

Review

The development of imitation in infancy

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An overview of existing data on imitation in infancy suggests that changes in the direction of imitation research are underway. The widely accepted view that newborn infants imitate lacks supporting evidence. Instead, existing data suggest that infants do not imitate others until their second year, and that imitation of different kinds of behaviour emerges at different ages. The evidence is consistent with a dynamic systems account in which the ability to imitate is not an inherited, specialized module, but is instead the emergent product of a system of social, cognitive and motor components, each with its own developmental history.

Keywords: imitation; infancy; human development; dynamic systems

The young child's ability to imitate the actions of others is an important mechanism for social learning—that is, for acquiring new knowledge. The child's ability to imitate is also important for what it tells us about the knowledge that the child already has. This article is concerned with when and how infants begin to imitate—that is, to voluntarily match the behaviours of others—and how the study of voluntary behavioural matching across the first 2 years might inform us about the development of motor, cognitive and social skills that are components of the ability to imitate.

To address these issues, I will review the research evidence on the imitative abilities of infants from birth to 2 years of age. The evidence will be used to evaluate two kinds of accounts of the origins of imitation. One is a nativistic account that derives from empirical reports of imitation by newborn infants. Reports of newborn imitation have been cited to support hypotheses about the origins and nature of imitation, including the hypothesis that imitation is a unitary competency—in the extreme, a dedicated behavioural module that could have evolved as a unit, can be inherited as a unit and may be shared as a unit by species with common ancestry (e.g. Myowa-Yamakoshi *et al.* 2004; Ferrari *et al.* 2006). Evidence of newborn imitation has also been cited as evidence that a specialized neurological mechanism underlies imitative behaviour in human infants and adults, and that this neurological mechanism—a 'mirror system'—is inherited (e.g. Iacoboni *et al.* 1999; Decety *et al.* 2002; Grezes *et al.* 2003; Iacoboni 2005; Iacoboni & Depretto 2006).

The second kind of explanation of the origins of imitation is not yet fully articulated, but is emerging

as a dynamic systems account (e.g. Thelen & Smith 1994; Gottlieb 2007). Recent data indicate that the ability to match the behaviours of others is not present at birth, but instead appears in the second year and continues to develop throughout infancy and beyond. The data also imply that there is no heritable, modular, specialized mechanism for imitation. Instead, imitative behaviour appears to emerge out of the infant's acquisition of different kinds of knowledge and motor, cognitive and social skills.

Two such different accounts of the development of imitation are possible because the literature contains both experimental data that are not consistent with one another and data that are consistent but open to different interpretations. The discussion that follows assumes that imitation is not something that we can directly observe. Instead, what we observe is one individual producing behaviour that matches the behaviour of another. There are many possible reasons why behaviours might match (e.g. Want & Harris 2002). Therefore, in this article, it is assumed that imitation is only one possible interpretation of behavioural matching and that other interpretations must often be considered.

I will begin with the newborn period. Reports of imitative abilities in newborns have shaped the rest of the research on imitation in infancy and influenced a number of scientific and non-scientific fields, from philosophy to neuroscience to robotics and beyond (e.g. Hurley & Chater 2005). Theories of how newborn infants might imitate the actions of others—in particular, the explanation in terms of a dedicated neurocognitive system—have caught the imaginations of scholars in an equally wide range of fields. Therefore, I will discuss newborn imitation—data and theories—in some detail.

1. DATA ON IMITATION IN THE NEWBORN PERIOD

In 1977, Meltzoff & Moore reported evidence that two- to three-week-old infants had imitated the

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behaviours of an adult model. This first formal study of newborn imitation was followed by many replications, most with even younger infants (e.g. Butterworth 1999; Meltzoff 2005). Although there have also been failures to replicate (e.g. Hayes & Watson 1981; McKenzie & Over 1983; Abravanel & Sigafos 1984; Anisfeld *et al.* 2001), there is now widespread agreement that newborn infants sometimes do match adult behaviours. The question is whether that behavioural matching is imitative or has another explanation.

Meltzoff & Moore (1977, 1983) have argued that newborn infants' matching of adult behaviour is imitative because it cannot be anything else. First, infants' matching behaviours cannot be learned responses, because their actions have not been matched or reinforced by others. Secondly, infants match a number of different behaviours, and it is unlikely that all could be evolved fixed action patterns. Finally, infants' behavioural matching cannot be because of increased general arousal, because increased arousal would affect multiple infant behaviours, not just the one that matched the modelled behaviour. If newborn behavioural matches are not learned behaviours, fixed action patterns, or the product of increased arousal, then they must be imitation.

That newborn infants imitate is an important claim in cognitive development because it argues strongly for a nativist stance on the origins of knowledge—the core issue in the field. Newborn imitation is only possible if infants inherit considerable knowledge about their own bodies and action capabilities and how those map onto the bodies and actions of others. Thus, it is important to ask whether the evidence that supports this claim is compelling or is open to alternative interpretation.

In newborn imitation experiments, infants are typically shown two different behaviours. In a large majority of cases, one of these is tongue protruding: almost as often, the other is mouth opening. Both behaviours are commonly produced by newborns outside of imitation experiments. In the experiments, however, it is reported that infants selectively increase their production of each behaviour over its baseline rate, after seeing that particular behaviour modelled (e.g. Meltzoff & Moore 1977, 1983).

It is vital to the imitation interpretation that the same infants selectively match two different behaviours in a single experiment, as an increase in only one behaviour might just reflect an increase in the infant's arousal (Meltzoff & Moore 1977). For example, Nagy *et al.* (2007) measured newborns' matching of index finger extension and found that females did more finger movements, responded faster and had higher heart rates than males. This combination of findings indicates that females were more highly aroused in the experiment than the males and suggests that this arousal accounts for females' greater frequency of finger movements.

Anisfeld (1996), see also Anisfeld (2005) examined 35 studies of newborn imitation, in 32 of which tongue protruding was one of the focal behaviours. He found that only tongue protruding was reliably matched by newborns in different studies and in different laboratories. If newborns match only one behaviour

in imitation experiments, then this matching may be a by-product of arousal and not imitation at all. Anisfeld (1996) proposed this relation: and in the same year, I reported data showing that infants increased their rates of tongue protruding when interested or aroused by stimuli (flashing coloured lights, dangling toys) that in no way resembled a human tongue-protruding model (Jones 1996).

In other studies, newborns have protruded their tongues in response to touches on the palm (Humphrey 1970), the sight of a looming and receding black pen or small ball (Jacobson 1979), the sight of a box with a bright blue lining opening and closing (Legerstee 1991) and short segments of the Barber of Seville Overture (Jones 2006). In the last of these studies, the experimental paradigm was the same as that commonly used in newborn imitation experiments, in which 20 s intervals of stimulation and no stimulation alternate. The pattern of results matched the pattern in imitation experiments very closely, suggesting that a tongue-protruding model and an interval of music play the same role in this paradigm: that is, both are arousing stimuli.

In short, tongue protruding is a common response of newborn infants to a range of interesting/arousing stimuli in different sensory modalities. Moreover, infants in Study 2 in Jones (1996) showed by their persistent looking that they found a tongue-protruding face interesting—in particular, more interesting than a mouth-opening face. It is likely, then, that tongue protruding to the sight of a tongue-protruding model is nothing more than infants responding as they usually respond to an interesting/arousing stimulus—and that the match between the infants' and model's actions is nothing more than a coincidence.

There are, of course, behaviours other than tongue protruding that newborn infants are said to imitate. After tongue protruding, mouth opening is the most commonly modelled behaviour. However, Anisfeld (1996) concluded from his meta-analysis of existing studies that infants do not reliably match mouth opening. Meltzoff & Moore (1977, Study 1) reported that infants also imitated pouting and sequential finger movements. In that report, the actual frequencies of infant behaviours were not provided. Instead, the data were adult judges' frequencies of correctly guessing which behaviour an infant in a film clip was watching. These data are difficult to interpret for two reasons: first, judges rank-ordered the four candidate behaviours for each film clip, and the experimenters counted both of the first two rankings equally. Thus, the chance that participants would guess correctly on each trial was 50 per cent. The judgements for sequential finger movements are especially difficult to interpret because they came from a different group of participants than the judgements for the other behaviours with which they are compared. Finally, no subsequent study has replicated the finding that either pouting or sequential finger movements are imitated by very young infants.

Newborns have also reportedly imitated head rotation (Meltzoff & Moore 1989), index finger movement (Nagy *et al.* 2007) and a variant on tongue protruding in which the tongue is directed to the side (Meltzoff & Moore 1994). None of these studies

has been replicated either, and the results of each can be explained in terms of different levels of infant arousal. As already stated, the index finger movements produced by infants in Nagy *et al.* (2007) are consistent with an arousal explanation—especially because the researchers actually found physiological signs of higher arousal in those infants who produced more finger movements. A closer look at Meltzoff & Moore's (1989) study of the imitation of head rotation shows that the newborns did not actually have to rotate their heads to be scored as having imitated. Instead, they had only to cross the midline with their noses. Infants' side-to-side head movements were more frequent in the head-rotating model condition than in a tongue-protruding model comparison condition in which infant tongue protruding was more frequent. This pattern of results would make sense if these infants, like those in Jones (1996), were interested/aroused by the tongue-protruding model and responded with tongue protrusions, but found the head-rotating model less interesting, so did not produce tongue movements, were more restless and so moved their heads more. Finally, Meltzoff & Moore's (1994) report that newborns imitated the specific direction of a model's tongue protrusions has been discussed in detail by Anisfeld (1996, 2005), who pointed out, among other criticisms, that in the measurement of change over trials in infants' tongue protruding to the side, 'sidedness' of the infants' tongue movements was entirely confounded with amplitude. Increased amplitude of tongue movements over trials would be expected if the infants' arousal increased over trials. This explanation of the results is consistent with evidence cited by Valenza & Bulf (2007, p. 494) that '... [visual] sensitivity to the directionality of motion is poorly developed before two months and may be absent in newborns'.

Meltzoff (2002, 2005) has provided three major arguments to rebut the critiques from Anisfeld (1996, 2005) and Jones (1996). (i) He suggests that the arousal view attributes special arousing properties to tongue protruding and predicts that tongue protruding should be the only behaviour imitated (Meltzoff 2002). In response, he points to the large number of studies reporting newborn imitation of a range of different behaviours. (ii) In both sources (Meltzoff 2002, 2005), the point is made that, whereas diffuse arousal would be expected to increase numerous behaviours, in fact infants specifically match the particular gestures they observe in the model. (iii) Finally, in Meltzoff (2002), evidence is cited to show that newborn imitation occurs in the absence of arousing stimuli: specifically, newborns imitate static facial poses, which are not arousing; and they imitate from memory—that is, when the putative source of arousal (the model's movements) is absent.

However, the arousal account of newborn tongue protruding is not directly addressed by some of these arguments, and evidence is lacking for others. In particular: (i) the arousal account as described by Jones (1996, 2006, 2007) attributes no special arousing properties to tongue protruding, and does not predict that tongue protruding should be the only behaviour that newborns imitate. Instead, the arousal account holds

that no behaviour is imitated by newborns, but that any sufficiently interesting/arousing stimulus, including a tongue-protruding model, can evoke infants' tongue-protruding response. Anisfeld's (1996) meta-analysis challenged the claim that newborn infants have imitated a range of different behaviours, concluding not that tongue protruding should be imitated, but that there was no clear evidence that newborns match any behaviour other than tongue protrusions. (ii) Jones' (1996, 2006) evidence, along with findings already in the literature, showed that stimulation in different modalities resulted not in diffuse arousal, but in an increase specifically in infants' tongue protruding. The disappearance of tongue protruding in response to toys with the onset of directed reaching (Jones 1996) suggests that tongue protruding might be a form of the same mouthing behaviour that characterizes oral exploration.

In response to (iii), the arousal account accommodates evidence that infants match static poses of tongue protruding and mouth opening (Meltzoff & Moore 1992), as these data are taken from six-week-old infants, and only from their first trial. At six weeks, the first sight of the tongue-protruding pose might be sufficiently interesting to elicit tongue protruding. Other evidence for 'imitating' static poses involves facial expressions of emotion (e.g. Field *et al.* 1982) that are species-typical, apparently innate behaviours and that a good deal of evidence suggests are readily but reflexively matched (e.g. Hess & Blairy 2001). Thus, to the extent that components of these faces may have been matched by infants, imitation is not the only likely mechanism. Finally, the arousal account explains tongue protruding after a model has ceased to tongue protrude, as arousal from the sight of the model's behaviour is not likely to disappear abruptly when the model stops moving (see Jones 2006 for an account of why infants in imitation experiments produce their matches when the model is passive).

In summary, newborn infants have repeatedly matched a human model's tongue protrusions in imitation experiments. Claims that newborns match other behaviours are not well supported by evidence. There is good evidence, however, that tongue protruding is a common response of newborn infants to a range of interesting/arousing stimuli and that a human model of tongue protruding is one such stimulus. Thus, it is likely that newborns' matching of tongue protruding in imitation experiments is not imitation, but an expression of the infant's interest in, or arousal by, the model's display of the same behaviour by which infants typically express interest or arousal.

It is possible that new, unambiguous evidence of human newborns' ability to imitate will be found in future. For the present, however, it seems fair to say that the evidence for the strong nativist claim that newborn infants do imitate is not compelling, and that we should proceed on the assumption that they do not.

2. NEWBORN IMITATION IN NON-HUMAN PRIMATES

In recent years, newborn imitation in chimpanzees (Myowa-Yamakoshi *et al.* 2004) and in rhesus

macaque monkeys (e.g. Ferrari *et al.* 2006) has been reported. Myowa-Yamakoshi *et al.* (2004) modelled mouth opening, tongue protruding and lip protrusion for two infant chimpanzees, following Meltzoff & Moore's (1977) procedure. The infants were tested twice weekly from their first to their 16th week. They saw each behaviour modelled for only 15 s at each test. The infants matched tongue protruding and mouth opening across their first eight weeks (lip protrusion was not reliably matched.) From 8 to 16 weeks, neither infant matched any modelled behaviours.

Ferrari *et al.* (2006) found behavioural matching in rhesus macaques for a very brief period soon after birth. The monkey infants were shown human models of mouth opening, lip smacking, tongue protruding, hand opening and eye opening. Testing occurred on days 1, 3, 7 and 14 after birth. The monkey infants saw each stimulus for only 20 s at each test. Subgroups of the infant monkeys matched lip smacking, tongue protruding or both on day 3. No other behaviour was matched on day 3, and there was no matching at all on any other test day.

As Myowa-Yamakoshi *et al.* (2004) comment, chimpanzees are not ready imitators: for example, adult chimpanzees immediately reproduce modelled actions only about 5 per cent of the time. It is not clear that adult rhesus macaques imitate at all (Visalberghi & Fragaszy 2002). Thus, the proposal that infants of these two species would immediately imitate behaviours they had seen modelled three or four times in 15 or 20 s is inconsistent with their apparent lack of ability to readily imitate at any later point in development. Clearly, something interesting is going on in these studies. The fact that all of the behaviours matched by newborns in all three primate species are mouth behaviours is striking and seems like a potent clue. In humans, the data show that tonguing is a common newborn response to interesting sights and sounds (e.g. Humphrey 1970; Jacobson 1979; Legerstee 1991; Jones 1996, 2006). The human data suggest that it would be valuable to ask how newborn chimpanzees and monkeys respond to stimuli that they find arousing, or more generally, what roles these mouth movements play in their everyday lives, to determine whether their behavioural matching can be explained without positing a mechanism for imitation that will not function beyond the newborn period.

3. THEORIES OF IMITATION IN THE NEWBORN PERIOD

An innate human ability to imitate would be strong evidence that specific knowledge can be inherited because imitation is only possible if a lot of knowledge is already in place. Imitation of tongue protruding and mouth opening, which the infant cannot see himself do, is especially dependent on a wealth of inbuilt knowledge. It is hard to imagine how the newborn could reproduce the seen movements of another with unseen movements of his own unless he already knew that he was the same kind of object as the object in his visual field, and that both had similar

parts laid out in similar locations. Additionally, he would have to know (at least):

- (i) how to identify and then locate his own body parts, and how to do both without visual guidance,
- (ii) the specific action capabilities of each of those parts, separately and in various combinations, and how to execute the different actions, and
- (iii) how his parts and actions mapped onto the parts and actions of the other object.

Clearly, a newborn infant could not know all of these things unless the knowledge was built in. But even with such built-in knowledge, the newborn could not imitate facial gestures unless he also had:

- (iv) reasonably good visual and proprioceptive perception,
- (v) the computational abilities required for object recognition,
- (vi) pretty good memory and representational abilities,
- (vii) amodal representational and/or intermodal matching abilities,

and—what is often overlooked,

- (viii) the motivation (some reason) to imitate.

An infant who imitates is testifying to his possession of all of these requisite kinds of knowledge and cognitive skills—and undoubtedly more. Attempts to explain newborn imitation have dealt with the implications of substantial inherited knowledge and precocious cognitive processing abilities in different ways.

(a) *Active intermodal matching*

In their models of newborn imitation, Meltzoff & Moore (1994, 1997) have posited the existence of the knowledge necessary for imitation and of the processes necessary for implementing that knowledge. As first presented, their model proposed that newborn infants were able to imitate others via a process of *active intermodal mapping* (AIM; Meltzoff & Moore 1977, 1983, 1994). The AIM hypothesis links the infant's perception of adult actions with the infant's own motor acts via the *supramodal representation of acts* and an *equivalence detector* that compares proprioceptive feedback from the infants' acts with the supramodal representations to achieve a match. Meltzoff & Moore (1997) subsequently proposed and described subcomponents of those three major components, to deal with questions concerning how a newborn might locate the right body parts to move, and generate the right pattern of movements of those parts. For example, within the supramodal representational system, subcomponents to represent and compare *organ relations* (configural relations among body parts) of infant and model were added.

The AIM model has been conceptually useful in the design of robots that can imitate (e.g. Breazeal & Scassellati 2002). However, as a model of a human psychological mechanism, it is somewhat abstract. Perhaps for this reason, there have been few empirical

studies testing aspects of the model, and those do not provide strong support. For example, the report (Meltzoff & Moore 1994) that newborns' reproductions of sideways directed tongue protrusions increase in amplitude and accuracy over time is cited as evidence for the feedback loop in the AIM model. However, as we have seen, this finding can also be explained by increasing arousal over time. Meltzoff & Borton (1979) reported evidence for intermodal transfer of information in data, indicating that four- to five-week-old infants transferred shape information from the somatosensory to the visual mode, but this study has been criticized by Maurer *et al.* (1999) as lacking important controls. When these controls were included, Maurer *et al.* (1999) failed to replicate Meltzoff & Borton's (1979) result. Kuhl & Meltzoff (1982) found that infants four and a half to five months of age looked longer at silent facial movements that matched specific vowel sounds they were hearing, again suggesting intermodal matching. However, by this age, the infants had had ample time to learn to associate the sight of faces articulating vowel sounds with the sounds themselves.

In general, then, it seems fair to say that research has not yet established the psychological reality of the AIM mechanism.

(b) *The human mirror system*

Recently, attention has turned to a new explanation of human imitative abilities as the output of a specialized mirror system. Neonatal imitation is cited as evidence that the human mirror system (HMS) is innate (e.g. Iacoboni *et al.* 1999; Decety *et al.* 2002; Grezes *et al.* 2003; Iacoboni 2005; Iacoboni & Depretto 2006). The mirror system in turn seems to offer a way to make newborn imitation feasible: the mirror system appears to bypass the requirement for precocious knowledge and cognitive abilities in newborn infants who imitate because the system itself embodies that knowledge. The HMS is thought to directly match visual input from an observed action—for example, a model's tongue protrusion—with a stored motor programme for the same behaviour (e.g. Decety *et al.* 2002; Rizzolatti 2005). If that motor programme is then executed, the result is imitation.

The idea of a mirror system specialized for imitation was suggested by the discovery of 'mirror' neurons in adult rhesus macaque monkeys. Single-cell recordings in the monkey's premotor cortex demonstrated that individual neurons responded whenever a particular action was either observed or performed by the monkey (Gallese *et al.* 1996; Rizzolatti *et al.* 1996). It is because mirror neurons appear to have both sensory and motor properties that some researchers see in them the potential for a straightforward, automatic and heritable mechanism for imitation in humans.

However, if human mirror neurons produce behavioural matching in newborns, they must differ substantially from the mirror neurons studied in the monkey. Monkey mirror neurons have been shown to discharge only for 'meaningful' goal-directed actions like reaching for food: they are not active during seemingly pointless actions like reaching when no object is

present (Umiltà *et al.* 2001). Thus, it appears that '...the activity of mirror neurons correlates with action understanding' (Rizzolatti & Craighero 2004, p. 174; see also Craighero *et al.* 2007). Evidence of action understanding is lacking for human newborns. In addition, the simple movements that newborns reportedly match seem to lack the goal-directed, meaningful qualities required to activate the mirror neurons found in the monkey. Thus, mirror neurons in the human newborn could not share this requirement for activation.

Mirror neurons have not yet been recorded in infant monkeys, so nothing is known about their development. However, evidence that adult monkey mirror neurons 'learn' to respond to previously neutral stimuli (Ferrari *et al.* 2005) suggests that monkey mirror neurons in general may similarly acquire their roles in post-natal development. However, in order to produce newborn imitation, some human mirror neurons would have to be pre-programmed without benefit of experience. Representations of simple motor movements like tongue protruding or mouth opening could be formed from the infant's production of these actions before birth (Meltzoff & Moore 1997). However, the infant would have no pre-natal opportunity to observe the same actions performed by others. Thus, the sensory component of the mirroring mechanism would have to be inherited.

Finally, caution in building on the proposal that human newborns do possess a pre-wired mirror neuron system seems advisable, given the documented immaturity of the ancillary abilities on which the functioning of such a system would have to rely. For example, the neonate would have to be able to see well enough to obtain adequate visual input to the mirror system. A large body of research (see Aslin 2001 for review) suggests that the newborn visual system, with its marked immaturities at both the peripheral and central levels, may not be up to the imitative task.

4. NEWBORN IMITATION: SUMMARY

A substantial number of studies have reported that newborn infants are able to imitate a range of simple behaviours (e.g. Meltzoff 2005). However, I have argued from this overview of the research to date that compelling evidence for newborn imitation is lacking. Methodological issues weaken the claims of many existing studies; and, although behavioural matching of tongue protruding in particular has been replicated many times, replication does not indicate the validity of the interpretation of that behavioural matching as imitation. In addition, the field has not yet built an empirical case for a plausible mechanism for newborn imitation. At the same time, new data and previously overlooked findings already in the literature support an arousal explanation of the limited newborn behavioural matching that does reliably occur.

Thus, while it is not possible to show that newborn infants cannot imitate, research has not established that they are capable of this complex form of behaviour. If newborn infants do not imitate, then there is

no evidence that the ability to imitate is innate, and an alternative to the nativist account of the nature and origins of imitation will have to be found. The sketch of one such alternative is emerging from data already accumulating on the imitative abilities of infants beyond the newborn period.

5. EVIDENCE ON IMITATION IN INFANCY BEYOND THE NEWBORN PERIOD

Research on infant imitation beyond the newborn period is patchy, with clusters of studies focusing on different theoretical issues. Many experiments have used imitation as a measure of other cognitive competencies, like memory, or the ability to detect and reason about factors affecting others' intentions and behavioural choices. Comparatively few studies have focused on imitation beyond the first two months, not as a measure of another cognitive competency, but as a phenomenon in its own right. Fewer still have focused on imitation of the specific actions measured in newborn imitation experiments. As a result, even the basic course of development is uncertain, as different studies provide widely differing pictures of the imitative abilities of infants at different ages. I will first discuss studies that address the developmental course of imitation through infancy. I will then proceed to studies of imitation as a measure of infants' memory, understanding and reasoning abilities. Together, these bodies of work show infants beginning to imitate different kinds of behaviour at different ages across the second year and suggest that such changes in infants' imitative abilities reflect changes in the component kinds of knowledge upon which imitation relies.

(a) *Evidence on the developmental course of imitation in infancy*

Studies of imitation beyond the newborn period have found little evidence of behavioural matching in the first year. Fontaine (1984) tested infants from two to six months of age for imitation of facial and manual gestures. He found (in line with the arousal hypothesis) that only tongue protruding and mouth opening were reliably elicited. Matching of these two behaviours diminished after the second month. Heimann *et al.* (1989) reported matching only of tongue protruding in infants seen at 2–3 days and three weeks. By three months of age, however, the same infants had stopped matching tongue protrusions.

Meltzoff & Moore (1992) suggested that two- to three-month-old infants are still capable of facial imitation, but prefer new kinds of social interactions. Jones (1996) provided a different view. Study 3 in Jones (1996) followed two male infants, subjects in a longitudinal study of the onset of reaching, weekly from three weeks of age. Each infant reliably produced tongue protrusions in response to dangling toys before he could reach, but stopped tongue protruding in the same week (different for each infant) in which he first successfully reached and grasped a toy. These findings suggested that tongue protruding and other mouthing movements are arousal responses that diminish as the infant develops more effective

responses to those stimuli—like reaching for and grasping objects and exploring them directly with mouth and tongue.

A number of studies of imitation in the first year have focused on infants' reproduction, not of observable actions, but of pre-verbal vocalizations during social interactions (e.g. Papousek & Papousek 1989; Masur & Rodemaker 1999; Kokkinaki & Kugiumutzakis 2000). These studies report that imitation of sounds is common during social interactions in the infant's first year—but it is the adults, not the infants, who are imitating. Kokkinaki & Kugiumutzakis (2000) made bi-weekly recordings of interactions between parents and their two- to six-month-old infants. Parents matched their infants' vocalizations about two to three times in each 10 min session. Infants, however, matched the behaviour of their parents only about once in every 20–30 min of interaction. This low rate of infant sound matching was probably owing to chance.

Pawlby (1977) studied imitation of all kinds of behaviour in eight infants weekly from about 4–10 months of age. As in Kokkinaki & Kugiumutzakis (2000), parents matched their infants' behaviours at several times the rate at which infants matched their parents. Because parents imitate infants' behaviours so frequently, the probability is high that an infant behaviour will match a parental behaviour by chance. Thus again, it is likely that infants' infrequent behavioural matches in Pawlby (1977) occurred by chance.

Abravanel *et al.* (1976) tested infants up to 15 months of age for their ability to imitate 22 simple acts. Production of modelled acts by 15-month-old infants exceeded spontaneous production of the same acts for only eight of the 22 actions. Thus, imitation was detectable, but not typical, at 15 months.

Masur (1998) and Masur & Rodemaker (1999) studied imitation at 10, 13, 17 and 21 months. The infants' produced less than one instance of apparent imitation on average during sessions at 10 and 13 months, but produced four or five instances on average at 17 and 21 months. Similarly, Nielsen & Dissanayake (2004) did not observe 'synchronic imitation' until 18–21 months of age.

Jones (2007) carried out a cross-sectional study of elicited imitation in infants from 6 to 20 months of age. In this study, mothers modelled simple behaviours for up to 3 min and encouraged their infants to imitate. The eight modelled behaviours included two from the newborn imitation literature—sequential finger movements and tongue protruding. The criterion for imitation of any behaviour at any age was that significantly more infants produced that behaviour while it was being modelled than produced it spontaneously during any of the seven conditions in which a different behaviour was modelled. Only one behaviour—making 'Aaah' sounds—met this criterion before the age of 12 months. The other seven behaviours met the criterion at different ages between 12 and 18 months. The two behaviours reportedly imitated by newborns—sequential finger movements and tongue protrusions—met the criterion for imitation at 16 and 18 months of age, respectively (Jones 2007).

Horne & Erjavec (2007) trained 1- to 2-year-old infants to match four behaviours modelled by the experimenters, then tested for infant matching of these four actions and four additional, untrained behaviours interspersed with the trained actions. None of the untrained behaviours was matched by the infants. The researchers then taught the infants to produce those four behaviours as responses to cues that did not resemble the behaviours, to ensure that the behaviours were in the infants' repertoires. Despite this training, the infants still did not imitate the target behaviours when they were modelled by the experimenters.

In summary, studies focusing directly on the frequencies with which infants imitate beyond the newborn period have tested for imitation of a wide range of behaviours, including intransitive actions, actions on objects and vocalizations. Despite giving infants ample opportunity, and in some cases active encouragement, to show their imitative abilities, these studies have consistently found little imitation before the second or third quarter of the second year.

(b) Imitation as a measure of infants' cognitive abilities

A large number of studies have used imitation as a measure of infant memory, or infants' ability to apprehend and reason about the intentions and constraints that affect the behavioural choices of others. In studies of 'deferred imitation', infants' behavioural matching is used to assess their memory for a model's actions after delays of varying lengths. Researchers familiar with studies of deferred imitation will recognize that they may well be studies of emulation learning rather than of imitation. 'Emulation' (Tomasello 1998; see also Tennie *et al.* 2009; Whiten *et al.* 2009) refers to behavioural matching that results from social learning, not of specific actions, but of the features and affordances of objects. Thus, for example, a child may learn from watching a model that the door on a doll house can be opened. His subsequent behaviour may match that of the model, not because his goal is to reproduce her actions, but because he too wants to open the door.

Meltzoff (1985) reported deferred imitation in 14-month-old infants who, having seen the experimenter pull apart two pieces of a wooden dumbbell, returned to the laboratory after a week's delay and pulled the dumbbell apart. These infants' actions may have reflected emulation learning—that is, learning that the object could be taken apart—rather than imitation.

In a subsequent study (Meltzoff 1988a), nine-month olds saw a different simple action on each of the three objects. Half of the infants in the experimental condition were said to have demonstrated deferred imitation because they reproduced two or three of the actions after a 24 h delay. However, although this study included conditions that controlled for stimulus enhancement owing to the adult's handling of the objects, there was no control for emulation learning. A total of six action-on-object demonstrations were shown to 14-month olds (Meltzoff 1988b). After a one-week delay, these infants reproduced the actions

at levels higher than chance. However, it is again likely that the infants did so because they had learned and remembered interesting features and affordances of the objects. (One of these six target actions is an exception, and the implications of infants' reproduction of this action will be considered below.)

Results throughout this literature are similarly indeterminate as to whether the infants' behavioural matches are imitation or emulation. For example, Barr and her colleagues have several times modelled a three-action sequence for infants and then measured the infants' production of those actions after a delay. The three actions are (i) removing a mitten from a puppet's hand, (ii) shaking the mitten to ring a bell inside, and (iii) replacing the mitten on the puppet's hand. Barr *et al.* (1996), using this sequence, reported deferred imitation by six-month-old infants after 24 h. However, 75 per cent of infants did only one action—removing the mitten; and the other 25 per cent did two—removing and shaking the mitten. To the extent that these already high-probability actions were made even more likely by a model, both could have reflected emulation learning that the mitten came off and made sounds, rather than imitation of the actions that revealed those features.

Several studies appear to support this interpretation. In designs that separate infants' performance of the same movements as the model from infants' achievement of the same outcome as the model, infants well into or beyond their second year do not imitate. Vallotton & Harper (2006) modelled the action of dropping a ball for infants from 7 to 27 months of age. The infants did not imitate the action: instead, most tried to reproduce the bounce by manually moving the ball up and down. Huang & Charman (2005) found that just showing actions to infants as old as 17 months was not enough to elicit performance of those actions. However, showing just *object* movements led the infants to produce actions that would produce those object movements.

Bauer *et al.* (2001) showed nine-month-old infants a number of sequences of two actions on objects at each of several laboratory visits about a week apart. The infants reproduced *none* of the actions after their first exposures. However, with successive visits, single action reproduction and then correct action sequences became more frequent. The fact that the increase in correct 2-action sequences lagged the increase in correct individual actions suggests that infants did not imitate the experimenters' actions, but learned over time to produce and combine specific actions to emulate the demonstrated outcomes. Support for this suggestion is found in Wenner & Bauer's (1999) report that infants up to 20 months of age perform at chance levels if given two-step sequences that do not exhibit 'enabling relations' in which one action makes the other action possible. If infants were imitating these simple actions, it is hard to imagine why the presence or absence of enabling relations between the actions would matter.

Meltzoff (1995) reported an experiment in which 18-month-old infants appeared to show understanding of a model's intentions by producing actions that matched, not what the model did, but what the

model intended to do. In this study, the model repeatedly slid a hand off the end of a wooden dumbbell as though trying, but failing to pull it apart. Infants pulled the object apart after watching this display. Bellagamba & Tomasello (1999) subsequently replicated this result with 18-month olds, though not with 12-month olds. Meltzoff (1995) argued that infants' performance of the model's intended actions demonstrated understanding of those intentions. However, Huang *et al.* (2002) were able to show that these findings could also be produced by non-imitative social learning.

In Meltzoff (1988*b*), 14-month-old infants saw the experimenter bend to tap a light box on the table with his or her forehead, and saw the light turn on. Infants this age have bent forward many times, but they have not turned on lights by tapping with their foreheads, and the probability that an infant would do so spontaneously must be very low. Thus, any infant who immediately reproduces this action is likely to be imitating. About two-thirds of the 14-month olds reportedly imitated the model. However, many of the infants were hampered by bulky clothing, and so were scored as imitating if they bent to within 10 cm of the light box but did not touch the box with their faces. Infants might have bent this far just to look through the translucent top of the box. Infants this age would also be likely to put their mouths to the light box with no thought of turning on the light. Thus, we do not know how many of the subjects in the study did turn on the light with any part of their faces—and of those, how many might have been imitating the model.

Infants who saw an experimenter produce both intentional and accidental behaviours on objects matched the intentional behaviours more often (Carpenter *et al.* 1998). Matching could have been either imitation or emulation. Accidental and intentional behaviours were distinguished for the infant only by the model's vocalizations—'There!' after intentional behaviours, 'Whoops!' after accidental behaviours. However, the researchers report that Whoops! was often accompanied by a slight jumping of the experimenter's upper body, intake of breath, a surprise face, etc. Thus, infants may have failed to match the model's 'accidental' behaviour because it was not intended, or because they were startled by her Whoops! and body language.

Gergely *et al.* (2002) report that 14-month-old infants not only imitate a model's behaviour, but imitate rationally. Specifically, they provide evidence that infants decide between imitation and emulation in Meltzoff's (1995) forehead/light task on the basis of their assessment of the model's motives and circumstances. When the model's hands are free, infants match her use of her forehead. When the model wraps her arms and hands in a blanket across her shoulders, infants do not match her use of her forehead, but tap the light with their hands. The authors argue that, when the model's hands are free, infants infer that tapping with her forehead is a free choice, and they therefore imitate. When the model's hands are occupied, the infants infer that she was forced to use her forehead, and therefore use their unencumbered hands to emulate.

Schwier *et al.* (2006) obtained similar results from 12-month-old infants in a different task. These infants saw a toy dog put through a 'chimney' in the top of a cardboard 'house'. A door in the side of the house was open in one condition, closed in the other. The door was always open in the test. Infants who saw a closed door in the demonstration put the dog through the door more often and through the chimney less often than infants who saw an open door during the demonstration. The authors infer that infants in the experiment believed that the dog's choice of chimney was free when the door was open, but forced when the door was closed, and that they chose to imitate the free choice.

These studies not only report imitation at quite young ages; they also view the infant's choice to imitate as a reflection of high-level cognitive processes. Thus, these experiments draw attention to the cognitive, social and motivational complexity of imitative behaviour. However, the case for rational imitation in infants could be made more compelling with additional evidence. First, replications that not only report the same outcome in the same paradigm, but also provide additional reporting of the infants' behaviours, would be desirable. For example, Gergely *et al.* (2002) employed the same behavioural measures as in Meltzoff's (1988*a,b*) original report, and it is again not clear whether infants in the two conditions differed in the probability that they would imitate the model, or just in the probability that they would look down into the light or mouth the light box and be credited with imitation. It seems possible that the apparent absence of arms and hands on the model might be reason enough to make the model in the hands-occupied condition more interesting to look at than the light, thus reducing the numbers of infants in that condition who bent to look into or mouth the light and were then counted as imitators.

The behaviour of the 12-month-old infants in Schwier *et al.* (2006) is consistent with the authors' attribution of rational imitation, but the same behaviour would be expected if the experimenter's act of opening the door in the box just before testing in the 'closed door' condition drew the infants' attention to the door and thus increased the probability that infants in this condition would put the toy through the door. Eliminating this and other alternative accounts in terms of moment-to-moment forces on infants' attention and perception would also strengthen the rational imitation interpretation.

Assuming that infants can be unambiguously shown to imitate more often when the model's behaviour is constrained, then the next step will be to show that—and explain why—the infants construct the specific chains of inference attributed to them and not any of a number of alternative inferences that could be made about the behaviour they witness. For example, in Gergely *et al.* (2002), we need to understand why infants would infer that the model could not release a hand to turn on the light if she wished. Also, we need to understand why infants' decision to imitate or not to imitate would depend on their analysis of the model's different motivations in the hands-occupied and hands-free conditions, and in

particular, why infants would imitate only unforced actions. These seem like important issues for investigation.

6. SUMMARY: THE DEVELOPMENT OF IMITATION BEYOND THE NEWBORN PERIOD

Research on changes in behavioural matching in infancy has not yet established a clear developmental trend. Some studies report evidence of strategic or 'rational' imitation by infants 12 and 14 months of age. Other studies show infants failing to imitate even simple modelled actions well beyond this age. Additional research designed to resolve these discrepancies is needed.

Along with conflicting results, there are many gaps in the descriptive record, with little information on behavioural matching at many age levels. And, as is true of the research on newborn imitation, there is a need for more empirical work on the mechanisms that researchers have proposed to account for the behavioural matching they report. Theoretical progress is currently hampered by the lack of both kinds of information.

7. GENERAL DISCUSSION

Developmental studies have repeatedly shown that even apparently stereotyped, species-typical behaviours have complex, often surprising developmental histories that involve both gene action and environmental influences, and multiple components interacting on multiple time scales at multiple epigenetic levels (e.g. Thelen & Smith 1994; Gottlieb 2007).

Imitation, which requires a long list of different kinds of knowledge and cognitive and social skills, is probably no exception. However, research on imitation in infancy has been strongly influenced by preformationism—the view that development is the growth of pre-formed complex structures. Claims that newborn infants imitate and that imitation is the product of an inherited mirror neuron system are preformationist claims. I have argued that the evidence does not provide the necessary support for these claims.

Recent reports that infants early in their second year exhibit imitation based on understanding of the intentions and circumstances of a model represent a break from the preformationist tradition in infant imitation research. Such studies emphasize the roles of social knowledge and cognitive processing in producing imitative behaviour. However, the kinds of knowledge and cognitive processes posited seem quite advanced. In particular, the reasoning attributed to infants involves many inferential steps, and those steps—that is, the particular sequences and combinations of rational inferences attributed to infants—seem underdetermined by the information provided to the infants. Meanwhile, alternative, simpler explanations of the infants' behaviours have not yet been ruled out. Thus, I have argued that more evidence is needed to strengthen support for these accounts.

The data from studies describing the developmental course of imitation across infancy are incomplete, and not mutually consistent. Findings to date indicate a

general developmental trend in which emulation learning appears late in the first year and imitation does not appear until the second year. Different studies attempting to elicit imitation of different behaviours across the second year report variable success at a range of different ages. This variability is a problem for a preformationist account, which expects imitation to appear as a unitary competency at some particular point in development. From an alternative theoretical perspective, however, the variability in infants' performance is an important datum. That alternative perspective regards the ability to imitate as a dynamic system and predicts different performances from the system both at different points in its development and at the same points in response to different environmental demands.

From a dynamic systems theoretical perspective (e.g. Thelen & Smith 1994), no dedicated modular system is needed to give imitation its form. Instead, imitation will be the emergent, stable product of the coming together of a range of distinct kinds of knowledge and skill. Such multi-component systems are not deterministic and do not follow a built-in blueprint for the development of behaviours. They are self-organizing and can generate new behaviours through their own activity. Development of the system occurs as its constituent components and the relationship among them change. Such change occurs as individual components continue to develop and new components come online. Additions to the available components of imitation, and changes in the interactions among components, may be what we are seeing in the reports of infants' first matching of different behaviours at different ages across the second year.

As I have argued here, and as research is beginning to show, the components of the ability to imitate are likely to include a host of different kinds of perceptual, cognitive, social and motor knowledge and competency. When we have traced the developmental course of each of these components, both separately and in interaction with other components of the system, then we will know the origins of imitation.

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