

# **Comprehensive longitudinal study challenges the existence of neonatal imitation in humans**

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## Summary

Human children copy others' actions with high fidelity, supporting early cultural learning and assisting in the development and maintenance of behavioral traditions [1]. Imitation has long been assumed to occur from birth [2-4], with influential theories [e.g., 5, 6, 7] placing an innate imitation module at the foundation of social cognition (potentially underpinned by a mirror neuron system [8, 9]). Yet, the very phenomenon of neonatal imitation has remained controversial. Empirical support is mixed and interpretations are varied [10-16], potentially because previous investigations have relied heavily on cross-sectional designs with relatively small samples and with limited controls [17, 18]. Here we report surprising results from the most comprehensive longitudinal study of neonatal imitation to date. We presented infants ( $N = 106$ ) with nine social and two non-social models and scored their responses at one, three, six, and nine weeks of age. Longitudinal analyses indicated that the infants did not imitate any of the models, as they were just as likely to produce the gestures in response to control models as they were to matching models. Previous positive findings were replicated in limited cross-sections of the data, but the overall analyses confirmed these findings to be mere artefacts of restricted comparison conditions. Our results undermine the idea of an innate imitation module and suggest that earlier studies reporting neonatal imitation were methodologically limited.

## Results

Our study aimed to chart the prevalence, time course and social-cognitive correlates of neonatal imitation using a large sample and a comprehensive longitudinal design [18]. Infants ( $N = 106$ ) were presented with eleven models for 60 seconds each when the infants were one, three, six, and nine weeks of age. These models (see Figure 1) included four facial gestures (tongue protrusion, mouth opening, happy face, and sad face), two non-social objects simulating the facial gestures (a spoon protruding through a tube and a box opening), two hand gestures (index

finger protrusion and grasping), and three vocal gestures (*mmm*, *eee*, and *click* sounds). We scored the number of times the infants displayed each of the nine facial, hand, and vocal gestures when viewing the models (see Table S1 for coding guidelines and inter-rater reliabilities). Unlike in other studies of neonatal imitation, this allowed us to compare the frequency of infants' behavior that matched the model with the frequencies of that same behavior in response to 10 different control models. Imitation would be evident if matching responses (e.g., infant makes tongue protrusions while viewing a tongue protrusion model) were more frequent than non-matching responses (e.g., infant makes tongue protrusions while viewing a happy face model). We excluded from analyses all infants who were sleeping or crying during a testing session, resulting in a final sample of 64 infants for the longitudinal tests and a range of 77-90 infants for the cross-sectional tests (see Supplemental Experimental Procedures for further details).

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Insert Figure 1 about here

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For each gesture we ran a series of generalized linear mixed model (GLMM) analyses. The dependent variable for each series of GLMMs was the number of responses produced by the infants averaged over four 15-second trial periods for each gesture modelled. The fixed predictors of infant behavior included (i) the gesture modelled by the experimenter (i.e., the matching gesture or one of the 10 control gestures), (ii) the age of the infant at the time of testing, and (iii) the interaction of the previous two predictors (to account for any change in imitation over time). These full GLMMs were tested against simpler nested GLMMs: gesture and age only without the interaction term, gesture only, age only, and a null model containing no fixed effects (see Supplemental Experimental Procedures for more details and justification of these statistical analyses, and also details of the model selection process for each gesture).

Contrary to expectations, the longitudinal analyses failed to uncover any evidence for imitation of any of the nine social gestures (see Figure 2). Specifically, for three gestures (mouth opening, sad face, and *eee* sound), there were no differences between the frequencies of the gestures in response to the matching models versus the control models and no changes in the frequencies of the gestures over time. For three other gestures (index finger protrusion, grasping, and *click* sound), the infants' likelihood of producing the gestures changed linearly over time but the type of model was not an informative predictor of their behavior. For the final three gestures (tongue protrusion, happy face, and *mmm* sound), both time and model (but not their interaction) were predictors. However, although the infants produced these gestures significantly more often when the model demonstrated them than when she demonstrated some control gestures, there were no significant differences when compared to other control gestures (see Table 1). These null results were evident even before applying Bonferroni corrections to control for familywise error rate (comprehensive longitudinal results are reproduced in Tables S2 and S3).

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Insert Figure 2 & Table 1 about here

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Since tongue protrusion has produced the most consistent evidence for neonatal imitation in the literature [14, 19], we present a separate detailed summary of this gesture across conditions in Figure 3. At each time point only about half of the infants (46.7-64.2%) produced any tongue protrusions in response to the tongue protrusion model (see Figure S4), and there was no sign of intra-individual consistency of such responses (i.e., response frequency correlations across the four time periods ranged from -.08 to .28). More of the control comparisons for tongue protrusion were significant than for any other gesture (see Table 1). Yet, across time points, the frequency of infant tongue protrusion responses to the tongue protrusion model did not significantly differ from the frequencies of such responses to the mouth opening, happy face, and

sad face models. Thus, there is no evidence infants were imitating the specific model. One may speculate about whether active faces in general may trigger a tongue protrusion response, but this begs the question of why infants did not respond in a similar manner to the vocal gestures.

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Insert Figure 3 about here

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The overall longitudinal results contradict previous reports of neonatal imitation. Nonetheless, our data do indeed replicate key cross-sectional findings, while confirming these results to be artefacts of restricted comparison conditions. When we used the most common cross-sectional procedure of comparing infants' tongue protrusions in response to the tongue protrusion model with their tongue protrusions to the single control model of mouth opening [2], for example, we found that infants were significantly more likely to produce matching responses than non-matching responses at one week,  $t(73) = 2.25, p = .028$  ( $n = 74$ ), and nine weeks of age,  $t(88) = 3.24, p = .002$  ( $n = 89$ ). This need not mean that the infants imitated the tongue protrusion model at these ages, however, as the effect does not hold across all control comparisons. When we used the happy face as the control model, for instance, there were no significant cross-sectional effects at any age, all  $t < 1.62, p > .11$ . More broadly, across nine gestures and four time points (36 total cross-sections of data), there were 15 occasions on which the infants produced the gesture matching the model significantly more often than to at least one control model. On no occasion, however, did the infants produce the gesture matching the model significantly more often than to *all* control models, even without applying Bonferroni corrections (see Table S4). Since there is no widely accepted *a priori* reason to choose one control model over another, even our cross-sectional results do not provide any evidence for a true imitation effect. Yet, if we had obtained or analyzed a less comprehensive dataset (as has been done in previous studies) then we may have been impelled to conclude otherwise.

## Discussion

Given the methodological strengths of the current study compared to previous studies [18], our results suggest that the many prominent theories built upon the assumption of neonatal imitation [e.g., 5, 6, 7] are not empirically supported and should be modified or abandoned altogether. To continue defending the phenomenon in light of our findings would require the non-parsimonious and empirically intractable assumption that infants produce the same amounts of certain gestures (e.g., tongue protrusions, happy faces, and *mmm* sounds) to matching and non-matching models for different reasons (imitative and non-imitative). Previous studies reporting imitative effects appear to have been limited by inadequate controls and analyses, and/or the presence of outliers in small cross-sectional samples of infants. A few studies reporting null results like ours can be found in the literature [17], but many more may have been filed away due to publication bias [20, 21].

If neonates do not imitate, as our results suggest, then the age of first emergence for the phenomenon may actually be closer to 6 to 8 months of age [22]—around the time that Piaget [23] classically proposed. Such a developmental trajectory would challenge the idea of a specialized, nativist module for imitation [2, 5], and would instead favor the view of imitation as an emergent product of both native and environmental influences [14, 19, 24, 25]. One key driver of the nativist account was the discovery of mirror neurons in the macaque monkey [26], but it remains unclear whether these neurons are an innate adaptation for imitation and action understanding [8, 9] or a by-product of associative learning [27, 28]. Our results provide evidence against the innate view, and they also bring into question findings suggesting that macaques and other non-human primates engage in neonatal imitation [29, 30].

In summary, our comprehensive longitudinal study, contrary to expectations [18], has failed to uncover any evidence for imitation in human neonates. Instead, the results challenge the

existence of this long-debated phenomenon and prompt revision of a number of influential theories placing it at the foundation of social cognition.

## **Experimental Procedures**

**Subjects.** Participants included 106 healthy infants (51 girls, 55 boys). The infants were tested at four longitudinal time points when aged approximately one, three, six, and nine weeks ( $M = 1$  week, 4 days,  $SD = 2.49$  days;  $M = 3$  weeks, 4 days,  $SD = 3.06$  days;  $M = 6$  weeks, 2 days,  $SD = 2.96$  days,  $M = 9$  weeks, 3 days,  $SD = 4.42$  days). All parents/guardians gave informed consent for their children to participate, as approved by the ethics board of the School of Psychology at the University of Queensland.

**Materials and Method.** At each time point infants were presented with eleven modelled actions (in one of five orders), including four facial gestures (tongue protrusion, mouth opening, happy face, and sad face), two non-social objects simulating the facial gestures (a spoon protruding through a tube and a box opening), two hand gestures (index finger protrusion and grasping), and three vocal gestures (*mmm*, *eee*, and *click* sounds). Following previous work [3], the experimenter first modelled the relevant action for 15 seconds (5 times at 3 second intervals) before engaging in a passive position for 15 seconds. This process was then repeated such that the infants saw 30 total seconds of active modelling during each one-minute trial. All sessions were videotaped and infants' responses were coded by two scorers, one blind to the aims of the study (see Table S1 for coding guidelines). These coders scored the total number of each of the nine social gestures produced by the infants towards each of the eleven models, with these gesture frequencies then averaged over each 15-second trial period in which the infants were in a suitable arousal state for testing. Approximately 20% of the videos were coded by both scorers, with good levels of inter-rater reliability for all nine gestures (see Table S1). Comprehensive methodological details can be found in the Supplemental Experimental Procedures section.

**Author Contributions:** J.O., T.S., M.N. and V.S. designed the study; J.O. and S.K. tested the infants; J.O., S.K. and S.C. contributed to behavioral coding; J.R. and J.D. analyzed the data; J.O., T.S., M.N., J.R. and V.S. wrote the manuscript.

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## Figure and Table Legends

**Figure 1.** Gestures modelled to infants in imitation testing: (A) tongue protrusion, (B) mouth opening, (C) happy facial expression, (D) sad facial expression, (E) index finger protrusion, (F) grasping, (G) tube protrusion, and (H) box opening. Not represented are the three vocal gestures: *mmm*, *eee*, and *click* sounds. See also Table S1 for coding guidelines and inter-rater reliabilities.

**Figure 2.** Mean frequencies of responses per 15-second trial period to matching models (red lines) and control models (black lines) for nine different infant gestures over the first nine weeks of life. Note that the y-axes are not scaled consistently, as some gestures were produced at much lower frequencies than others. (See Figure 3 and Figures S1-S3 for more detailed graphs that distinguish between control models. See Tables S2 and S4 for results of the longitudinal and cross-sectional analyses for each gesture.)

**Figure 3.** Mean frequency of tongue protrusions (TPs) per 15-second trial period to the matched tongue protrusion model and the 10 control models. See also Figure S4, and Tables S2 and S3.

**Table 1. Summary of pairwise comparisons between matching and control models for infants' tongue protrusion, happy face, and *mmm* sound responses, collapsed across longitudinal time points.** For more details see Table S3.

**Table 1.**

Gesture produced by infants	Matching model > control model*	Matching model = control model	Matching model < control model*
Tongue protrusion	Tube protrusion Box opening Finger protrusion Grasping <i>MMM</i> sound <i>EEE</i> sound <i>CLICK</i> sound	Mouth opening Happy face Sad face	
Happy face	Tube protrusion Box opening Finger protrusion Grasping	Tongue protrusion Mouth opening Sad face <i>EEE</i> sound <i>CLICK</i> sound	<i>MMM</i> sound
<i>MMM</i> sound	Box opening	Tongue protrusion Mouth opening Tube protrusion Happy face Sad face Finger protrusion Grasping <i>EEE</i> sound <i>CLICK</i> sound	

\*  $p < .05$  (prior to Bonferroni correction)