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Neonatal imitation: Temporal characteristics in imitative response patterns

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Abstract

Neonatal imitation has been an area that has attracted intense attention within developmental psychology. Reported here are data from 33 newborn infants (16 girls; mean age: 47 hr) assessed for imitation of tongue protrusion (TP) and mouth opening (MO). The stimuli were presented dynamically, in three 20-second-long gesture modeling intervals, interwoven with three 20-second-long intervals in which the presenter kept a passive face. Imitation of TP emerged among a majority of the infants during the first 60 s of the experiment. In contrast, MO showed a protracted response and a majority exhibited imitation after 60 s. The individual response pattern of the participating infants varied substantially over the course of the experiment. The study provides renewed support for neonatal imitation of MO and TP, and, in addition, suggests that the temporal organization of the responses observed is an important factor to consider, which in turn has methodological and theoretical implications.

1 | INTRODUCTION

How we understand a newborn infant's behavioral capacities influences our theories of how the mind is formed and develops. Thus, there is no wonder that the issue of neonatal imitation has drawn intense interest within developmental psychology. Meltzoff and Moore (1977) published two studies in *Science* that discussed methods for assessing early imitation, effective eliciting conditions, and the

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three mechanisms that might underpin this early social competence. They reported imitation of three facial gestures (tongue protrusion [TP], mouth opening [MO], and lip protrusion) as well as manual imitation. This work was related to prior, less formal reports of early imitation (Gardner & Gardner, 1970; Maratos, 1973; Zazzo, 1957), but went beyond them in terms of methodological rigor and in describing the implications for the infants' representation of action and social cognition.

Meltzoff and Moore's findings motivated further empirical work testing neonates' imitative capacity, with results both confirming and extending their findings (e.g., Field, Woodson, Greenberg, & Cohen, 1982; Heimann & Schaller, 1985; Kugiumutzakis, 1998; Meltzoff & Moore, 1983a, 1989; Nagy, Pal, & Orvos, 2014; Nagy, Pilling, Orvos, & Molnar, 2013; Vinter, 1986) and in several unsuccessful studies (e.g., Hayes & Watson, 1981; Koepke, Hamm, Legerstee, & Russell, 1983), with the latter rebutted as having methodological problems (e.g., Meltzoff & Moore, 1983b).

Lately, interest in the existence and mechanisms of early imitation has intensified, as exemplified by the suggestion that early imitative responses are acquired through associative learning (Heyes, 2016) and a study which attempted a new design and reported null effects (Oostenbroek et al., 2016). However, Meltzoff, Murray et al. (2018) reported a detailed reanalysis of Oostenbroek et al.'s raw data, which revealed significant support for imitation of TP at 1, 3, 6, and 9 weeks, with an accompanying explanation for how the authors may have missed the pattern. Meltzoff, Murray et al. (2018) also presented five recommendations for future studies to consider in order to facilitate comparisons between findings: Limit the number of models used in within-subjects studies, allow sufficient time for neonates to visually process the display and organize their motor responses, have a good control of the physical environment in which the experiment is carried out, have a better control of the social environment (limit the infant's prior social interactions with the experimenter), and finally, use pilot testing to ensure that the methods used are suitable for the age tested (in their new design, Oostenbroek et al. used too many models in a within-subject procedure and 11 different displays, and some of the displays were motorically impossible for neonates to generate). These recommendations are relevant to the current study. Although the current study was carried out before these recommendations were codified by Meltzoff, Murray et al. (2018), many of these issues had been discussed in previously published papers on early imitation, and thus, we were able to capitalize on recommended "effective eliciting conditions" in designing the current study.

Theoretically, several mechanisms or explanations have been proposed of an early imitative capacity. Two dominant accounts are the active intermodal matching (AIM) mechanism (Meltzoff, 1990; Meltzoff & Moore, 1997) and various attempts to describe the neural underpinnings of early perception–action coupling (Ferrari et al., 2012; Marshall & Meltzoff, 2014). In addition, it has recently been suggested that the characteristics of newborn's imitative responses might fit an imprinting process (Bard & Nagy, 2017; Nagy & Molnar, 2004). According to the AIM account, newborn imitation does not entail a passive association. Instead, it is described as a "matching to target" process (Meltzoff & Moore, 1997, p. 180) and an "active attempt to adapt and gradually refine their own movements with respect to others" (Dumas, Kelso, & Nadel, 2014, p. 1). The imprinting hypotheses, in contrast, build on Nagy's (2011) arguments for viewing the neonatal period as a sensitive period for early imitation. According to this view, neonatal imitation serves a communicative purpose and is a response most easily elicited during the neonatal phase.

Bjorklund (1987) pointed out that an observed behavioral response in neonates can reflect several underlying processes, both hard-wired and voluntarily controlled. It might very well be the fact that early facial gestures in a neonate could reflect several processes such as a response pattern important for feeding, an increase due to arousal, and increases due to an active effort of the infant to match an adult's behavior. The last part, the voluntary response, is probably the most demanding process for the neonate, but we know that it is possible for newborns to guide their motor responses already during the first week of life (Rönnqvist & von Hofsten, 1994).

It has also been reported that it takes time for the neonate to organize a coherent response, and thus, if the displays and response measurement intervals are too brief, this may suppress the imitative responses (Holmlund, 1995; Meltzoff & Moore, 1983a, 1997). Heimann, Nelson, & Schaller (1989) found support for neonatal imitation during the first 60 s of the 150-s response period (in this study, the response period started after a 60-s baseline and a 40-s stimulus demonstration period). Moreover, Holmlund (1995) describes how 1-week-old infants orient and respond to an adult in a face-to-face situation. The infants "stay oriented for at least 20 seconds without activity in any part of the body. It seems that their attention has to remain focused for quite a long time for storing and identification processing" (Holmlund, 1995, p. 56). In line with this observation, Heimann (2002) stated that "a newborn child achieving reasonable matching does so in spite of the fact that many systems are immature" (Heimann, 2002, p. 81). Thus, it is possible that how different researchers design their experiments, for example, how the stimuli are presented, how long one waits for a response to occur, or how the data are collapsed might affect the results of any specific study (and may explain some of the divergent findings in the literature). Some of these issues are addressed in the current study, which focuses on two gestures, TP and MO, and how the newborn's responses emerge over time both when the dynamic stimuli are demonstrated and when the adult's face is passive during the "burst–pause" test paradigm. The methodology builds on our earlier study (Heimann et al., 1989) and the procedure proposed by Meltzoff and Moore (1983a), which was designed for newborn infants.

Neonatal imitation, as used in this paper, is defined on purely behavioral grounds. This implies that a neonate is judged to imitate a specific behavior, for example, MO, if the observed frequency of that behavior increases while watching an adult model that behavior in comparison with when an alternate behavior is modeled (e.g., TP). This "cross-model comparison" was introduced by Meltzoff and Moore (1977, 1983b, 1994) and has since then been used to define imitation in newborn infants in both recent (e.g., Nagy et al., 2013; Simpson, Murray, Paukner, & Ferrari, 2014) and earlier (e.g., Heimann, 1989; Meltzoff & Moore, 1983a, 1989; also see Meltzoff, Murray et al., 2018, for a recent update on how to measure neonatal imitation) publications. The cross-model comparison paradigm also implies, as pointed out by Meltzoff and Moore (1983b), that no assumption of the underlying mechanism is needed when judging if an infant imitates or not. Furthermore, "differential imitation neutralizes the arousal explanation" (Vincini, Jhang, Buder, & Gallagher, 2017, p. 14).

Opponents have suggested that what looks like an imitative response might be better explained through arousal processes or a coincidental match (Jones, 1996, 2017), an innate releasing mechanism (Anisfeld, 1996), as based on learning since a neonate does not have the cognitive capacity to "solve the correspondence problem that link self with other for imitation" (Heyes, 2016, p. 6), or as a response dependent on the aerodigestive system (Keven & Akins, 2017; but see Meltzoff 2017 and Simpson et al. 2017 for critiques of this view). More specifically, Heyes proposes that an associative learning model explains how and why our capacity to imitate develops, whereas Vincini et al. (2017) specifies an association by similarity process as most likely to explain early imitation. These opposing views, it should be noted, are not all compatible with one another; for example, the innate releasing view contradicts the idea of gradual associative learning and the claims that the effect is wholly reducible to arousal or artifacts.

In contrast, those interpreting the evidence in favor of an early imitative ability usually propose that neonatal imitation is an early socio-communicative skill (e.g., Meltzoff, 2007; Trevarthen, 2011). Neonatal imitation has been described as a starting state for the process leading up to theory of mind—Meltzoff's (2007) "Like-Me hypothesis," as an active communicative act (Nagy & Molnar, 2004) or as a first step in the development of intersubjectivity (Trevarthen, 2011; Trevarthen & Aitken, 2003). Furthermore, neonatal imitation has also been documented among non-human primates (Bard, 2007;

TABLE 1 Overview of the procedure: imitation of tongue protrusion and mouth opening was each observed separately during six intervals: three dynamic demonstrations when the target gesture was modeled (TP or MO; intervals 1, 3, and 5) intertwined with three passive-face periods (intervals 2, 4, and 6)

	Gesture A[a]							Gesture B[a]					
Interval	**1**	**2**	**3**	**4**	**5**	**6**	**Pause[b]**	**1**	**2**	**3**	**4**	**5**	**6**
Stimuli	Demo	Passive	Demo	Passive	Demo	Passive		Demo	Passive	Demo	Passive	Demo	Passive
Length (s)	20	20	20	20	20	20		20	20	20	20	20	20
Cumulative time (s)	20	40	60	80	100	120		20	40	60	80	100	120

[a]The order was counterbalanced: For half of the infants, TP was presented as the first gesture during the experiment, else MO was presented first.
[b]The length of the pause was 20–30 s or longer if the infant was not in an alert state.

Ferrari et al., 2006; Paukner, Simpson, Ferrari, Mrozek, & Suomi, 2014; Simpson et al., 2014), and studies on infant rhesus macaques suggest that neonatal imitation is important for later social development (Dettmer et al., 2016; Simpson, Miller, Ferrari, Suomi, & Paukner, 2016).

The main aim of this paper is not to discuss whether or not neonatal imitation is present at the population level, although this issue will also be addressed to some extent. Instead, the paper primarily aims at presenting new observations from a Swedish sample of newborns using a study designed to take into account the motor limitations of neonates and also one that was sensitive to possible individual differences among neonates. Several years ago, we reported replications of the findings of neonatal imitation and also introduced observations supporting the notion that individual differences in imitation are observable already during the neonatal period (Heimann, 1989; Heimann & Schaller, 1985; Heimann et al., 1989). These findings also suggested that imitation of TP was easier to elicit than imitation of MO and moreover that imitation is particularly salient after the infant observes the modeling and when the presenter is passive (Heimann, 1991, 2001, 2002; Heimann et al., 1989).

Thus, two hypotheses were formulated. First, we hypothesized that we would observe neonatal imitation of both TP and MO as evident by an increase in observed frequency when presenting the gesture (e.g., MOs when MOs are presented) as compared to observed frequencies when presenting an alternate gesture (e.g., MOs when TPs are presented). Formulating our expectations more precisely, we predicted that that the clearest evidence of neonatal imitation would occur not as an instant reaction but when the infant had had some time to organize a coherent response. Thus, we decided to split the analysis into different time windows, one early focusing on responses during the first minute and one late window covering responses emitted later. Second, building on Heimann et al.'s earlier studies, we hypothesized that imitative responses would occur primarily during the intervals in which the presenter kept a passive face rather than during the intervals when the stimuli were demonstrated dynamically. Third, for exploratory reasons but also building on earlier reports (e.g., Heimann, 1992; Heimann et al., 1989; Meltzoff & Moore, 1983a), we aimed at presenting observations on the infants' individual imitation pattern.

2 | METHODS

2.1 | Participants

Thirty-three newborn infants (16 females) were observed at 2 days of age ($M = 47$ hr; $SD = 22.9$), all recruited from the maternity ward at Sahlgrenska University Hospital, Gothenburg, Sweden. All newborns were healthy (Apgar score at 5 min: $M = 8.65$; $SD = 1.5$), full-term (mean gestational age = 40.3 weeks; $SD = 1.3$), and in a good clinical condition.

2.2 | Procedure

The test took place in a separate room at the maternity ward. All sessions began when the infant was judged to be awake and alert, and all observations included demonstration of two gestures: TP and MO. The order was counterbalanced: For half of the participants, MO was presented first, and for half, TP came first. The procedure for each gesture was 120 s long (see Table 1). The observation began by experimenter A (female) presenting the first gesture to the infant. Experimenter B controlled the video camera and the exact timing of the procedure; experimenter A did not know until the start of the procedure whethshe should present MO or TP (this verbal signal from experimenter B was absent from the edited videotapes for coding).

The aim was always to start the demonstration of a gesture at a time when the infant did not display any spontaneous mouth movements (no yawning, no obvious MO, or TP). For each gesture, the experimental procedure was broken up into six intervals of 20 s each (M = 20.1 s; SD = 3.1 when presenting TP and M = 20.3; SD = 3.1 for the MO part of the experiment) following the Meltzoff and Moore (1983a) "burst–pause" methodology, which alternated a demonstration period with a passive-face period: Three dynamic demonstrations of the stimuli (Demo intervals 1, 3, and 5) and three passive-face periods (intervals 2, 4, and 6) allowed the infant to build up a response. The mean number of times TP was presented during each demonstration period varied from 9.68 to 10.84 (SD = 3.39–3.97). For MO, the presentation frequency varied between 9.21 and 9.48 (SD = 2.01–2.59).

During the passive-face intervals, the experimenter kept eye contact with the infant but did not present any facial movement. There was a brief pause of about 20–30 s after 120 s, when the first gesture had been presented, in order to make sure that the infant was alert and ready for the next gesture.

During the test, the majority of the infants were securely supported on experimenter A's lap, while a few were supported in an infant chair in order to promote face-to-face interaction between the experimenter and the infant. The distance between the experimenter's face and the infant was approximately 25 cm during the session. For all subjects except one, the mother was present during the experiment. She was seated behind the infant (approximately at an angle of 45°) so that she could view the procedure but precluding any gaze contact between her and her infant while the gestures were presented. The mother was passive and silent throughout the experiment.

2.2.1 | Attrition

Of 73 families approached, 47 indicated that they were willing to participate. However, 11 mothers left the hospital earlier than planned, one mother changed her mind, and two infants were excluded due to drowsiness. Thus, acceptable observations exist for 33 newborns although some of them became tired or fussy during the experiment. A few of these 33 infants were excluded from part of the analysis due to fussiness or not spending enough time in an alert state during the whole observation period. Thus, the actual n varies from 33 during intervals 1 and 2 (the first 40 s of the experiment) to 26 for MO and 24 for TP during intervals 5 and 6 (the last 40 s of the experiment).

2.3 | Coding criteria and definition of imitation

2.3.1 | Tongue protrusion (TP)

The minimum criteria were that the tongue had to pass the posterior part of the lip. The minimum criterion was that a clear forward movement of the tongue was noted although the tongue was not protruded beyond the outer part of the lips. Responses associated with hiccups or strong bowel movements were not included in the analysis. This was true for both gestures.

2.3.2 | Mouth opening (MO)

Mouth opening was defined as a clearly visible separation of the lips, although the end state needed only to be a minor change (not exceeding the width of the lips). In order to be coded as a MO, no simultaneous protrusion of the tongue was accepted. Yawning was not included as an adequate MO response.

2.3.3 | Definition of imitation

Imitation was operationalized as a difference between gestures emitted when the target gesture was modeled as compared to responses observed when the non-target gesture was demonstrated. More specifically, this means that imitation of TP was measured by comparing the frequency of relevant tongue movements when TP was modeled (imitation condition) as compared to the frequency of when MO was modeled (control condition; see Meltzoff & Moore, 1983a, 1989, for a similar analysis). Similarly, imitation of MO was measured by comparing the frequency of relevant mouth movements as defined above when MO was modeled (imitation condition) with the frequency when TP was modeled (control condition).

2.3.4 | State

In addition to the above facial categories, independent coders also judged the infant's state from the obtained video recordings based on the following criteria (adopted from Theorell, Prechtl, Blair, & Lind,1973 and Wolff, 1987): State 1: quiet and/or active sleep or drowsiness; State 2: quiet awake, eyes open, no movements; State 3: active awake, eyes open, gross movements; and State 4: crying. State was monitored continuously, and only intervals when the infants had been judged to be in state 2 or 3 were included in the final analysis.

2.3.5 | Reliability

All tapes were coded blind by four graduate students who were trained until they performed at a minimum level of 85 percent agreement. The coding entailed two behaviors (MO and TP) and state. The final overall agreement was calculated using Cohen's kappa (Cohen, 1992). The obtained reliability coefficients were $\kappa > 0.75$ for all measures.

2.4 | Ethics

The present study was conducted according to guidelines laid down in the Declaration of Helsinki, with written informed consent obtained from a parent or guardian for each child before any assessment or data collection. All procedures involving human subjects in this study were approved by the ethical committee at the University of Gothenburg, Sweden.

2.5 | Statistical analysis

The repeated-measures ANOVAs conducted for the main analyses were based on the observed frequencies of gestures produced divided by seconds for each time window, thus controlling for the unequal length of the time windows used. For the pre-analysis of the infants' looking pattern, Student's *t* test was used. An $\alpha \leq 0.05$ was used as a cutoff for statistical differences, and effect sizes are reported as η_p^2 for ANOVAs and as Cohen's *d* (Cohen, 1992) for Student's *t* test. SPSS (Statistical Package for the Social Sciences, version 23.0) was used for all statistical analyses.

3 | RESULTS

The result section is organized into four parts. The first part deals with pre-analyses presented for clarity reasons, while the three following parts present results pertinent to our hypotheses and aim:

TABLE 2 The mean length in seconds (s) of the three demonstration periods and the amount of time the infants were judged to be attentive to the model (looking toward the face) when the gesture was presented

	Demo intervals		Looking[a] (s)					
	Length in s		At model		Away			
Gesture modeled	*M*	*SD*	*M*	*SD*	*M*	*SD*	$p^b <$	*d*
Tongue protrusion	20.1	3.1	11.6	6.2	7.7	5.9	0.01	0.64
Mouth opening	20.3	3.1	12.4	5.5	6.5	4.4	0.01	1.18

[a]Not codable frames (e.g., eyes closed): on average 0.6 s for tongue protrusion and 1.4 s for mouth opening.
[b]Comparison between looking at model or away (*t* test).

Findings regarding neonatal imitation within different time windows are presented first followed by findings relevant to our second hypothesis stating that imitation would be more likely during the intervals in which the presenter keeps a passive face. Finally, imitative response patterns are presented.

3.1 | Pre-analysis

3.1.1 | Attention

The participating infants looked significantly more toward the model's face than looking away when any of the two gestures were modeled (see Table 2). The mean percentage of looking at the model was 61.1% when MO was dynamically presented and 57.7% when the model presented TP. An additional correlational analysis between looking time and observed imitative responses revealed no significant associations.

3.1.2 | Number of time windows

Although hypothesis 1 specified two time windows (within the first minute or during the second minute), this was changed before carrying out the final analysis based on the observation that few infants (<40%) imitated during the final 20 s of the experiment. Thus, the experiment was divided into three time windows: The first 60 s (time window 1), 60–100 s into the experiment (time window 2), and finally, the last 20 s of the experiment (time window 3).

TABLE 3 Imitation of *tongue protrusion* (TP): rate of TP per second after modeling of TP (TP Demo) compared with when mouth opening was modeled (MO Demo) during three different time windows

			Rate of TP/s				ANOVA (*p*-value)		
			TP Demo		MO Demo				
Time Window[a]	*N*	Interval[b]	*M*	*SD*	*M*	*SD*	C	*T*	C × *T*
1. Early, 0–60 s	30	1, 2 and 3	0.091	0.079	0.059	0.063	0.036	0.040	ns
2. Middle, 61–100 s	26	4 and 5	0.097	0.086	0.090	0.012	ns	ns	0.037
3. Late, 101–120 s	24	6	0.056	0.074	0.083	0.094	—	ns	—

Note: C: condition; *T*: time; C × *T* interaction.
[a]Only children judged to be alert within the complete time window are included in the analysis; thus, there is variation in *N*.
[b]Each interval is 20 s long.

TABLE 4 Imitation of *mouth opening* (MO): rate of MO per second after modeling of MO (MO Demo) compared with when tongue protrusion was modeled (TP Demo) during three different time windows

			Rate of MO/s				ANOVA (*p*-value)		
			MO Demo		TP Demo				
Time Window[a]	*N*	Interval[b]	*M*	*SD*	*M*	*SD*	*C*	*T*	C × *T*
1. Early, 0–60 s	31	1, 2 and 3	0.109	0.085	0.130	0.083	ns	ns	ns
2. Middle, 61–100 s	27	4 and 5	0.162	0.109	0.119	0.076	0.030	ns	ns
3. Late, 101–120 s	26	6	0.136	0.126	0.139	0.125	—	ns	—

Note: C: condition; *T*: time; C × *T* interaction.

[a]Only children judged to be alert within the complete time window are included in the analysis; thus, there is variation in *N*.

[b]Each interval is 20 s long.

3.2 | Responses within the three time windows (Hypothesis 1)

3.2.1 | Time window 1, the first 60 s

A 2 (condition: experimental/control) × 3 (intervals 1, 2 and 3) repeated-measures a significant main effect for imitation of TP, $F(1,29) = 4.857$, $p = 0.036$, $\eta_p^2 = 0.143$; see Table 3. The main effect for time was also significant ($F[2,28] = 3.605$, $p = 0.04$; $\eta_p^2 = 0.205$), while the condition x time interaction was not ($p = .277$). A comparable analysis of MO (see Table 4) during the first minute revealed no significant effects for imitation or for time or the interaction.

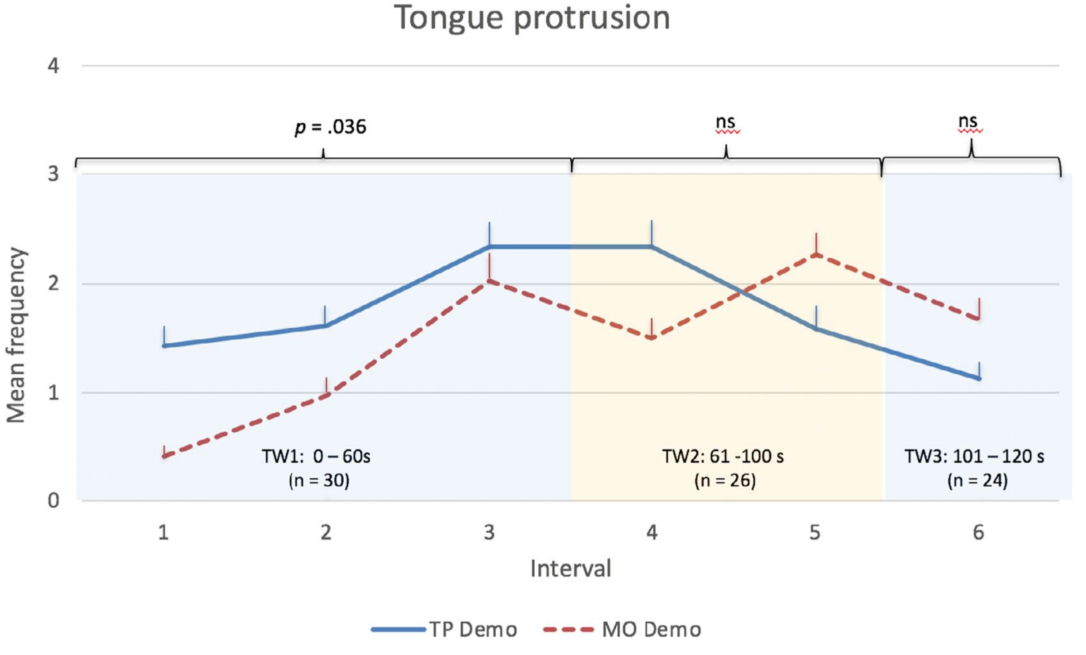

FIGURE 1 Mean frequencies (*Y*-axis) of *tongue protrusion* (TP) plotted over the six intervals constituting the three time windows (TWs) used in the main analysis. Observed frequency of TP when TP is demonstrated (TP Demo) is represented by a blue line and the mean frequencies of TP when mouth opening is demonstrated (MO Demo) is represented by the red line. Intervals 1, 3, and 5 represent active presentation of the gesture, while intervals 2, 4, and 6 depict periods when the experimenter keeps a passive face. Error bars = *SE*

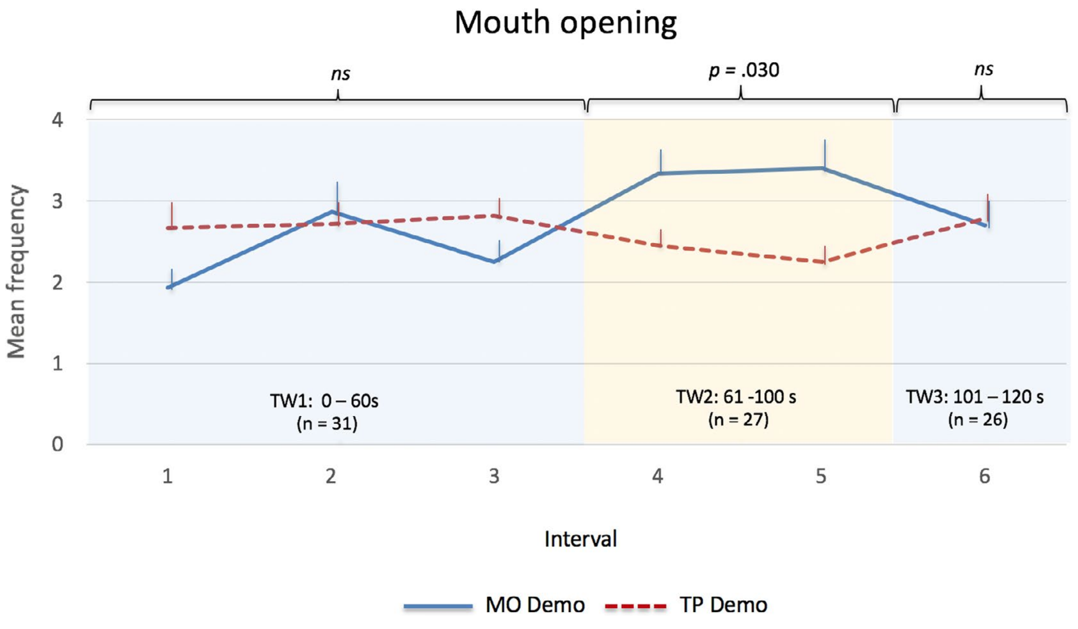

FIGURE 2 Mean frequencies (*Y*-axis) of *mouth opening* (MO) plotted over the six intervals constituting the three time windows (TWs) used in the main analysis. Observed frequency of MO when MO is demonstrated (MO Demo) is represented by a blue line and the mean frequency of MO when tongue protrusion is demonstrated (TP Demo) is represented by the red line. Intervals 1, 3, and 5 represent active presentation of the gesture, while intervals 2, 4, and 6 depict periods when the experimenter keeps a passive face. Error bars = *SE*

3.2.2 | Time window 2, 61–100 s

A 2 (condition: experimental/control) × 2 (intervals 4 and 5) repeated-measures ANOVA revealed no main effect of imitation of TP. Time was also non-significant, while the interaction condition × time was significant ($F(1,25) = 4.859$, $p = 0.037$, $\eta_p^2 = 0.163$). A closer inspection of the results suggests that this significant interaction reflects a tendency toward imitation of TP noted during the fourth interval ($p = 0.088$).

A similar analysis for MO revealed a different pattern. The main effect for imitation of MO was significant, $F\ (1,26) = 5.269$, $p = 0.030$; $\eta_p^2 = 0.169$; (see Table 4) but neither the effect of time nor the interaction condition × time.

3.2.3 | Time window 3 (TW3), 101–120 s

As evident from Tables 3 and 4, there was no indication of imitation of any of the two gestures during the final 20 s of the experiment. A visual illustration of how the infants changed their tendency to respond to the target gestures across the three different time windows is depicted in Figures 1 and 2.

3.3 | Comparing demonstration and passive-face periods (Hypothesis 2)

Comparing the mean frequencies across the three demonstration intervals with the three passive-face intervals (see Table 1 for the design) revealed a non-significant difference as a function of whether the display was currently in view or had just been demonstrated, for both MO and TP (see Table 5). The infants were as likely (or not likely) to open their mouth or protrude their

TABLE 5 Mean frequencies across the three Demo and the three passive-face intervals for *tongue protrusion* during the tongue protrusion part of the experiment and for *mouth opening* during the mouth opening part of the experiment

		Intervals					
		Demo[b]		Passive face[c]			
Behavior	*N*[a]	*M*	*SD*	*M*	*SD*	*t*	*p*
Tongue protrusion	24	1.97	1.63	1.79	1.27	−0.644	ns
Mouth opening	26	2.47	1.78	2.81	1.65	1.23	ns

[a]Only children with valid data within in all intervals are included in the analysis.
[b]Demo = intervals when the gesture is modeled.
[c]Passive = the experimenter keeps a passive face.

tongue when the experimenter kept a passive face as during the dynamic demonstration of the gesture.

3.4 | Individual response patterns (exploratory aim)

Imitation was also analyzed based on each infant's individual tendency to imitate or not imitate during the three time windows used in the analysis. As suggested by Meltzoff and Moore (1983a), a participating infant was judged to imitate a gesture if the frequency of that gesture in the imitation condition exceeded the frequency observed in the control condition. As evident from Table 6, more than half (53.3%) of the infants imitated TP during the first time window but less so during time windows two (42.3%) or three (29.2%). For MO, a strong majority imitated during time window two (66.7%), while only about one-third of the infants displayed an imitative response during time windows one or three.

TABLE 6 Number of infants displaying an imitative (+), non-imitative (−), or an equal response (0) pattern during the three time windows[a] in the experiment

		Individual response pattern					
		Imitation (+)[b]		Unclear (0)[b]		No imitation (−)[b]	
Time windows (TW)[a]	*N*	*n*	%	*n*	%	*n*	%
Tongue protrusion							
TW1	30	16	53.3	5	16.7	9	30.9
TW2	26	11	42.3	4	15.4	11	42.3
TW3	24	7	29.2	8	33.3	9	37.5
Mouth opening							
TW1	31	11	35.5	2	6.5	18	58.1
TW2	27	18	66.7	1	3.7	8	29.6
TW3	26	10	38.5	4	15.4	12	46.2

[a]TW1 = 0–60 s, TW2 = 61–100 s, and TW3 = 101–120 s, see text for detailed information.
[b]A plus (+) sign indicates imitation; a minus (−) sign indicates that the frequency of the target behavior is higher in the control condition, and a zero (0) indicates that the frequency is equal in both the imitation and control condition.

4 | DISCUSSION

Two hypotheses and one exploratory aim were formulated at the outset of the study: (a) That the infants were expected to display their strongest imitative response when they had had time to organize a coherent response, (b) that the strongest evidence for imitation would be found during the passive-face intervals, and finally (c) we also expected to describe individual variation patterns in imitation observed among the infants. Globally, we found support for neonatal imitation of TP during the first minute and for MO 1 min into the experiment, thus confirming our first hypothesis. In contrast, no support was found for hypothesis 2, the infants' imitative responses were not more common during the passive-face intervals overall, compared to the demonstration periods. Finally, the individual imitation patterns were found to vary strongly between the three defined time windows used in the analysis.

Support for an imitative response pattern was found for TP during the first time window (the first 60 s of the experiment), a finding in line with a large number of previous papers that have reported evidence for an ability to imitate TP (see summaries in Meltzoff & Moore, 1997; Meltzoff, Murray et al., 2018; Nagy et al., 2014; Simpson et al., 2014). It has also been proposed that evidence of an early imitative capacity exists for TP only (Anisfeld, 1996), but this is countered by our findings of neonatal imitation of MO as well.

The finding that imitation of TP was evidenced during the first time window was not according to our hypothesis. We had expected that the infants' imitative responses would build up over a longer time frame and that the strongest indication of imitation would be observed about 1 min into the experiment, an expectation not confirmed for TP (but was confirmed for MO). Regardless, our finding adds support to the many previous studies having found evidence of an imitative capacity in newborns (e.g., Heimann et al., 1989; Meltzoff & Moore, 1977, 1983a, 1983b; Nagy et al., 2013).

A different temporal response pattern was observed when the infants were faced with a model presenting MO. Here, no indication of imitation was detected during the first minute of the experiment. This seemingly supports the argument in the literature that imitation of MO is absent or more difficult to elicit (Anisfeld, 1996; Heyes, 2016; Oostenbroek et al., 2016). However, the picture changed after the first minute, and an imitative response pattern was observed during the middle time window, 61–100 s into the procedure, which is in accordance with our first hypothesis, namely that it might take some time for the infants to display imitation, as also suggested by a few previous papers (Heimann et al., 1989; Holmlund, 1995; Meltzoff & Moore, 1994). It has also been reported that infants often adjust their responses over time and that their responses become more precise over trials (Kugiumutzakis, 1998; Meltzoff & Moore, 1977, 1983a, 1994, 1997). In the current study, it took a full minute until the infants displayed a differential response indicating imitation of MO. This supports our expectation that infants this young are able to imitate MO and, in addition, the hypothesis that they need time to organize a coherent imitative response. This result, if upheld, also suggests that MO, as a specific response, takes longer time to organize for the newborn than TP. Although speculative, MO might be controlled differently than TP (e.g., proprioceptive information from lip and jaw movements may be different from simple tongue movements) and also be more prone to arousal fluctuations[1]. After the newborn period, MO might also be a more socially reinforced behavior (Murray et al., 2016; Rayson, Bonaiuto, Ferrari, & Murray, 2017) and be influenced by the speech and smile movements infants see in social interactions (Kuhl & Meltzoff, 1996; Meltzoff & Moore, 1994). Rayson et al. (2017) found that the mothers' mirroring of smiles and MO when the infant was 2 months predicted "infant motor system activity

[1]MO is, at least in our study, a more common behavior as evident by the overall higher mean frequencies compared to TP (but clearly, this depends on the response definitions adopted).

during observation of the same expressions at nine months" (Rayson et al., 2017, p. 1). Murray and colleagues also followed mother–infant dyads over the first 2 months finding that the degree of the mothers' mirroring increased over time and especially so for social behaviors such as mouth movements. These observations suggest that early infant behaviors and mirroring (and imitation on the infant's part) can be influenced by infant–parent face-to-face interactions as suggested for early imitative behaviors by Heimann (1989) and Meltzoff, Murray et al. (2018). These observations do not, however, explain why imitation of MO took a minute to manifest itself in the current newborn study, except inasmuch as the proprioceptive information may take some time to be used by young infants.

Our second hypothesis specified that imitation would be most strongly evidenced not when the experimenter demonstrated the gesture but instead during the passive-face periods. This prediction was not confirmed by the results. Comparing the total number of responses emitted when a gesture was dynamically presented with the responses during the passive-face intervals did not reveal any significant differences. This was true for both MO and TP. This suggests that our initial idea that infants imitate differently in these two situations—seeing the action or seeing a passive face—might be false. In retrospect, previous microanalyses of newborns' response profiles also reported imitation during both the stimulus demonstration and the passive-face intervals (e.g., Meltzoff & Moore, 1989). Thus, using the burst–pause procedure with 20-s intervals, the obtained effect seems to be a robust phenomenon. However, it might also be that longer passive-face period as for instance used in some other studies (e.g., Heimann et al., 1989; Nagy et al., 2013) would have been better suited to achieve support for our second hypothesis.

In order to understand more about the variability in imitation, we also explored the individual response patterns of the infants. This analysis revealed that the number of infants actually showing an imitative response varied between the different time windows used. The strongest indication of imitation was observed for MO during time window 2 when nearly 70% of the infants imitated. A similarly strong figure was not noted for TP. Even during the first time window, when the overall result was significant, only slightly more than 50% of the infants actually imitated TP. This kind of variation in newborn infant's proneness to imitate should not come as a surprise; several previous studies have reported on individual variations in neonatal imitation (Ferrari et al., 2009; Heimann & Schaller, 1985; Heimann et al., 1989; Meltzoff & Moore, 1983a, 1989; Nagy, Kompagne, Orvos, & Pal, 2007), and the causes and sequelae of individual differences are a topic of importance to pursue in future studies.

Imitation is a response that emerges from the interplay between what the newborn perceives (e.g., the adult demonstration), the infant state (motivational state, alertness, and attention), and what the infant selects to do (motor output). Thus, to imitate is a complex process that relies on several systems, many of which are immature at birth, for example, systems that controls vision, motivation, attention, and motor responses. Sometimes the outcome is a clear match between perception and action, and an imitative response is observed quickly. At other times, it takes some time for the infant to imitate, and sometimes there is no match at all and imitation is not observed. As a note for further studies, we found that the infants did not focus 100% on the experimenter's face when the gestures were demonstrated. In fact, they spent approximately 60% of their time looking at the experimenter and 40% of the time gazing away. It is not possible to evaluate what this pattern means but we suspect that gaze away might in part reflect periods when the infant is processing the information available, allowing time to prepare for a possible motor response. Such a pattern has been evidenced in older children (e.g., Previc, Declerck, & de Brabander, 2005).

Meltzoff and Moore (1997) and Heimann (2001, 2002) offered proposals about the role of experience in early imitation. According to Meltzoff and Moore (1997, p. 184) "infants move their limbs and facial organs in repetitive body play analogous to vocal babbling." The authors labeled this as "body babbling," and their AIM theory proposes that infant motor experience, specifically including prenatal movements, may play a major role in early imitation (Meltzoff & Moore, 1997). In fact, fetuses have been found to respond to some maternal vocalizations with related movements already at gestation week 25 (Ferrari et al., 2016). We suspect that newborns differ in how these patterned movement representations actually are constructed over time. Moreover, if "comparative processes between own movements and other movements are involved in neonatal imitation, and if prenatal differences in patterned movements exist, then this comparison must lead to different outcomes between children" (Heimann, 2002, p. 81). This development might then, in part, explain why individual newborn infants differ in their proneness to imitate at birth. If neonatal imitation can be elicited for both TP and MO, as the current findings suggest, it raises the issue about the neuropsychological mechanisms behind this ability.

Nagy (2011) has argued for a unique place in development for the neonatal period, being a stage defined by the transition from intrauterine to extrauterine environment representing a sensitive period and an "experience-expectant stage of development." More specifically, she highlights the first week of life, the perinatal period, as a moment in time when the infant might be especially prone to produce imitative responses (Nagy et al., 2013, 2014). In line with this, Nagy and Molnar (2004) have suggested that, since temporal cortex is immature at birth, it is likely that also subcortical structures are involved in imitation during the neonatal period. One such candidate is the superior colliculus (Bjorklund, 1987; Heimann et al., 1989; Vinter, 1986), a subcortical structure relatively mature at birth suggested to process multisensory information (Stein & Meredith, 1993; Stein & Stanford, 2013). A recent computational modeling experiment of the maturing superior colliculus successfully demonstrated how visual and somatotopic input could be combined through a multimodal visuotactile layer (Pitti, Kuniyoshi, Quoy, & Gaussier, 2013), but this computer modeling finding is suggestive at the most. A more common and probably also widespread theoretical account proposes that infant body representations may also play a role, as described by Meltzoff and Moore's (1997) AIM theory. Interestingly, there are emerging electrophysiological studies (EEG and MEG) documenting cortical body maps in infants as young as 60 days old (Marshall & Meltzoff, 2015; Meltzoff & Marshall, 2018; Meltzoff, Saby, & Marshall, 2018; Saby, Meltzoff, & Marshall, 2015), with arguments offered about how these neural body maps may link self and other in imitation (Meltzoff, Ramírez, et al., 2018). Taken together, it seems possible that several different processes, for example, prenatal experience, biological preparedness (e.g., a spatial representation of the body), and perceptual–motor skills all might contribute to the imitative capacity we observe in a newborn infant.

In conclusion, we interpret our findings in support of the AIM model proposed by Meltzoff (1990; Meltzoff & Moore, 1997) although other theories exist that might accommodate our results. An alternative theory of special interest is the idea of rapid learning based on a filial imprinting process as proposed by Nagy et al. (2014). Although our finding that for MO the infants needed a minute to build up an imitative response could be viewed as an instance of rapid learning, the AIM model is, in our view, still the most comprehensive theoretical framework for explaining neonatal imitation. Furthermore, we hypothesize that this system is mainly governed subcortically early in development. It also seems possible that early imitation processes rely more on distributed networks while later imitation will rely on more specialized circuitry as recently found for the development of working memory (Bathelt, Gathercole, Johnson, & Astle, 2017). Associative learning seems less plausible as an explanation of imitation in newborns, although it probably comes into play as a child's imitative ability or motivation to imitate develops over time. We view it as highly unlikely that a mechanism such as associative learning can explain the imitative response observed for newborn TP. The age of infants—only around 2 days—leaves little room for establishing a capacity for facial imitation through parent–infant interactions and parental training. This is especially true for the act of TP, a behavior not commonly observed within spontaneous social interactions between parents and their baby; tongue movements are rather seen as important for sucking in feeding situations during the neonatal period (Keven & Akins, 2017).

4.1 | Limitations

The sample size used in this study was not large, and the low N was further hampered by loss of infants due to changes in their state. That is, they moved from an alert state to drowsiness or sleep. Thus, we cannot exclude that our study, at least in part, suffers from low statistical power. Another limitation is the decision not to include a separate passive-face period prior to the demonstrations in which to collect baseline data. This decision was based on our aim to focus on the differential response between the two gestures and the fact that our participants were newborns with a limited window of awake time. Although useful, such baseline periods are probably more suitable for older infants. The within-group design used might also have introduced unwanted noise in the data since, as pointed out by Ullman (2016), there is a risk that representations that resemble each other create interference. A use of a wider range of gestures would also be useful. Nonetheless, by counterbalancing the demonstrations of the two facial gestures in the experiment and having second experimenter strictly controlling when to start and when stop presenting the gestures, we were able to conduct a study that focused on our key questions and was short enough to be tolerated by these young infants.

5 | CONCLUSION

Building on the methodology used in a seminal paper on newborn imitation (Meltzoff & Moore, 1983a), this study provides further support for the idea that human newborns have the capacity to match MO and TP gestures in an imitative-like fashion. However, our findings also provide useful details, texture, and refinements to the overall picture. First, whether imitation is observed depends partly on the time window used. This was true for both TP and MO, imitation being observed within different time windows for the two gestures (which may explain why some investigators, using brief test periods, have found it difficult to elicit MO using other designs). Second, we did not find support for our initial idea that neonates are more prone to imitate during the periods when the presenter kept a passive face, and finally, we note as several others have done before us (e.g., Heimann et al., 1989; Heimann, 2002; Meltzoff & Moore, 1983a; Simpson et al., 2014) a large variability in imitation among the infants. The causes and consequences of these individual differences are of great interest.

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CONFLICT OF INTEREST

The authors declare no conflicts of interest with regard to the funding source for this study.

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