et al., 2006; Fontaine, 1984) suggests that neonatal imitation may
90 be a specific adaptation for early bonding and a different imitation faculty develops later to

91 facilitate learning (Oostenbroek, Slaughter, Nielsen, & Suddendorf, 2013). There are few
92 studies of the development of imitation in infancy, a deficiency that Jones (2007) attributes to
93 the widely held belief that infants imitate from birth, however, early work in the field of
94 developmental psychology suggested imitation develops with time.

95 Before Metlzoff and Moore's seminal work on neonatal imitation, Jean Piaget (1962)
96 proposed a stage model of imitation that did not presuppose any innate imitative ability. By
97 studying his own children Piaget described the development of imitation throughout the first
98 two years. While no evidence of intentional imitation was noted in the first months of life, after
99 six months, all of Piaget's children imitated actions present in their behavioral repertoires that
100 were not opaque to themselves. Subsequently, Piaget noted that imitation of opaque actions
101 developed through practice, with imitation of sound-producing-actions (i.e., clapping)
102 preceding other actions (Piaget suggested that sounds might act as indices that allow the
103 mapping of an observed action performed by another onto the unobservable action performed
104 by the infant; 1962). Before performing novel actions, Piaget's children made approximate
105 attempts at imitating these actions, and actions were only imitated when they were in some way
106 analogous to actions already in the infant's repertoire. In the second year, Piaget observed these
107 imitative attempts become more exact but often retaining some level of gradual approximation,
108 or training, before expert imitation was achieved. Finally, in the middle of the second year,
109 more advanced imitative ability was noted, and Piaget described how the experimentation
110 observed in the earlier stages became internalized, facilitating quicker imitation of novel
111 actions. While the generalizability of these findings is limited by the preliminary nature of these
112 case studies, this work is still the most detailed longitudinal account of the development of
113 imitative ability in infancy, and suggests that the imitative faculty develops gradually.

114 More recent observations align quite closely with Piaget's earlier reports. Jones (2007)
115 conducted a cross-sectional study of imitative behavior in 162 infants from six months of age

116 to 20 months. Eight actions were modelled by a parent and were categorized according to
117 certain properties, including whether the actions were visible when being performed, or
118 whether the actions produced a sound. Reliable imitation of any kind was not identified at six
119 months, and actions that produced sounds were first imitated between eight and 12 months of
120 age. Actions that were silent and unobservable by the infant performing them were the final
121 actions to be reliably imitated (interestingly, one of these actions was tongue protrusion which
122 was not imitated reliably until 16 months). Other studies support the idea that imitative ability
123 develops throughout the 2nd year. Nielsen and Dissanayake (2004) found that infants start
124 imitating synchronous actions around 18 months of age. Masur and Rodemaker (1999) found
125 that at one year of age infants are already imitating actions performed on objects, but that
126 intransitive actions only begin to be imitated consistently at around 17 months. These findings
127 paint a different picture of imitation in infants and how it may develop throughout infancy.
128 Regardless of whether imitation is innate or learned it is clear that imitation in the first years
129 of life is limited in its diversity, however, by the age of three it is widely recognized that
130 children are highly competent imitators, often over-imitating unnecessary actions to achieve
131 outcomes (Horner & Whiten, 2005; McGuigan, Whiten, Flynn, & Horner, 2007; Piaget, 1962).
132 If imitation develops throughout infancy, it is necessary to explain what shape this learning
133 may take.

134 The Associative Sequence Learning (ASL) approach was developed by Ray and Heyes
135 in 2000 to describe the cognitive process facilitating imitative learning, and this model has
136 subsequently been adapted to describe the development of mirror neurons (Catmur, Walsh, &
137 Heyes, 2009; Heyes, 2010; see also ideomotor theory which has been described as being largely
138 compatible with the ASL view, e.g., Brass & Heyes, 2005). The ASL theory proposes that an
139 imitator develops links between sensory and motor representations of actions through
140 experience. This experience occurs whenever sensory and motor representations are available

141 at the same time, for example, when someone performs an action they can see, or during
142 synchronous social interactions (Heyes & Ray, 2000). These sensory-motor associations are
143 created prior to imitation, and facilitate imitation when an action is observed at a later time.
144 Other stimuli may facilitate the link between sensory and motor action units, for example, the
145 vocalized word “smile” may become associated with both the performance of a smile and the
146 observation of someone else smiling, facilitating an indirect association between sensory and
147 motor representations of an action (analogous to the indices described by Piaget). It may be
148 that this indirect route to forming an association might be especially important when an action
149 is opaque (e.g., facial expressions). More recently, the ASL approach has been applied to
150 explain mirror neurons where sensory and motor representations are instead discussed as
151 sensory and motor neurons (Heyes, 2010). Connections between neurons develop through
152 sensorimotor experience and after an association has been created a motor neuron may fire
153 solely upon seeing an action being performed. This model is gathering empirical support from
154 studies of adult humans through the analyses of automatic imitation effects.

155 Automatic imitation is a stimulus-response compatibility effect that is detected when
156 the presentation of an action stimulus (e.g., a picture of a hand opening) facilitates the
157 performance of that action and interferes with the execution of an opposite action (e.g., closing
158 a hand; for a review see Heyes, 2011). This automatic imitation effect may be a behavioral
159 indicator of the associations between sensory and motor representations of an action (or mirror
160 neuron activity), and the effect has been reliably identified in a number of studies (e.g., Boyer,
161 Longo, & Bertenthal, 2012; Brass, Bekkering, Wohlschläger, & Prinz, 2000; Heyes, Bird,
162 Johnson, & Haggard, 2005; Stürmer, Aschersleben, & Prinz, 2000). Automatic imitation has
163 been employed to test assumptions of the ASL hypothesis (Heyes et al., 2005; Press,
164 Gillmeister, & Heyes, 2007). For example, a number of studies have demonstrated automatic
165 imitation effects are reduced significantly or reversed following training sessions where

166 participants are required to respond to action stimuli with incompatible actions (e.g., closing
167 their hand upon seeing a hand open; Gillmeister, Catmur, Liepelt, Brass, & Heyes, 2008; Heyes
168 et al., 2005). Similar results have been noted in studies of mirror neuron activity (Catmur et al.,
169 2008; Catmur, Mars, Rushworth, & Heyes, 2011). For example, Catmur and colleagues (2008)
170 found that after training participants to move their foot after seeing a hand move (and vice
171 versa), activation in brain areas associated with mirror neuron function for specific actions
172 (e.g., hand movement) were activated by seeing moving images of the other effector (e.g., foot
173 movement). This suggests that experience of contiguous sensory-motor activity forges
174 connections between representations of actions that can be observed at the neurophysiological
175 level, even if the sensory and motor actions are different. Support for the ASL model is growing
176 based on experimental studies with adults; however, for the model to be useful it must take into
177 account the real social experience of infants and children, and explain whether this experience
178 can facilitate the development of imitation.

179 A crucial aspect of the ASL approach to imitation is that experience is essential for
180 connections between sensory and motor representations to form, and while this has been
181 explored in laboratory settings through training protocols (Gillmeister et al., 2008; Heyes et
182 al., 2005) it is less clear whether this type of experience is common in an infant's environment.
183 A few studies have examined imitation of both parents and infants in naturalistic play settings.
184 Pawlby (1977) observed mother-infant interactions between the ages of four and eight months
185 and found that approximately 16% of interactions involved some form of imitation by the
186 mother. More recently, Kokkinaki and Vitalaki (2013) found that three to four imitative
187 interactions (including both actions and vocalizations) took place every ten minutes between
188 caregivers and infants with children aged two to 10 months, with 66-79% of imitative
189 interactions performed by the caregiver. Similarly, parents have been found to imitate a child's
190 vocalization once every four to five minutes (Kokkinaki & Kugiumutzakis, 2000), and an

191 earlier study reports that 41-57% of non-cry vocalizations were matched between infants and
192 mothers, primarily driven by mothers imitating infants (Papousek & Papouskek, 1989). While
193 this research demonstrates that a substantial amount of synchronous and imitative experience
194 takes place during an infant's development, some authors have questioned whether the
195 experience observed in free-play scenarios is adequate for the development of imitative ability
196 (Simpson et al., 2014). Nevertheless, knowing that imitative or synchronous experience occurs
197 during infancy the next step is to observe the effect of this type of interaction on behavior.

198 In the current study we aimed to test specific predictions of the ASL approach with
199 children. Taking inspiration from previous studies of automatic imitation in adults and animals
200 (Range, Huber, & Heyes, 2011; Stürmer et al., 2000) a method for assessing behavioral
201 phenomena similar to automatic imitation in children aged between three and seven was
202 developed. The decision to study children already possessing imitative ability was largely due
203 to a methodological necessity; in this study children were required to perform different actions
204 after seeing an action stimulus, and previous studies have found that young children (aged
205 three-four) struggle with this task (see pilot study reported in Simpson & Riggs, 2011). The
206 task used in this study required participants to make one of two actions in response to an action
207 performed by an experimenter. Four different actions were used: hand clapping, hand waving,
208 hand closing (i.e., making a fist), and finger pointing. One game required participants to clap
209 or wave, while the other game required participants to create a fist or point. In compatible
210 conditions participants were asked to respond with the same action as the experimenter, and
211 during incompatible conditions they were asked to perform the opposite action. Each
212 participant experienced all iterations of the game. We expected strong stimulus-response
213 compatibility effects as suggested by previous research on automatic imitation (Brass,
214 Bekkering, & Prinz, 2001; Stürmer et al., 2000), however, the primary aim of our study was to
215 predict specific automatic imitation effects based on the ASL hypothesis.

216 Note, we describe the stimulus-response compatibility effects under investigation in
217 this article as *automatic imitation*, however, this term, as defined in the broader cognitive
218 literature, is operationally different, occurring only when compatibility effects are influenced
219 by task-irrelevant stimuli; that is, when participants are required to respond discriminatorily to
220 non-action stimuli (e.g., shapes, colors, etc.), and so compatibility effects induced by task-
221 irrelevant action stimuli are “automatic” in the sense of being unrelated to the task-
222 requirements. In the current study, on the other hand, the stimulus-set and response-set are the
223 same (i.e., children respond with action responses to compatible or incompatible action
224 stimuli), and so the compatibility effect cannot be said to be automatic in the same sense. In
225 the comparative literature, however, the term automatic imitation is used more broadly, and
226 also refers to contexts where animals learn to respond to action stimulus-response associations
227 more easily when the stimulus (e.g., a hand action) is congruent with the reinforced response
228 (e.g., a paw action; Range, et al., 2011; Mui, Haselgrove, Pearce, & Heyes, 2008). The
229 compatibility effects examined in the current study, while operationally different from the adult
230 and comparative literature, still relate specially to the imitative domain (i.e., action and
231 response sets consist of the same actions), and any delays or mistakes caused by the task-
232 instructions will be unintentional. Furthermore, we predict that underlying mechanism
233 resulting in the any potential differences across action-sets observed in our own study would
234 be the same as those mechanisms driving the effects found in adult studies, and therefore we
235 chose to use the same term, automatic imitation, when describing this stimulus- response
236 compatibility effect.

237 The action sets used in this study were chosen based on two criteria. First, all actions
238 had to be simple to perform. Second, it was expected that children would have more experience
239 of performing two of the actions in a socially synchronous or imitative context. To our
240 knowledge, no previous study has described the frequency of specific synchronized behavior

241 in childhood and therefore these actions were chosen through a thoughtful consideration of
242 actions regularly imitated during social interactions. Clapping and waving, for example, are
243 performed socially during applause and when saying goodbye respectively. Indeed, clapping
244 specifically is often described as occurring in a group context (e.g., Repp, 1987). On the other
245 hand, pointing and making a fist are not socially synchronous or imitated behaviors. While a
246 rich literature describes the varied function of pointing as a communicative gesture (e.g., Kita,
247 2003; Tomasello, Carpenter, & Liszkowski, 2007) this gesture is seldom, if ever, described as
248 occurring in imitative contexts. Rather, a typical interaction involves the use of language and
249 results in a social partner's attention being guided towards a referent (Butterworth, 2003).

250 Our first prediction based on the ASL approach to imitation is that automatic imitation
251 effects (i.e., the difference in reaction time between imitating actions and performing different
252 actions) will be greater for actions that have been performed in synchrony in past interactions.
253 The ASL approach predicts that external stimuli may facilitate the association of visual and
254 motor properties of an action. We may then predict that an automatic imitation effect may be
255 stronger for an action that produces other non-visual stimuli. The only action that produces a
256 non-visual stimulus is clapping which also produces sound, and so we predict that the automatic
257 imitation effect will be greatest for this action. Finally, if automatic imitation effects develop
258 through imitative or synchronous experience, it follows that short periods of counter-imitative
259 experience preceding imitation trials will increase reaction time when imitating. If this is the
260 case we should find that when incompatible experimental trials precede imitative trials that
261 automatic imitation effects will be suppressed. It is difficult to predict whether, or how, age
262 might affect automatic imitation. For example, it might be expected that cumulative effects of
263 social sensorimotor experience throughout development might facilitate quicker reaction time
264 on imitative trials in older children while making it more difficult to inhibit imitative responses
265 during counter imitative-trials; this might lead to an increase in automatic imitation through

266 development. However, children get better at inhibiting imitative responses as they develop
267 (Simpson & Riggs, 2011), which may lead to quicker reaction times when counter-imitating,
268 subsequently reducing automatic imitation effects in older children. These developmental
269 effects together may cancel themselves out leading to a stable automatic imitation effect
270 throughout development with overall quicker reaction times for both imitative and counter-
271 imitative responses. Due to the uncertainty over the direction of these effects, age related
272 variation will be examined without a priori hypotheses.

273 **Methods**

274 **Participants**

275 Participants were 101 children aged between three and seven. Twenty-nine participants
276 were excluded from the analyses for either not finishing the research session, for not
277 performing more than 60% correct responses in any one of the four conditions, for not paying
278 attention to the experimenter during the stimulus presentation, or for having parents or
279 guardians interfere in their responses (mean age of excluded participants = 4.33 years, standard
280 deviation, $SD = 1.24$ years). Seventy-two participants were included in the initial analysis;
281 mean age was 5.74 years ($SD = 1.29$ years) and 39 participants were female (see analysis
282 section for further information in inclusion criteria). Participants were recruited at the XXXX,
283 UK in July 2013, and voluntarily completed research sessions for rewards of stickers. Ethical
284 approval was granted by the University of XXXX ethics committee for the project titled
285 “Automatic imitation in children”, and consent was given by the child’s parent or guardian
286 before the session began.

287 **Design**

288 Over the course of a research session four different games were played using two
289 different sets of actions. For two of the games, participants had to produce actions that are

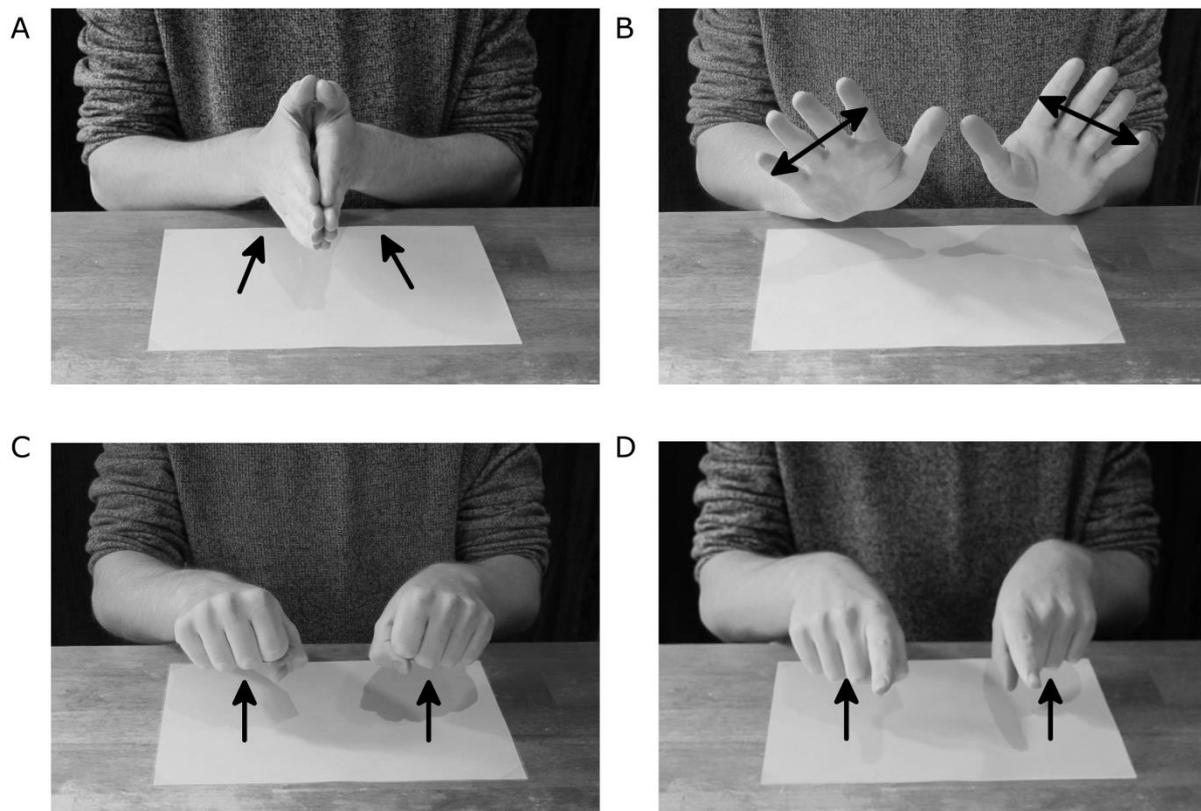
290 commonly imitated or performed in synchrony during social interaction (we will refer to these
291 actions as the Commonly Imitated Set, or CIS). The actions chosen for the CIS were “wave”
292 and “clap” (see Figure 1, A-B), as children are likely to clap their hands in synchrony during
293 applause, and waving is also a socially synchronous behavior performed when waving
294 goodbye. The actions performed in the other action set (which we will call the Rarely Imitated
295 Set, or RIS) were “point” and “fist” (see Figure 1, C-D), as these actions are not considered to
296 be socially-coordinated.

297 Using a stimulus-response compatibility paradigm two different games were played
298 with each action set; both games required the participant to respond to the actions performed
299 by the experimenter. One game required the participant to watch the actions of the experimenter
300 and respond with the same action (compatible response rule), and the other game required the
301 participant to perform the alternate action (incompatible response rule). To be included in the
302 analysis a participant had to complete both actions sets with both response rules.

303 **Procedure**

304 During a research session the experimenter and participant sat facing each other across
305 a table. Two sheets of A4 paper were attached to the table in front of both the participant and
306 the experimenter (see Figure 1). At the beginning of the session the experimenter explained
307 that a game was to be played and to begin the child must place their hands flat on the sheet of
308 paper.

309



310

311 *Figure 1.* Action stimuli used in study; arrows indicate movement. Actions A (clap) and B
 312 (wave; note that an open hand wave was always demonstrated) are part of the commonly
 313 imitated set of actions while actions C (fist) and D (point) made up the rarely imitated action
 314 set.

315

316 The experimenter demonstrated the two actions to be performed in the first game and
 317 asked the participant if they were also able to perform each of the two actions: E.g., “Can you
 318 wave your hands like this?”. Next, the experimenter explained the response rule for each of the
 319 two actions and asked the participant to demonstrate a response: E.g., “In this game if you see
 320 me wave my hands (*experimenter waves his hands*), you do the different action, the opposite
 321 action, and you clap your hands (*experimenter claps his hands*). So, if I do this (*experimenter
 322 waves his hands*) what do you do?” After explaining the response rules for both actions the
 323 participant’s understanding of the rules was tested by asking the child to respond to both actions

324 in order. If the participant performed an incorrect response the rules were repeated and a further
325 two trials tested comprehension. Correct responses during this pre-test phase were rewarded
326 with verbal praise, and if both responses were correct the child progressed to the testing phase.
327 If the child did not perform two consecutive correct responses after four pre-test trials the child
328 progressed to the testing phase nonetheless. If these children passed the criteria for inclusion
329 (see below), their data was included in the analysis.

330 The testing phase consisted of ten response trials presented in a pseudorandomized
331 order. Children were told to react as quickly as possible. To begin a trial both experimenter and
332 participant placed their hands flat on the sheet of paper; if the child did not have their hands on
333 the paper they were prompted to do so (e.g., “hands flat”, “hands on the paper”). The
334 experimenter would rapidly perform an action, return his hands to the starting position, and
335 wait for the child to respond. During this testing phase correct responses were not praised and
336 incorrect responses were not corrected by the experimenter. If an incorrect action was
337 performed the experimenter would wait for approximately two seconds for the child to change
338 their action. Between trials, children were encouraged to prepare themselves for the next trials
339 with various verbal cues including “hands flat”, “ready”, and “next one”. After the tenth trial
340 the child was praised for his or her performance, and told that the game was to be played again
341 but with different rules. The procedure described above was then repeated but with the response
342 rules reversed. After completing ten test trials with both response rules, the same overall
343 process was repeated with the different action set. The order of the games was counterbalanced
344 for both response rule and action set. However, due to the removal of some participants (see
345 criteria below), for the CIS the compatible trials took place first for 35 of 72 participants, while
346 for the RIS, 38 participants received the compatible condition first.

347 Video Coding

348 All sessions were recorded on a Sony CX405 camcorder, and each trial was coded
349 frame-by-frame to measure reaction time. Each session was recorded at 25 frames per second
350 (fps; interlaced), however, interlaced video allows for greater temporal resolution by
351 overlapping adjacent frames to create a perceived resolution of 50 frames per second. The
352 videos were coded at this higher rate of temporal resolution, and frame measurements were
353 subsequently converted into second (s) measurements for analysis, and all measurements are
354 reported to the nearest significant digit (i.e., 20 milliseconds).

355 To assess whether a participant had understood the rules we recorded how many correct
356 responses the participant performed in each condition including trials where the participant
357 may have initially performed the wrong action before quickly changing to the correct response
358 (we included these corrected trials, as we felt that this change of action indicated that the child
359 understood the rule for that trial). However, we also recorded the number of “mistakes” made
360 per condition, considering both incorrect trials and corrected trials. We felt this measure better
361 captured an automatic response to a stimulus, and therefore was relevant to the study of
362 automatic imitation. This measure of mistakes was analyzed when examining automatic
363 imitation effects.

364 A measure of reaction time started once an action was completed by the experimenter
365 and ended once the completion criteria was met by the participant (see Table 1 for definitions
366 of action completion), and these measures were kept consistent across all participants. Reaction
367 time measurements were not taken for trials when an incorrect response was performed,
368 whether this incorrect response was corrected or not. As actions were sometimes performed
369 quicker by one of the participant’s hands, the measurement of reaction time ended once the
370 action was completed by one hand in the case of all actions other than clapping.

371

372 Table 1

373 *Definitions used to begin and end a measurement of reaction time on a given trial.*

Action	Action Completion Criteria
Wave	Hands first change direction of movement (i.e., if hands were moving inwards, measurement began once hands began moving away from each other)
Clap	Hands make contact.
Point	Pointing finger visibly extended from the rest of the fingers
Close hand	Fingers are closed and pressed into the palm

374

375

376 **Data analyses**

377 To be included in the analyses participants had to perform correct responses on 60% of
 378 trials within each condition. This criterion was used to ensure that each participant had
 379 understood the rules of each condition (see above). If the participant met this criterion, their
 380 total number of mistakes made per condition (i.e., across action set and response rule) was
 381 analyzed using a repeated measures ANOVA.

382 Reaction time (RT) was also examined. For each participant, an average RT score was
 383 calculated for each condition (i.e., CIS-Compatible, CIS-Incompatible, RIS-Compatible, and
 384 RIS-Incompatible), considering only RTs for correct trials. Trials where mistakes were made

385 were not included, as were RTs that fell outside 2 SD of the mean RT for each condition. If,
386 after excluding trials due to mistakes and outlying RTs, there were less than six data-points for
387 each of the four conditions the participant's data was not included in the RT analysis. Overall,
388 data from 55 participants was analyzed (mean age = 5.86; SD = 1.31). These inclusion criteria
389 were set to ensure that the average RT for a given condition was representative of an unbiased
390 response on each condition of the task. To examine the effect of rule-order, a measure of
391 automatic imitation was calculated for each action set, taking the average RT in the compatible
392 condition and subtracted it from the average RT in the incompatible condition. Correlations
393 between age and automatic imitation effects for both actions, as well as average RT for each
394 condition were also examined.

395 Automatic imitation effects were also calculated for each of the four actions (i.e., the
396 difference in reaction time to specific action stimuli when responding in compatible or
397 incompatible conditions), except in this case, as each participant responded to five
398 presentations of each stimulus in each condition, the criterion for inclusion was three or more
399 correct responses to each stimulus in each condition. Overall, data from 43 participants was
400 analyzed (mean age = 5.95, SD = 1.27). Again, this inclusion criterion helped establish that
401 RTs were representative of participant's response to a given action stimulus, however, note
402 that this average score will in each case be based upon only three to five responses.

403 To examine RT data from all 72 participants, a complementary analysis was performed
404 with RT on each trial examined using a Linear Mixed Model (LMM) with participant and
405 condition (i.e., action set/response rule) included as random effects to account for repeated
406 observations within participants. This additional analysis was performed to examine
407 interactions between dependent variables and to demonstrate that when all variables are
408 included in the same analyses (in comparison to the individual analyses reported below) that

409 the same general findings hold. This analysis and the model details can be found in the
410 supplementary materials.

411 **Statistical Software**

412 All statistical analyses were performed using SPSS 23 and R (R Core Team, 2014; we
413 used the Rstudio environment; RStudio Team, 2014), and all figures were created using the
414 ggplot2 package in R (Wickham, 2009). The LMM was developed using the “lme4” package
415 (Bates et al., 2015), and Wald chi-square tests for this model was calculated using the “car”
416 package (Fox et al., 2016).

417 **Results**

418 **Overall Automatic Imitation Effects**

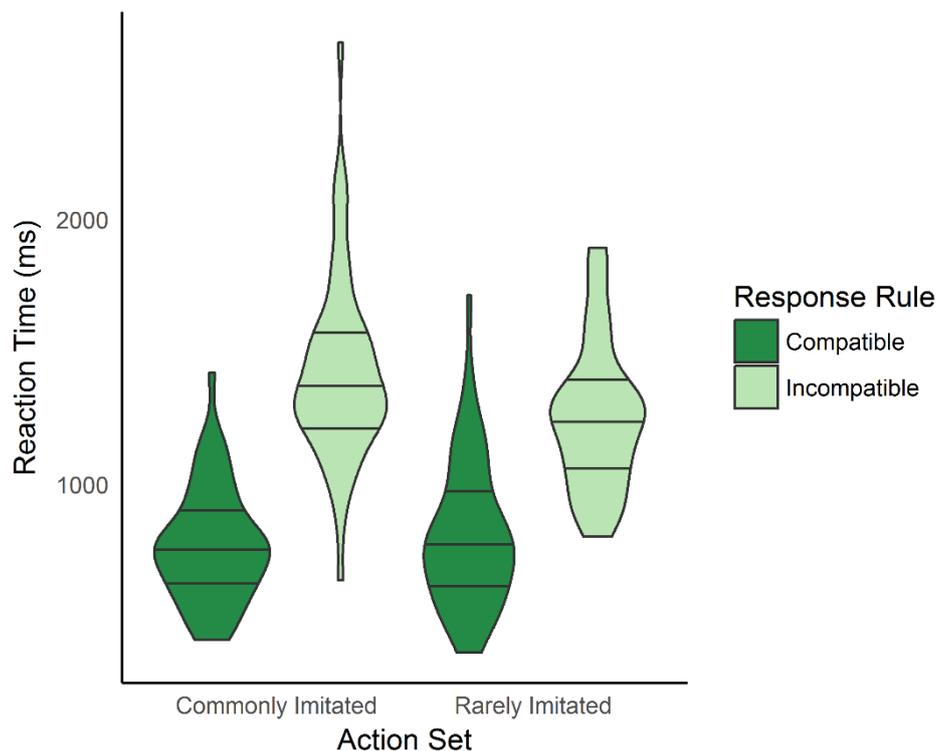
419 To examine the overall effect of the two response rules and two action sets on mistakes,
420 a 2X2 repeated-measures analysis of variance (ANOVA) was performed with all 72
421 participants. A main effect of response rule was identified ($F(1, 71) = 21.28, p < .001; \eta_p^2 = .23$)
422 with an estimated 0.72 fewer mistakes made when responding with compatible responses
423 (standard error, SE = 0.16, CIs = 0.41 – 1.02). Also, a main effect of action set was found ($F(1,$
424 $71) = 51.18, p < .001; \eta_p^2 = .42$) with an estimated 1.17 more mistakes (SE = .16; CIs = .85 –
425 1.50) in the RIS (M = 2.08) when compared with the CIS (M = 0.90). An interaction between
426 action set and response rule was not identified ($F(1,71) = 0.20, p = .657; \eta_p^2 < .01$).

427 A 2X2 ANOVA examined the effect of condition on reaction time (RT) using data from
428 the 55 participants that reached the inclusion criteria (see data analysis section above for
429 details; also, see the Supplementary Materials for a Linear Mixed Model examining trial RT
430 with all 72 participants). A main effect of response rule was identified ($F(1, 54) = 350.65, p$
431 $< .001; \eta_p^2 = .87$) with compatible trials performed an estimated 0.56 s quicker on average than
432 incompatible trials (standard error, SE = 0.02, CIs = 0.50 – 0.62). A main effect of action set

433 was also found ($F(1, 54) = 5.57, p = .022; \eta_p^2 = .09$) with an estimated mean difference of 0.06
434 s ($SE = 0.02; CIs = 0.01 - 0.12$) between the CIS ($M = 1.10$ s) and the RIS ($M = 1.04$ s). A
435 significant interaction between action set and response rule was also identified ($F(1, 54) =$
436 $22.08, p < .001; \eta_p^2 = .29$), suggesting automatic imitation (i.e., RT difference between
437 compatible and incompatible responses rules) varied across action set; indeed, the average
438 automatic imitation effect in the CIS was 0.66 s, and 0.44 s in the RIS. Examining these
439 differences further, we found that compatible responses were not significantly quicker in the
440 CIS ($M = 0.76$ s) when compared to those in the RIS ($M = 0.80$ s; $t(54) = -1.18, p = .242$),
441 however, incompatible responses in the CIS ($M = 1.42$ s) were significantly slower than those
442 in the RIS ($M = 1.26$ s; $t(54) = 4.31, p < .001$; see Figure 2).

443 **Stimuli Effects**

444 To examine the automatic imitation effects associated with specific action stimuli we
445 subtracted average RT for compatible responses from average RT for incompatible responses
446 for each action. Comparing these automatic imitation effects, we identified a significant effect
447 of stimulus ($F(2.67, 112.29) = 11.37, p < .001; \eta_p^2 = .21$; Mauchly's test indicated that the
448 assumption of sphericity was violated so degrees of freedom were corrected using Huynh-Feldt
449 estimates, $\epsilon = .89$). Post-hoc comparisons with Holm-Bonferroni corrections identified that the
450 automatic imitation (AI) effect for the clap stimuli ($M = 0.72$ s, $SE = 0.06$) was significantly
451 greater than the AI effect for the wave ($M = 0.58$ s, $SE = 0.04; p = .046$), point ($M = 0.46$ s, SE
452 $= 0.04; p < .001$), and fist stimuli ($M = 0.44$ s, $SE = 0.04; p < .001$). Waving stimuli resulted in
453 a significantly greater AI effect when compared with fist stimuli ($p = .036$), and point stimuli
454 ($p = .036$), and there was no difference in AI effect between the point stimuli and fist stimuli
455 ($p = .755$).



456

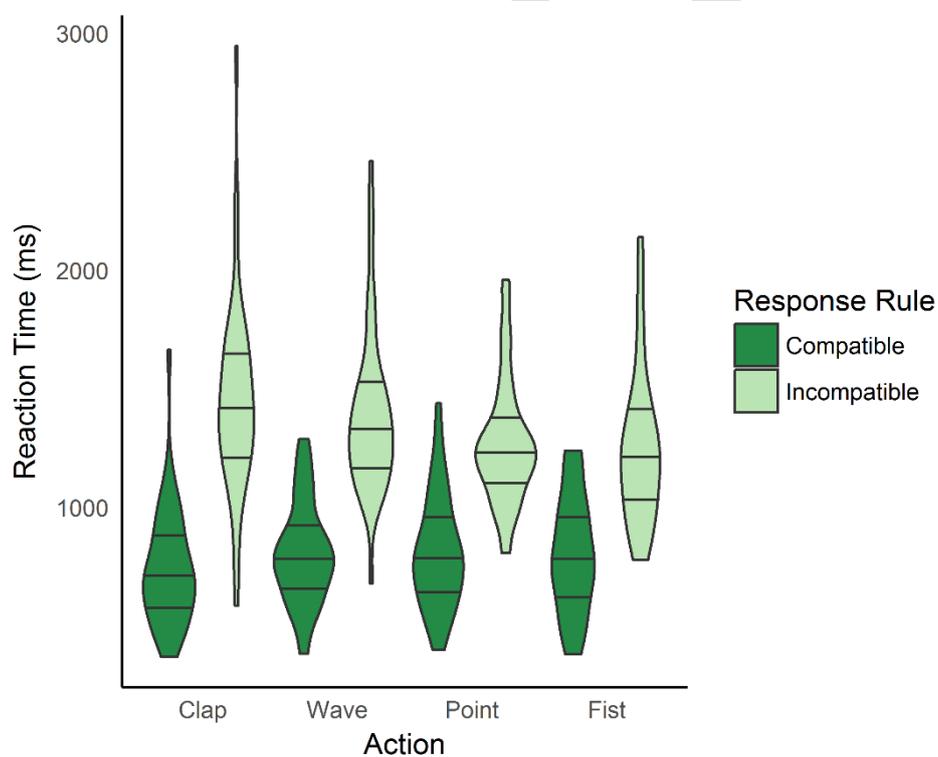
457 *Figure 2.* Violin plots for each response rule (Compatible and Incompatible), for each action
 458 set (Commonly Imitated Set and Rarely Imitated Set). Horizontal lines represent the median
 459 and interquartile range for each condition and the width of the plot represents the kernel
 460 probability density of the data for each condition.

461

462 To examine what was driving these AI differences we examined RTs for compatible
 463 and incompatible responses for each stimulus separately. We performed two one-way repeated
 464 measures ANOVAS, one for compatible rules and one for incompatible rules, with action
 465 stimulus as the independent variable. In both cases, Mauchly's tests indicated that the
 466 assumption of sphericity was violated ($X^2(5)_{\text{compatible}} = 42.40, p < .001$; $X^2(5)_{\text{incompatible}} = 22.83,$
 467 $p < .001$), so degrees of freedom were corrected using Greenhouse-Geisser estimates for both
 468 compatible actions ($\epsilon = .58$) and incompatible actions ($\epsilon = .74$; see Field, 2016). We found no
 469 significant effect of stimulus type for compatible responses ($F(1.75, 73.65) = 2.30, p = .114$;

470 $\eta_p^2 = .05$; see Figure 3), but a significant effect of stimulus type for incompatible responses
471 ($F(2.21, 92.64) = 9.15, p < .001; \eta_p^2 = .18$, see Figure 3). Note that while this might suggest that
472 incompatible trials are driving the automatic imitation effects, these individual action
473 comparisons cannot explain the effect given baseline performance times for actions may vary
474 based upon motoric difficulty, for example. Thus, conclusions based upon these comparisons
475 are speculative.

476



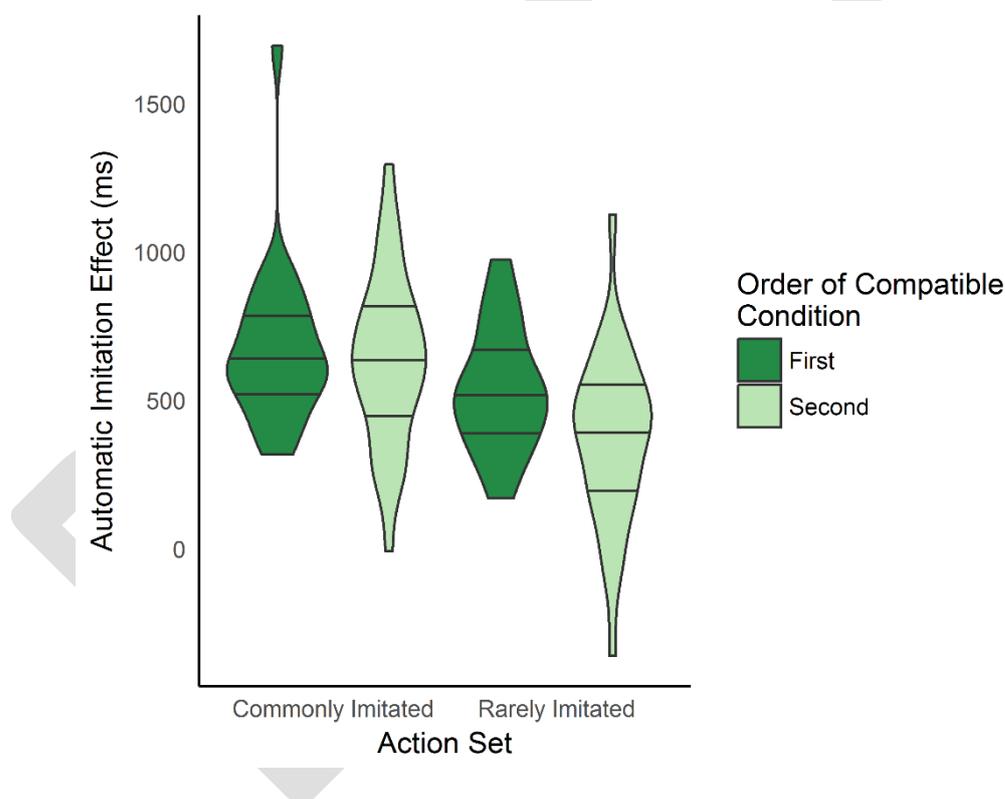
477

478 *Figure 3.* Violin plots representing RTs to each response rule (compatible and incompatible)
479 for each action stimulus. Horizontal lines represent the median and interquartile range for each
480 condition and the width of the plot represents the kernel probability density of the data.

481

482 When responding with incompatible actions, post-hoc tests with Holm-Bonferonni
 483 corrections identified significantly slower average RTs to clap stimuli ($M = 1.46$ s, $SE = 0.06$)
 484 when compared with point ($M = 1.26$ s, $SE = 0.04$; $p = .010$) and fist stimuli ($M = 1.24$ s, SE
 485 $= 0.04$; $p < .001$). Incompatible responses to wave stimuli ($M = 1.40$ s, $SE = 0.06$) did not
 486 significantly differ in comparison to average RTs to clap stimuli ($p = .308$), but were
 487 significantly slower than responses to point ($p = .033$) and fist stimuli ($p = .016$). No RT
 488 differences were found in incompatible responses to point and fist stimuli ($p = .483$).

489



490

491 *Figure 4.* Violin plots representing the automatic imitation effect (i.e., difference between
 492 average RT in the incompatible and compatible conditions) for each action set (Commonly
 493 Imitated Set and Rarely Imitated Set), when compatible rules are performed first, and second.
 494 Horizontal lines represent the median and interquartile range for each condition and the width
 495 of the plot represents the kernel probability density of the data for each condition.

496

497 **Order Effects**

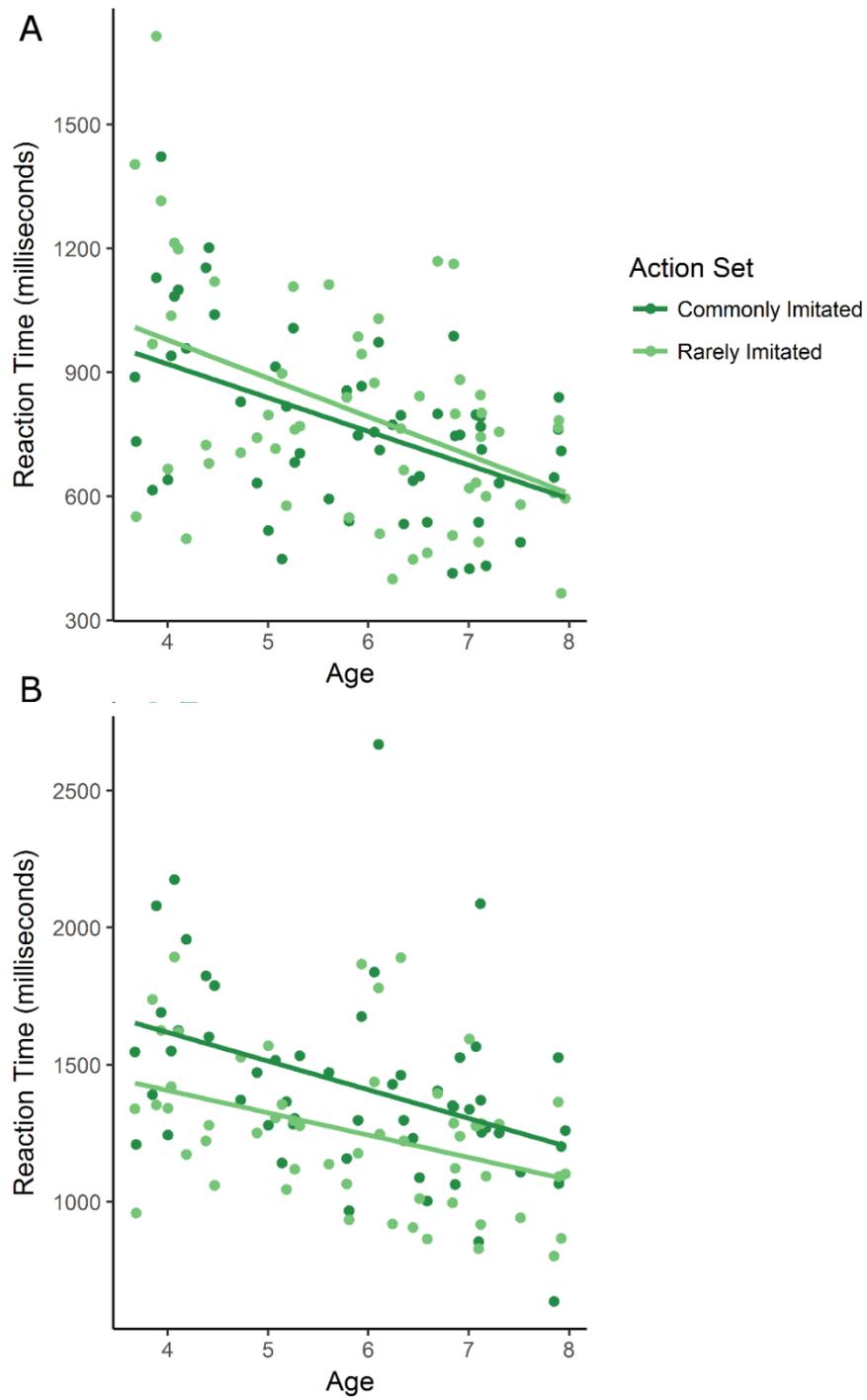
498 We examined whether the order that response rules were completed had an effect on
499 automatic imitation by comparing the automatic imitation effects found when compatible
500 responses were performed first and when they were performed second. For the CIS, we found
501 no significant difference in AI effects dependent on whether compatible responses were
502 performed first ($M = 0.68$ s, $SE = 0.06$), or second ($M = 0.64$ s, $SE = 0.06$; $t(53) = 0.48$, $p =$
503 $.632$; *Cohen's d* = 0.13; see Figure 4). However, for the RIS, when compatible responses were
504 performed first, the AI effect ($M = 0.54$ s, $SE = 0.04$) was significantly larger than when the
505 compatible responses were performed second ($M = 0.38$ s, $SE = 0.06$; $t(53) = 2.35$, $p = .023$;
506 *Cohen's d* = 0.64; see Figure 4). However, comparing the effect-sizes from these two tests
507 identifies no significant difference between these results ($Z = 1.32$, $p = .188$). Furthermore,
508 when a three-way interaction between the automatic-imitation effect, order of rules, and action
509 set was examined using a Linear Mixed Model, a significant interaction was not found ($X^2(1)$
510 = 2.21; $p = 0.137$; see Table 1, Supplementary Materials), again, suggesting that while order
511 effects are different across conditions, this difference is not statistically significant.

512 **Age effects**

513 Age was not significantly correlated with AI effect in either the commonly imitated
514 action set ($r = -.11$, $p = .432$) or the rarely imitated action set ($r = .06$, $p = .681$), and any
515 difference between AI effects (calculated by subtracting a participant's AI effect in the RIS
516 from the CIS effect), similarly, did not vary across age ($r = -.14$, $p = .311$). RTs to compatible
517 rules in both action conditions quickened with age ($r_{cis} = -.50$, $p < .001$; $r_{ris} = -.45$, $p < .001$;
518 see Figure 5), and similarly, incompatible responses quickened with age ($r_{cis} = -.40$, $p = .003$;
519 $r_{ris} = -.39$, $p = .004$; see Figure 5). As all RTs were strongly correlated with age, we performed
520 a correlation between AI effects for both action sets and age while partialling out the effect of

521 a participant's mean RT performance; we found no relationship between age and the AI effect
522 for the commonly imitated set ($r = .20$, $p = .158$), or rarely imitated actions ($r = .07$, $p = .629$).

523



524

525 *Figure 5.* Participant's average reaction time as a function of age when responding in (A)
526 compatible trials and (B) incompatible trials for both commonly imitated actions (dark
527 green/grey) and rarely imitated actions (light green/grey). Lines represent the linear
528 regression lines for the predicted effect of age on reaction time for each condition and action
529 set.

530 **Discussion**

531 This study of automatic imitation specifically tests predictions of the ASL model of
532 imitation in children. Unsurprisingly, given the impressive imitative skills of children from the
533 age of three we found a significant automatic imitation effect for both sets of actions when
534 examining reaction time (see Figure 2), and the number of mistakes made in each condition.
535 However, it is the difference in automatic imitation effects between action sets that is of the
536 most interest. The ASL model, as well as the ideomotor approach (Brass & Heyes, 2005),
537 predicts that associations between sensory and motor representations of actions are formed
538 through experience and so actions that receive more of this particular type of sensorimotor
539 experience should be quicker to imitate and more difficult to inhibit. Commonly imitated
540 actions were not imitated quicker than rarely imitated actions overall, however, incompatible
541 responses to commonly imitated actions were significantly slower than incompatible responses
542 to rarely imitated actions. This resulted in a significantly greater automatic imitation effect in
543 the commonly imitated set when examining reaction times. However, note that while this result
544 may suggest that incompatible trials are driving the AI effect, as each action has its own level
545 of motoric difficulty, this may not be the case; for example, a clap may take longer to complete
546 than a point in general, however, when imitating, the advantage granted clapping may be
547 greater than that afforded pointing and so RTs are instead comparable in this condition). This
548 finding supports an experiential account of imitation, demonstrating that inhibition of a learned
549 imitative response varies in line with predictions of previous social sensorimotor experience.

550 Overall, more mistakes were made when participants were required to respond with
551 incompatible actions, and more mistakes were made when responding to rarely imitated
552 actions. However, there was no interaction between response rule and action set, suggesting
553 the automatic imitation effect measured in this context did not vary in line with predictions of
554 synchronous experience. While inconsistent with the reaction time analysis, the failure to find
555 a significant effect here may be driven by a tradeoff between speed and accuracy that is found
556 in choice reaction-time paradigms (Wood & Jennings, 1976). Also, it is unclear why more
557 mistakes were made overall in the rarely imitated set, but as the reaction time analyses only
558 considered correct trials, this difference is unlikely to impact these findings.

559 Further evidence in support of a domain-general account is provided by our finding that
560 the greatest automatic imitation effect was found when responding to clapping stimuli, an
561 observation that is predicted by the ASL model's account of environmental stimuli facilitating
562 the connection between sensory and motor representation of an action. Environmental stimuli
563 are thought to bridge cognitive representations in cases where actions may not provide sensory
564 feedback (Ray & Heyes, 2011); and in cases where sensory information is available, auditory
565 stimuli may act to provide a more complex network of associations. This interpretation
566 corresponds with evidence of audio-visual mirror neurons identified in monkeys that fire when
567 performing an action, seeing an action, and hearing an action (Keysers et al., 2003). If
568 automatic imitation is indeed a behavioral effect of mirror neuron activity formed through
569 associative processes, we may expect this more pronounced effect when motor actions have
570 become associated with multiple stimuli over different modalities. Other actions performed in
571 this study also involve the proprioceptive modality of course, but only when performed.
572 Clapping on the other hand, incorporates both the visual and auditory sensory modality during
573 performance as well as social perception. While it is known that reaction times to multisensory
574 stimuli are quicker than reaction times to a single stimulus (Andreassi & Greco, 1975;

575 Hershenson, 1962), here, we see differences in automatic imitation effects driven by slower
576 reaction times when responding with an incompatible action suggesting a compatibility-
577 specific effect. If reaction times were quicker for both compatible and incompatible trials, we
578 could conclude that bimodal stimulation alone may drive this stimulus specific effect, however,
579 here we see an interaction between bimodality and compatibility. To our knowledge, studies
580 of bimodal stimuli presentation have not examined the inhibition of a prepotent response to a
581 bimodal stimulus but if associative processes underlie advantages when responding to bimodal
582 stimuli in reaction paradigms, we would predict that responses would be more difficult to
583 inhibit when compared to a unimodal case. Also, it may be possible that of all the actions used
584 as stimuli, clapping is by chance the action performed in synchrony the most often, leading to
585 the observed effect. This interpretation, while compatible with the ASL view of imitation,
586 incorporates a conceptually different mechanism. Future studies could easily differentiate
587 between these two interpretations by manipulating the degree of experience participants receive
588 as well as the degree of intermodal sensory information available during learning and
589 subsequent inhibition of responses to novel associative stimuli. This protocol could isolate the
590 role of both experience and stimulus complexity in imitative learning.

591 Partial support for the ASL view of imitation is found when examining the effect of
592 counter-imitative experience preceding imitative action. Overall, it was found that a short
593 session of counter-imitative training significantly reduced the automatic imitation effect for
594 rarely imitated actions but not for commonly imitated actions. Previous research has eliminated
595 automatic imitation effects entirely through counter-imitative training (Heyes et al., 2005),
596 while here we merely reduce it. However, the training received in this study (approximately 12
597 trials including practice trials) is not comparable to the training in other studies (e.g., 6 blocks
598 of 72 trials, Heyes et al., 2005). While simple order effects are common in experimental
599 paradigms of this sort, we feel it is important to highlight that imitative compatibility effects

600 are not immune to such effects. Furthermore, while we didn't predict that the order of response
601 rule would vary across actions sets, this finding is consistent with an experiential account, as
602 an automatic imitation effect might be resistant to counter-imitative experience when strong
603 sensory-motor associations have been formed. However, it is important to note that while an
604 order effect was only found for automatic imitation effects in the rarely imitated action set (see
605 Figure 4), this effect was not significantly different from the null result found in the commonly
606 imitated set, and so conclusions concerning this difference are speculative.

607 While older participants responded more quickly for both response rules within each
608 action set, no change in automatic imitation was found over development. This is not
609 necessarily surprising. As previously mentioned, based on the ASL approach one might predict
610 that an automatic imitation effect would increase with age as cumulative experience would lead
611 to increased inter-representational connectivity. However, in the paradigm explored here we
612 are dealing with two effects: An imitation effect and an inhibitory effect, since reacting to an
613 action stimulus with a different action necessitates the inhibition of imitation. Previous studies
614 of inhibition in children have found that the ability to inhibit prepotent responses increases with
615 age (Simpson & Riggs, 2011). With this in mind, as children age we might expect that
616 experience would contribute to greater sensorimotor co-ordination resulting in quicker reaction
617 times in imitative trials, and developing inhibitory control should reduce reaction times when
618 responding to incompatible stimuli. If this is the case it is not surprising that we see a consistent
619 automatic imitation effect throughout development. It could be argued that the automatic
620 imitation effect reported here is solely a result of a higher memory load required to react to
621 incompatible rules (i.e., the "different action" has to be remembered for an incompatible rule,
622 while this information is readily available in the stimulus in the compatible condition). Indeed,
623 under the present paradigm automatic imitation is likely to function in conjunction with
624 working memory and other inhibitory effects, but as this study is more orientated towards

625 examining the extent of automatic imitation across different contexts where memory load and
626 inhibitory context are kept constant, we believe this interaction does not affect our conclusions.
627 Nonetheless, future studies with children should attempt to isolate automatic imitation effects.

628 It could be argued that the effect of action-set on automatic imitation is driven solely
629 by the fact that one action in the CIS produced a sound, while neither action in the RIS produced
630 sound. Under this interpretation, the difference in automatic imitation observed between sets
631 is not driven by previous experience of synchrony but by an interaction between action- and
632 sound-compatibility. While a valid observation, a similar argument could be made for any
633 perceptual feature unique to a specific action, and in this study we did not aim to, and could
634 not, control for every perceptual feature across actions sets, and indeed, retaining ecological
635 validity of actions was an important goal of this study. Nonetheless, if a discrepancy in sound
636 production was the sole driver of the stronger compatibility effect in the CIS, this would be an
637 important example of how action planning is strongly inhibited when the sound, and indeed
638 absence of sound (in the case of the wave stimulus), does not correspond with the sound
639 produced by an action to be performed, and more work is needed for this effect to be fully
640 understood. However, even if sound-compatibility was the primary driver of the difference
641 across action-sets, the initial development of a link between the perceptual and motor
642 representations of an action (so called event codes, see Hommel, 2004; or common codes, see
643 Prinz, 1997) would be facilitated by the previous experience of that action in both asocial and
644 social contexts. The performance of an action in synchrony with others, for example, would
645 help develop a richer stimulus-set with which to facilitate action planning at a later stage, and
646 sound production would just be one element of the event code. Sound-compatibility may be an
647 important driver of this compatibility-effect, even potentially the sole driver, however, it is not
648 possible to disentangle the effect of previous experience of synchronous action from specific
649 stimulus-components of an action (e.g., sound) from this data. Only future empirical work with

650 this paradigm will identify the impact of each stimulus-element on these compatibility effects
651 and how prior social experience interacts with these stimuli-effects.

652 It is important to note here that the theoretical perspectives that account for action
653 planning in the asocial domain described by Prinz (1997) and others (e.g., Hommel, 2004),
654 are largely consistent with the account that examines this effect in the social domain (e.g., the
655 ASL approach to imitation). In fact, following from this perspective, it could be argued that
656 different automatic imitation effects are driven by the mere frequency of action performance,
657 rather than social experience (e.g., imitative or synchronous action). Indeed, an experiential
658 view of imitation does not necessarily require experience to be social in nature. For example,
659 associations between sensory and motor representation of the same actions can develop through
660 self-observation (Heyes, 2011). While to our knowledge there is no observational work
661 comparing the baseline frequency of different actions performed by children, we cannot think
662 of a reason for why a simple action like the closing of a hand or a frequently used
663 communicative gesture like pointing (Cochet & Vauclair, 2010), would be performed less often
664 than waving or clapping. Importantly, the differences identified in this study are not solely
665 related to the motor performance of these actions but the sensory context preceding their
666 performance which is specifically social in nature, and so these results are directly applicable
667 to the domain of social imitation, rather than action performance alone.

668 We acknowledge that a limitation of our study is that our assumptions regarding
669 previous social experience were not based upon observations of adult-child or peer interactions,
670 but instead, upon a priori consideration of specific behaviors that are known to be coordinated
671 in time through social convention. As mentioned in the introduction, clapping (as performed in
672 applause for example) and waving (as performed as a greeting/departure display) have specific
673 social significance in the country where this study was performed that will lead to actions being
674 performed synchronously (or at least, resulting in these actions being temporally clustered),

675 while hand closing and pointing gestures do not occur in this socially synchronous context, at
676 least in the same extent. For example, to our knowledge, there is no cultural-practice in the UK
677 of pointing in synchrony with others, and descriptions of pointing in the developmental
678 literature define pointing occurring in communicate contexts where copying or synchronous
679 action is not typical. We acknowledge that in a communicatory context a complementary
680 pointing action may be used to clarify a specific referent, but a pointing bout is likely to end
681 once the goal of the gesture has been completed (i.e., once attention has been guided to a
682 referent). However, this is an empirical question that should be examined through naturalistic
683 observational, and future work should examine a broader range of behaviors and the social
684 contexts in which they occur in normal interaction. Indeed, this observational work could
685 inform specific predictions concerning imitation effects across actions, and allow further
686 testing of key predictions of an experiential approach. Further, to complement this ecological
687 approach to the development of imitative ability, experimental avenues could manipulate levels
688 of synchronous experience before testing imitative ability in children. This experimental
689 perspective has had some success in revealing the importance of experience in automatic
690 imitation in adults (Catmur et al., 2008; Press, Gillmeister, & Heyes, 2007), but this role in
691 children has yet to be thoroughly explored.

692 While early work in the field of developmental psychology presented a detailed
693 description of the development of imitation in infancy (Piaget, 1962), recent work on this
694 subject is sparse. It is crucial to consider developmental approaches to imitation as even an
695 innate imitative system must interact with the environment to generate adaptive behavioral
696 responses. From this perspective an associative model complements innate dispositions. In fact,
697 to account for the vast difference in imitative ability between humans and other animals (e.g.,
698 Whiten, Horner, & Marshall-Pescini, 2005) the ASL account must recognize innate differences
699 in motivation or attention to account for the unique routes human development takes (Heyes,

700 2012). The strength of a good theory rests on the reliability and validity of its predictions. There
701 is no doubt that the ASL model of imitation has need for further empirical support, but
702 converging evidence from cognitive (Heyes et al., 2005), neuroscientific (Catmur et al., 2008),
703 comparative (Range et al., 2011), and now developmental fields suggests that this model is
704 reliable in varied contexts. For a thorough understanding of the development of imitation,
705 future research should examine the predictive power of this model in younger children that are
706 still developing their imitative skills. This study marks a first step towards realizing that goal.

707

708

709

710

711

712

713

714

715

716

717

718

719

720 References

- 721 Anisfeld, M. (1996). Only tongue protrusion modeling is matched by neonates. *Developmental*
722 *Review, 161*, 149–161. doi: 10.1006/drev.1996.0006
- 723 Anisfeld, M., Turkewitz, G., Rose, S. A., Rosenberg, F. R., Sheiber, F. J., Couturier-Fagan, D.
724 A., ... Sommer, I. (2001). No compelling evidence that newborns imitate oral gestures.
725 *Infancy, 2*, 111–122. doi: 10.1207/S15327078IN0201_7
- 726 Bard, K. A. (2007). Neonatal imitation in chimpanzees (*Pan troglodytes*) tested with two
727 paradigms. *Animal Cognition, 10*, 233–242. doi: 10.1007/s10071-006-0062-3
- 728 Bates, D., Maechler, M., Bolker, B., Walker, S., Christensen, R. H. B., Singmann, H., ... Green,
729 P. (2015). Fitting linear mixed-effects models using lme4. *Journal of Statistical*
730 *Software, 67*, 1-48. doi:10.18637/jss.v067.i01
- 731 Boyer, T. W., Longo, M. R., & Bertenthal, B. I. (2012). Is automatic imitation a specialized
732 form of stimulus-response compatibility? Dissociating imitative and spatial
733 compatibilities. *Acta Psychologica, 139*, 440–448. doi: 10.1016/j.actpsy.2012.01.003
- 734 Brass, M., Bekkering, H., & Prinz, W. (2001). Movement observation affects movement
735 execution in a simple response task. *Acta Psychologica, 106*, 3–22. doi: 10.1016/S0001-
736 6918(00)00024-X
- 737 Brass, M., Bekkering, H., Wohlschläger, A., & Prinz, W. (2000). Compatibility between
738 observed and executed finger movements: comparing symbolic, spatial, and imitative
739 cues. *Brain and Cognition, 44*, 124–143. doi: 10.1006/brcg.2000.1225
- 740 Brass, M., & Heyes, C. (2005). Imitation: Is cognitive neuroscience solving the correspondence
741 problem? *Trends in Cognitive Sciences, 9*, 489–495. doi: 10.1016/j.tics.2005.08.007
- 742 Butterworth, G. (2003). Pointing is the royal road to language for babies. In S. Kita (Ed.),

- 743 *Pointing: Where language, culture, and cognition meet* (pp. 9–34). Mahwah, NJ:
744 Psychology Press.
- 745 Catmur, C., Gillmeister, H., Bird, G., Liepelt, R., Brass, M., & Heyes, C. (2008). Through the
746 looking glass: Counter-mirror activation following incompatible sensorimotor learning.
747 *The European Journal of Neuroscience*, 28, 1208–1215. doi: 10.1111/j.1460-
748 9568.2008.06419.x
- 749 Catmur, C., Mars, R. B., Rushworth, M. F., & Heyes, C. (2011). Making mirrors: Premotor
750 cortex stimulation enhances mirror and counter-mirror motor facilitation. *Journal of*
751 *Cognitive Neuroscience*, 23, 2352–2362. doi: 10.1162/jocn.2010.21590
- 752 Catmur, C., Walsh, V., & Heyes, C. (2009). Associative sequence learning: The role of
753 experience in the development of imitation and the mirror system. *Philosophical*
754 *Transactions of the Royal Society of London. Series B, Biological Sciences*, 364, 2369–
755 2380. doi: 10.1098/rstb.2009.0048
- 756 Cochet, H., & Vauclair, J. (2010). Features of spontaneous pointing gestures in toddlers.
757 *Gesture*, 10, 86–107. doi: 10.1075/gest.10.1.05coc
- 758 Ferrari, P. F., Visalberghi, E., Paukner, A., Fogassi, L., Ruggiero, A., & Suomi, S. J. (2006).
759 Neonatal imitation in rhesus macaques. *PLoS Biology*, 4, e302. doi:
760 10.1371/journal.pbio.0040302
- 761 Field, A. (2016). *An adventure in statistics: The reality enigma*. London: Sage.
- 762 Field, T. M., Woodson, R., Greenberg, R., & Cohen, D. (1982). Discrimination and imitation of
763 facial expression by neonates. *Science*, 218, 179–181. doi: 10.1126/science.7123230
- 764 Fontaine, R. (1984). Imitative skills between birth and six months. *Infant Behavior and*
765 *Development*, 7, 323–333. doi: 10.1016/S0163-6383(84)80047-8

- 766 Fox, J., Weisberg, S., Adler, D., Bates, D., Baud, G., Ellison, S., ... Rip-, B. (2016). Package
767 "car": version 2.1-3 [computer software]. Retrieved from [https://cran.r-](https://cran.r-project.org/web/packages/car/car.pdf)
768 [project.org/web/packages/car/car.pdf](https://cran.r-project.org/web/packages/car/car.pdf)
- 769 Gerstadt, C. L., Hong, Y. J., & Diamond, A. (1994). The relationship between cognition and
770 action: performance of children 3 ½ -7 years old on a Stroop-like day-night test.
771 *Cognition*, 53, 129–153. doi: 10.1016/0010-0277(94)90068-X
- 772 Gillmeister, H., Catmur, C., Liepelt, R., Brass, M., & Heyes, C. (2008). Experience-based
773 priming of body parts: a study of action imitation. *Brain Research*, 1217, 157–70. doi:
774 10.1016/j.brainres.2007.12.076
- 775 Hayes, L. A., & Watson, J. S. (1981). Neonatal imitation: Fact or artifact? *Developmental*
776 *Psychology*, 17, 655–660. doi: 10.1037/0012-1649.17.5.655
- 777 Heimann, M., Nelson, K., & Schaller, J. (1989). Neonatal imitation of tongue protrusion and
778 mouth opening: methodological aspects and evidence of early individual differences.
779 *Scandinavian Journal of Psychology*, 30, 90–101. doi: 10.1111/j.1467-
780 9450.1989.tb01072.x
- 781 Heyes, C. (2010). Where do mirror neurons come from? *Neuroscience and Biobehavioral*
782 *Reviews*, 34, 575–83. doi: 10.1016/j.neubiorev.2009.11.007
- 783 Heyes, C. (2011). Automatic Imitation. *Psychological Bulletin*, 137, 463–483. doi:
784 10.1037/a0022288
- 785 Heyes, C. (2012). What's social about social learning? *Journal of Comparative Psychology*,
786 126, 193–202. doi: 10.1037/a0025180
- 787 Heyes, C., Bird, G., Johnson, H., & Haggard, P. (2005). Experience modulates automatic
788 imitation. *Cognitive Brain Research*, 22, 233–40. doi:

789 10.1016/j.cogbrainres.2004.09.009

790 Heyes, C., & Ray, E. (2000). What is the significance of imitation in animals? *Advances in the*
791 *Study of Behavior*, 29, 215–245. doi: 10.1016/S0065-3454(08)60106-0

792 Hommel, B. (2004). Event files: Feature binding in and across perception and action. *Trends in*
793 *Cognitive Sciences*, 8, 494–500. <http://doi.org/10.1016/j.tics.2004.08.007>

794 Horner, V., & Whiten, A. (2005). Causal knowledge and imitation/emulation switching in
795 chimpanzees (*Pan troglodytes*) and children (*Homo sapiens*). *Animal Cognition*, 8, 164–
796 181. doi: 10.1007/s10071-004-0239-6

797 Jones, S. S. (2007). Imitation in infancy: The development of mimicry. *Psychological Science*,
798 18, 593–9. doi: 10.1111/j.1467-9280.2007.01945.x

799 Jones, S. S. (2009). The development of imitation in infancy. *Philosophical Transactions of the*
800 *Royal Society of London. Series B, Biological Sciences*, 364, 2325–35. doi:
801 10.1098/rstb.2009.0045

802 Kita, S. (Ed.). (2003). *Pointing: where language, culture, and cognition meet*. Mahwah, NJ:
803 Psychology Press.

804 Kokkinaki, T., & Kugiumutzakis, G. (2000). Basic aspects of vocal imitation in infant-parent
805 interaction during the first 6 months. *Journal of Reproductive and Infant Psychology*,
806 18, 173-187. doi: 10.1080/713683042

807 Kokkinaki, T., & Vitalaki, E. (2013). Exploring spontaneous imitation in infancy: A three
808 generation inter-familial study. *Europe's Journal of Psychology*, 9. doi:
809 10.5964/ejop.v9i2.506

810 Lodder, P., Rotteveel, M., Elk, M. Van, Alejandro, E., Paolo, D., Alejandro, E., & Paolo, D.
811 (2014). Enactivism and neonatal imitation: conceptual and empirical considerations and

- 812 clarifications. *Frontiers in Psychology*, 5, 1–11. doi: 10.3389/fpsyg.2014.00967
- 813 Masur, E. F., & Rodemaker, J. E. (1999). Mothers' and infants' spontaneous vocal, verbal, and
814 action imitation during the second year. *Merrill-Palmer Quarterly*, 3, 392–412. doi:
815 10.1016/j.infbeh.2008.04.005
- 816 McGuigan, N., Whiten, A., Flynn, E., & Horner, V. (2007). Imitation of causally opaque versus
817 causally transparent tool use by 3- and 5-year-old children. *Cognitive Development*, 22,
818 353–364. doi: 10.1016/j.cogdev.2007.01.001
- 819 Meltzoff, A. N. (1996). The human infant as imitative generalist: A 20-year progress report on
820 infant imitation with implications for comparative psychology. In C. M. Heyes & B. G.
821 Galef (Eds.), *Social Learning in Animals* (pp. 347–370). New York, NY: Academic
822 Press. doi: 10.1016/b978-012273965-1/50017-0
- 823 Meltzoff, A. N., & Moore, M. (1997). Explaining facial imitation: A theoretical model. *Early*
824 *Development and Parenting*, 6, 179–192. doi: 10.1002/(SICI)1099-
825 0917(199709/12)6:3/4<179::AID-EDP157>3.0.CO;2-R
- 826 Meltzoff, A. N., & Moore, M. (1977). Imitation of facial and manual gestures by human
827 neonates. *Science*, 198, 75–78. doi: 10.1126/science.198.4312.75
- 828 Meltzoff, A. N., & Moore, M. (1983). Newborn infants imitate adult facial gestures. *Child*
829 *Development*, 54, 702–9. doi: 10.2307/1130058
- 830 Mui, R., Haselgrove, M., Pearce, J., & Heyes, C. (2008). Automatic imitation in budgerigars.
831 *Proceedings of the Royal Society of London. Series B, Biological Sciences*, 275, 2547–
832 53. <http://doi.org/10.1098/rspb.2008.0566>
- 833 Myowa-Yamakoshi, M., Tomonaga, M., Tanaka, M., & Matsuzawa, T. (2004). Imitation in
834 neonatal chimpanzees (*Pan troglodytes*). *Developmental Science*, 7, 437–442. doi:

- 835 10.1111/j.1467-7687.2004.00364.x
- 836 Nagy, E., Compagne, H., Orvos, H., Pal, A., Molnar, P., Janszky, I., ... Bardos, G. (2005).
837 Index finger movement imitation by human neonates: Motivation, learning, and left-
838 hand preference. *Pediatric Research*, 58, 749–753. doi:
839 10.1203/01.PDR.0000180570.28111.D9
- 840 Nagy, E., Pilling, K., Orvos, H., & Molnar, P. (2013). Imitation of tongue protrusion in human
841 neonates: Specificity of the response in a large sample. *Developmental Psychology*, 49,
842 1628–1638. doi: 10.1037/a0031127
- 843 Nehaniv, C. L., & Dautenhahn, K. (2002). The Correspondence Problem. In C. L. Nehaniv & K.
844 Dautenhahn (Eds.), *Imitation in animals and artifacts* (pp. 41–61). Cambridge, MA:
845 MIT Press.
- 846 Nielsen, M., & Dissanayake, C. (2004). Pretend play, mirror self-recognition and imitation: a
847 longitudinal investigation through the second year. *Infant Behavior and Development*,
848 27, 342–365. doi: 10.1016/j.infbeh.2003.12.006
- 849 Oostenbroek, J., Slaughter, V., Nielsen, M., & Suddendorf, T. (2013). Why the confusion
850 around neonatal imitation? A review. *Journal of Reproductive and Infant Psychology*,
851 31, 1–14. doi: 10.1080/02646838.2013.832180
- 852 Oostenbroek, J., Suddendorf, T., Nielsen, M., Redshaw, J., Kennedy-Costantini, S., Davis, J., ...
853 Slaughter, V. (2016). Comprehensive longitudinal study challenges the existence of
854 neonatal imitation in humans. *Current Biology*, 26, 1334–1338. doi:
855 10.1016/j.cub.2016.03.047
- 856 Papousek, M., & Papouskek, H. (1989). Forms and functions of vocal matching in interactions
857 between mothers and their precanonical infants. *First Language*, 9, 137–157. doi:
858 10.1177/014272378900900603

- 859 Pawlby, S. (1977). Imitative interaction. In H. Schaffer (Ed.), *Studies in mother-infant*
860 *interaction* (pp. 203–233). London, UK: Academic Press.
- 861 Piaget, J. (1962). *Play, dreams and imitation in childhood (Translation)*. New York, NY:
862 Norton.
- 863 Press, C., Gillmeister, H., & Heyes, C. (2007). Sensorimotor experience enhances automatic
864 imitation of robotic action. *Proceedings of the Royal Society B: Biological Sciences*,
865 *274*, 2509–14. doi: 10.1098/rspb.2007.0774
- 866 Prinz, W. (1997). Perception and action planning. *The European Journal of Cognitive*
867 *Psychology*, *9*, 129–154. doi: 10.1080/713752551
- 868 Range, F., Huber, L., & Heyes, C. (2011). Automatic imitation in dogs. *Proceedings of the*
869 *Royal Society of London. Series B, Biological Sciences*, *278*, 211–7. doi:
870 10.1098/rspb.2010.1142
- 871 Ray, E., & Heyes, C. (2011). Imitation in infancy: The wealth of the stimulus. *Developmental*
872 *Science*, *14*, 92–105. doi: 10.1111/j.1467-7687.2010.00961.x
- 873 Repp, B. H. (1987). The sound of two hands clapping: An exploratory study. *The Journal of the*
874 *Acoustical Society of America*, *81*, 1100–1109. doi: 10.1121/1.394630
- 875 Simpson, A., & Riggs, K. J. (2011). Under what conditions do children have difficulty in
876 inhibiting imitation? Evidence for the importance of planning specific responses.
877 *Journal of Experimental Child Psychology*, *109*, 512–24. doi:
878 10.1016/j.jecp.2011.02.015
- 879 Simpson, A., Riggs, K. J., Beck, S. R., Gorniak, S. L., Wu, Y., Abbott, D., & Diamond, A.
880 (2012). Refining the understanding of inhibitory processes: how response prepotency is
881 created and overcome. *Developmental Science*, *15*, 62–73. doi: 10.1111/j.1467-

882 7687.2011.01105.x

883 Simpson, E. A., Murray, L., Paukner, A., & Ferrari, P. F. (2014). The mirror neuron system as
884 revealed through neonatal imitation: Presence from birth , predictive power and
885 evidence of plasticity. *Philosophical Transactions of the Royal Society B: Biological*
886 *Sciences*, 369, 20130289. doi: 10.1098/rstb.2013.0289

887 Stürmer, B., Aschersleben, G., & Prinz, W. (2000). Correspondence effects with manual
888 gestures and postures: a study of imitation. *Journal of Experimental Psychology: Human*
889 *Perception and Performance*, 26, 1746–1759. doi: 10.1037/0096-1523.26.6.1746

890 Tomasello, M., Carpenter, M., & Liszkowski, U. (2007). A new look at infant pointing. *Child*
891 *Development*, 78, 705–722. doi: 10.1111/j.1467-8624.2007.01025.x

892 Wood, C.C. & Jennings, J.R. (1976). Speed-accuracy tradeoff functions in choice reaction time:
893 Experimental designs and computational procedures. *Perception & Psychophysics*, 19,
894 92-102. doi:10.3758/BF03199392