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Imitation of Gestures in Children is Goal-directed

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The view that the motor program activated during imitation is organized by goals was investigated by asking pre-school children to imitate a set of hand gestures of varying complexity that were made by an experimenter sitting in front of them. In Experiments 1 and 3, children reached for the correct object (one of their own ears or one of two dots on a table) but preferred to use the ipsilateral hand. This ipsilateral preference was not observed when hand movements were made to only one ear (Experiment 2), or when movements were diercted at space rather than physical objects (Experiment 3). The results are consistent with the notion that imitation is guided by goals and provide insights about how these goals are organized.

Imitation, or performing an act after perceiving it, guides the behaviour of a remarkable range of species at all ages. Imitation also serves an important function in human development, offering the acquisition of many skills without the time-consuming process of trial-and-error learning. It has been shown that infants as young as 12 to 21 days of age can imitate facial and manual gestures (Meltzoff & Moore, 1977). However, although imitation is well documented in different species, it is still unclear how a motor act is constructed from a perceived action performed by a model.

The common view about how perception and action are mediated in imitation postulates that observing actions performed by another individual activates a matching motor program by direct perceptual-motor mapping (e.g. Butterworth, 1990; Gray, Neisser, Shapiro, & Kouns, 1991; Meltzoff, 1993; Vogt, 1996). Infant imitation of diverse facial and manual gestures is taken as evidence that imitative behaviour entails a direct matching

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between the visually perceived input and the motor output. In their active intermodal mapping theory (AIM), Meltzoff and colleagues (Meltzoff, 1993; Meltzoff & Moore, 1997) claim that humans have the inborn ability actively to match visible movements of others with non-visible but felt movements of one's self. The theory assumes a supramodal representational system in which the information of the perceptual system and the action system are registered. This supramodal representational system is supposed to match the perceptual information of the seen act with the proprioceptive information of the produced act; the matching-to-target process will be activated until the model's act and the infant's act match.

Perhaps the strongest support for the direct-mapping view of imitative behaviour comes from neurophysiological observations. For example, in songbirds, motor neurons have been found that innervate the vocal organ in response to sound (Williams & Nottebohm, 1985). In humans, increased electromyographic activity has been registered in the arm while watching models arm-wrestle (Berger, Irwin, & Frommer, 1970). Furthermore, similar motor-evoked potentials were observed in conditions in which human participants observed movements performed by an experimenter as when the participants executed the observed action themselves (e.g. Fadiga, Fogassi, Pavesi, & Rizzolatti, 1995), and similar findings have been observed in monkeys (e.g. Pellegrino, Fadiga, Fogassi, Gallese, & Rizzolatti, 1992: Rizzolatti, Fadiga, Gallese, & Forgassi, 1996).

Several observations about imitation, however, indicate that a direct mapping view does not capture the complexity of human imitation behaviour. In particular, consistent error patterns in imitation can be reliably observed. One such error pattern, which was reported by Head (1920, 1926), has motivated a large number of studies (e.g. Benton, 1959; Gordon, 1923; Kephart, 1971; Schofield, 1976; Wapner & Cirillo, 1968). In these studies, a test was used in which participants imitated a model (or photographs of a model) who touched a left ear (or eye) or a right ear (or eye) with a left hand or a right hand. The main finding has been that pre-school children (and also patients with aphasia—Head, 1920, 1926) offer more ipsilateral but fewer crosslateral responses than are required. This error pattern has been interpreted in terms of existing midline translation problems in young children, which would explain why they fail to achieve the correct matching motor program. However, Schofield (1976) has challenged this lateral bifurcation hypothesis of perceptual-motor organization by showing that even 8-year-old children make fewer contralateral than ipsilateral hand movements, although it is hard to believe that children at this age still suffer from lateral bifurcation.

The aim of this study is to explore a new view on the representation that mediates perception and actions in imitation. This view postulates, first, that behaviours are not simply replicated as unified, non-decomposed motor patterns. Rather, imitation involves first a decomposition of the motor patterns into their constituent components and later a reconstruction of the action pattern from these components. Second, the decomposition–reconstruction process is guided by an interpretation of the motor pattern as a goal-directed behaviour. Thus, the constituent elements in the mediating representation involve goals rather than motor segments. Third, we assume that these goals are represented in a hierarchical pattern with some of the encoded goals being dominant over others. Finally, the reconstruction of motor patterns from its analysed goals in participants is subject to resource constraints: when resources are limited, a more simplified version of the original act will be reproduced—one that contains only the dominant goal(s).

This view was investigated in the present study by focusing on errors of reproduction. In general, we believe that such errors best disclose the nature of the representation that mediates between perception and action. Hence, the present study focuses on pre-school children, who have been found to make consistent and reliable errors. We used participants in the age range at which the errors in the unimanual conditions are most evident (see also Schofield, 1976). If the above-described view of goal-directed behaviour is valid, the logical consequence of the previously observed error pattern is that pre-school children do represent the most salient goal—here the correct object (an ear)—but they ignore lower goals, such as the hand used. A straightforward test of this assumption would be to manipulate the saliency of possible goals while keeping the hand movement similar. Therefore, we added the two possible bimanual hand movements to this design (both hands to the ipsilateral ears and to the contraleral ears). If imitation is guided by goals, then we may expect fewer errors in the bimanual contralaterial condition than in the unimanual contralateral condition: for example, having the arms crossed should make the encoding of the arm movement more salient. However, if the crosslateral inhibition effect is due to lateral bifurcation, we may expect at least as many errors in the bimanual contralateral condition as in the unimanual condition, as children will still perform ipsilateral hand movements to reach for their ears.

EXPERIMENT 1

The procedure of Experiment 1 used a slightly modified version of Head's clinical test (1920, 1926). An adult model touches the left and/or right ear(s) with one or both of the ipsilateral and/or contralaterial hand(s) (see Figure 1). Thus, three ipsilateral hand movements (left hand to left ear, right hand to right ear, both hands to ipsilateral ears) and three contralateral hand movements (left hand to right ear, right hand to left ear, and both hands to contralateral ears) were modelled. Note that the bimanual movements were not included in Head's original pardigm.

Method

Subjects

Fifteen pre-school children, aged 3:11 to 5:11 years (mean age 4:5 years), participated in Experiment 1. Each child was tested individually in a quiet room.

Design and Procedure

The experimenter asked the child to play a game called "The Mirror Game". Young children typically copy movements as if they were looking in a mirror (Schofield, 1976), and therefore the children were instructed: "Try to imitate me as if you were my mirror. You do what I do". During the experiments, the experimenter knelt in front of the child. The order of the six possible movements was randomized within one block of trials, and each participant was asked to perform the task for three blocks of trials with a short break in-between. Following each response, the experimenter

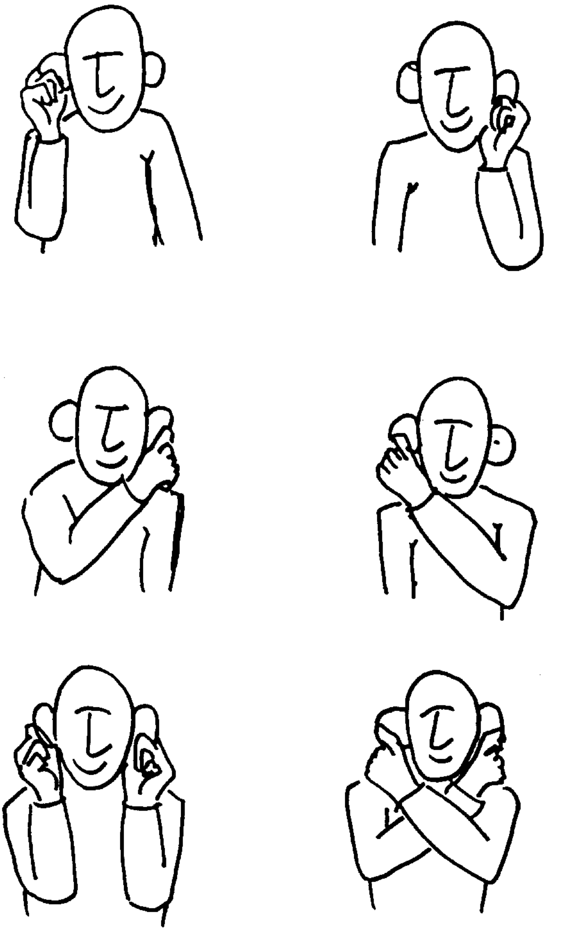

FIG. 1. An illustration of the six hand movements used as target actions in Experiment 1.

paused for a few seconds before initiating the next trial. Both model and participant returned hands to standard position between items. Each response was followed by encouragement. A video camera placed behind the experimenter, focused on the upper body parts of both the child and the experimenter, recorded the movements for each action. The final hand position was then analysed from the video recording. Although latency data were also collected, they yielded results that mimic those obtained with errors and will therefore not be reported.

Results and Discussion

Children always produced one of the six possible movements, but not always the matching movement. Overall, participants produced errors in 24.5% of the trials, most of which occurred in response to contralateral modelled movements. In 40.0% of the contralateral trials, children produced ipsilateral movements instead—a so-called contra-ipsi error (CI-error). In contrast, ipsilateral movements were usually imitated correctly: children made a contralateral movement in response to an ipsilateral modelled movement (IC-error) on only 3.8% of trials. A matched-pairs signed rank test confirmed that this difference in imitation behaviour was significant, $T_0' = 5$. $p < .001$ (Pratt's exact test, see Lienert, 1973). Importantly, in 95.7% of the unimanual trials, children touched the correct ear. Thus the majority of errors were due to choosing the wrong hand during contralateral trials.[1] In addition, the rate for this type of error was found to be higher for unimanual hand movements than for bimanual movements, 48.2% and 10.8%, respectively, which was confirmed by a matched pairs signed rank test $T_0' = 9$, $p < .01$ (Pratt's exact test), as seen in Figure 2(A).

A multiple regression analysis showed that the variable body midline had the strongest explanatory power for predicting whether or not imitation would occur (2 Log Likelihood = 71.210, $p < .001$, explanatory power of 76.34%). Another small improvement to the prediction reliability of the model was added by the variable number-of-hands (with a 2 Log Likelihood of 5.3, $p < .02$, increasing the explanatory power to 79.89%). No significant influence was found for the factor age (with a 2 Log Likelihood < 1).

Our data confirm the observation that young children who are asked to make hand movements across the body midline are likely to show hand movements confined to one body side (see also Kephart, 1971; Schofield, 1976)—but only for unimanual movements. Childen made fewer errors on bimanual than on unimanual trials, indicating that the crossing of the hand was indeed a dominant goal in the imitative act, which was easy to reconstruct.

Remarkably, goals like reaching for a specific ear in the unimanual task or crossing the hands in the bimanual task seem to be inferred in a consistent way across individuals and across trials. Furthermore, these goals seem to be hierarchically organized, as indicated by the relatively high frequency of hand selection errors and the relatively low frequency of ear selection errors. It would appear that when multiple goals compete for capacity, one goal is more likely to be preserved than another, leading to specific and consistent errors in imitative behaviour (see Prinz, 1997, and Stränger & Hommel, 1995. See also Jeannerod, 1997, for a neurophysiological approach to goal representation in action). Therefore, the purpose of Experiment 2 was to manipulate the goal construction process by limiting the number of possible goals.

EXPERIMENT 2

Experiment 2 investigated the hypothesis that the unimanual contralateral errors observed in Experiment 1 were due to an encoding competition of goals encoding one of two ears and one of two hands. Therefore, in Experiment 2, we again used hand-to-ear-movements but minimized the action set. Participants saw only unimanual hand movements to only one ear. Because children made almost no ear selection errors in Experiment 1, choosing the correct ear appeared to be the most important goal guiding

[1] Moving to the correct ear with the wrong hand also has the consequence that the path of the movement is incorrect (ipsilateral instead of contralateral).

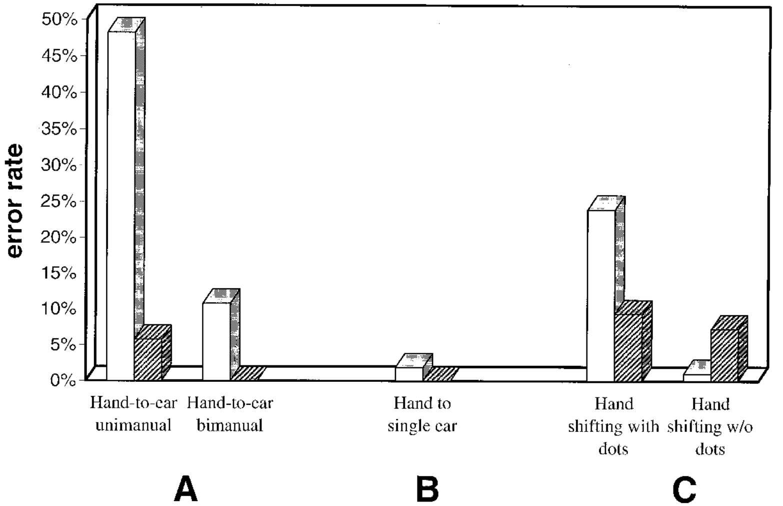

FIG. 2. Percentage of errors for the different conditions in Experiments 1–3. The blank bar represents errors on contralateral movement trials, and the striped bar represents errors on ipsilateral movment trials.

children's imitation of these gestures. We reasoned that limiting the set of movements to only one ear would eliminate the problem of choosing an ear. As a consequence, another goal—using the correct hand—might be fulfilled.

Method

Subjects

Participants were nine pre-school children, aged 4:0 to 5:11 years (mean age of 4:4 years). Each child was tested individually in a quiet room.

Design and Procedure

Experiment 2 was similar to Experiment 1, with the exception that now only two movements were modelled: an ipsilateral and a contralateral movement, both to the same ear. Right and left ear were counterbalanced between-participants. For four children, the model always moved with either the left (thus with the ipsilateral) hand or the right (thus with the contralateral) hand to the left ear; for the other five participants the model always moved to the right ear. The two movements were repeated 12 times in total, in a random order, resulting in 6 ipsi- and 6 contralateral hand movements. This time, all children were simply instructed, "You do what I do".[2]

[2] Although in Experiment 1 we instructed the children with the words, "Try to imitate me as if you were my mirror. You do what I do", in Experiments 2 and 3 we used the minimal instruction "You do what I do", because in a pilot experiment we observed that for children this automatically implies that they will copy the movements as if they were looking in a mirror, as previously observed by Schofield (1976).

Results and Discussion

Overall, participants produced errors on 1.9% of the trials, as seen in Figure 2B. In fact, only two participants made one error each, both being CI-errors. As in Experiment 1, children always moved to the correct ear. A matched-pairs signed rank test showed that the CI-errors did not differ significantly from the zero IC-errors $T_0' = 17$, $p = .75$ (Pratt's exact test). These results confirm that young children are capable of contralateral hand-to-ear movements and therefore that the crosslateral inhibition effect is not due to lateral bifurcation. Rather, contralateral errors in manual imitation appear to be a consequence of the hierarchical organization of goals guiding imitation. In Experiment 1 children almost always moved to the correct ear, or more generally the physical object at which the gesture was directed, but they frequently used the incorrect hand, particularly in unimanual contralateral gestures. In contrast, in Experiment 2, where all movements were directed at the same ear, children virtually always used the correct hand, even for the contralateral gestures. Thus the error pattern observed in Experiment 1 arises from goal complexity, a cognitive constraint, rather than from neurophysiological constraints. Decreasing the goal complexity by directing movements at only one ear, or by directing it at both ears, thereby eliminating ear choice as a goal, enabled children to preserve another goal in the reconstruction of the imitative act, namely to use the correct hand and therefore the correct path of the movement.

However, in Experiment 2, not only the number of objects was decreased relative to Experiment 1, but also the total number of possible movements; that is, although Experiment 2 still employed two agents—i.e. the left and right hand—the action set for one specific subject consisted of only two out of the four possible unimanual actions from Experiment 1. A stronger test of the hypothesis is to show that similar modelled unimanual hand movements can lead to different imitative behaviour, depending on the goal-constructing process of the imitator. This was done in Experiment 3 by requiring participants to make similar movements in either of two conditions, one requiring the gestures to be directed at objects and one requiring them to be to locations. Thus, Experiment 3 employed the four ipsilateral and contralateral unimanual hand movements again, but now instead of the ears, the model in one condition made hand movements to dots or locations on a table. If the dots could be seen to represent a similar higher goal in the constructing process as ears, we might expect participants to direct the hand movements at the correct object and therefore to make errors in lower goals, such as the hand selection process. Taking away this higher goal (the objects) should enable participants to fulfil lower goals, like hand choice.

EXPERIMENT 3

Experiment 3 employed the same unimanual hand movements as Experiment 1. However, now for half of the participants, the model initiated hand movements to one of two dots on a table (dot condition), whereas for the other half of the participants the movements were directed to the same places on the table without any dots (no-dot condition). Using dots rather than ears as objects enabled manipulation of the presence or absence of the objects and therefore the availability of objects as a possible goal of the imitative act. We reasoned that when dots are on the table, object selection becomes the highest goal of the imitative act, similar to the accurate ear selection found in Experiment 1. As a consequence, we expected children in this condition to yield more errors involving hand choice than children in the no-dot condition. In the absence of the objects (the dots), we expected children to choose the correct hand, and as a consequence the correct movement path, as the highest goal of the imitative act.

Method

Subjects

Thirty-two pre-school children aged 3:9 and 6:1 years (mean age of 4:4 years) participated in Experiment 3.

Design and Procedure

Of the 32 children, 16 children, aged 3:9 to 6:1 years (mean age of 4:4 years) were assigned to the dot condition. They were asked to imitate left and right, ipsi- and contralateral movements of an adult model after the model had returned her hands to the starting position. The model sat across from the children. There were four blue dots, two at a distance of about 20 cm in front of the model, and two about 20 cm in front of the child. The other 16 children, aged 3:10 to 5:11 years (mean age of 4:4 years) were assigned to the no-dot condition. They were asked to imitate the same hand movements on a table as described above, but now *without* the dots on the table (no-dot condition). Again children in both conditions were simply instructed, "You do what I do".

Results and Discussion

Consistent with Experiment 1, children in the dot-condition of this experiment reached to the correct position in space (92.7%). The participants in the dot condition produced a total of 22.9% errors. CI-errors occurred in 24.0% of the contralateral trials, whereas IC-errors occurred on only 9.4% of the ipsilateral trials. A matched-pairs signed rank test confirmed that this difference in imitation behaviour was significant, $T_0' = 22.5$, $p < .05$ (Pratt's exact test).

The children in the no-dot condition, in contrast, showed a totally different pattern of results. They made errors in only 9.9% of all trials. These children made 1.0% CI-errors and 7.3% IC-errors—see Figure 2C. A *t*-test confirmed that the rate for the typical error—imitating unimanual contralateral movements with ipsilateral ones—was significantly lower in the no-dot condition than in the dot condition, $t = 3.33$, $p < .001$. In summary, the results of Experiment 3 are consistent with the view that goals are hierarchically organized in the reconstruction process of an imitative act. Children's imitation of four unimanual movements directed at dots on a table revealed the same contralateral error pattern as found in Experiment 1. Removing the physical targets (the dots on the table), and therefore removing the availability of the object as the goal of the imitative act, significantly reduced contralateral errors and led to more accurate hand selection. The results seems to be consistent with the view that the contralateral imitation errors of Experiments 1 and 3 and those observed in previous studies are indeed due to competition between encoding of goals, one of two objects, and one of two hands. Reducing the number of possible goals (objects) reduced the imitation errors in both experiments.

GENERAL DISCUSSION

Implicit in most of the work on imitation is the idea that perceived actions can lead to the production of similar motor acts by a direct mapping between perception and action. The general aim of this study was to investigate a new view on the representation that mediates perception and actions in imitation. This view postulates that imitation involves first a decomposition of the motor patterns into their constituent components and later a reconstruction of the action pattern from these components. Importantly, the decomposition–reconstruction process is guided by an interpretation of the motor pattern as a goal-directed behaviour. This view also assumes that the goals are represented as a hierarchical pattern with some of the encoded goals being dominant over others. When processing resources are taxed, errors are likely to be committed involving primarily a misproduction of the less dominant goals.

To explore this idea, we compared similar contralateral and ipsilateral gestures. A comparison of unimanual and bimanual imitation errors in Experimental 1 revealed that contralateral imitation errors occur, counterintuitively, more often in unimanual gestures than in the more complex bimanual gestures, thus demonstrating that contralateral errors are not caused by neurophysiological constraints. Instead, the observation that the majority of the errors consisted of touching the correct ear but with the wrong hand suggests that the mapping of perceptual information to motor schemas is directed by goals inferred by the imitator, such as the physical object at which an action is directed (a particular ear) and the agent of that action (a particular hand).

Experiments 2 and 3 tested a further implication of the idea that perceptual-motor mediation is directed by a goal representation. We reasoned that if unimanual contralateral errors were due to competition between multiple goals, reducing the number of possible goals should reduce imitation errors. This was indeed the case. Experiment 2 showed that limiting the number of objects at which the gestures were directed resulted in a significant decrease in the number of errors in the choice of hand and movement paths. In Experiment 3, children's imitation of four unimanual movements directed at dots on a table revealed the same contralateral error pattern as found in Experiment 1. However, removing the dots, and therefore removing the availability of the object as the goal of the imitative act, led to more accurate hand selection.

In the present study we deliberately used 4–6-year-old children, because they were the children who showed the most consistent errors in Schofield's (1976) study. The view that we advanced in this paper is more general, however, and should hold true for other age groups as well. Indeed, in a recent extension of the present study we found that also younger children between 29 and 38 months of age show a similar, although even higher, error pattern for unimanual contralateral hand-to-ear movements. In future work, we intend to explore the basic phenomenon with adults. Although, obviously, adults are able to copy an unimanual hand-to-ear movement, we might find a similar pattern of results when response latency rather than proportion of errors is used as the dependent variable.

Together, the results of all three experiments provided support for the view that imitation in children is mediated by a goal representation, such as an object (a particular ear to reach for), an agent (a particular hand to move with), or a movement path (ipsi- or contralateral to the object) or salient features (the crossing of the arms in the bimanual contralateral gesture). This view departs from the notion that imitation involves a direct mapping of a non-decomposed action pattern. Such a goal-directed notion of imitation is able to explain (a) why participants almost always grasped the correct ear or correct dot on the table, (b) why participants made fewer errors in the bimanual condition compared to the unimanual condition, (c) why participants neglected the contralateral hand movements to the ears or the dots, (d) why they imitated the contralateral hand movement when no physical objects are present on the table, (e) why children were able to translate an adult's action into motor terms, despite the large differences in body size, orientation, and available motor skills, and (f) why consistent errors could be observed without an active matching-to-target process, as supposed in AIM (see Introduction).

In addition, the results of Experiments 2 and 3, in which imitation performance varied with the number of goals present in the target action, suggest that in multiple-goal tasks, like the hand-to-object-movements in this study, the goals are hierarchically organized (see Gattis, Bekkering, & Wohlschläger, 1998, for a discussion). Although the children in some conditions in our study used the wrong hand, they almost always reached for the correct object (ear or dot), suggesting that objects defined the highest-level goal. When the object was removed (or their number was limited), participants were better able to use the correct hand.

Our results also raise the possibility that goals may influence the development of imitative behaviour in a manner consistent with previous investigations of imitation in non-human primates. Tomasello, Kruger, and Ratner (1993) proposed a distinction between imitation and emulation, where imitation refers to the reproduction of the model's actual behaviour or behavioural strategies (see also Tomasello, 1990), whereas emulation refers to the reproduction of a goal, independently of precise means. In this respect, a major finding has been that 2-year-old human children as well as chimpanzees raised in a human-like cultural environment used a tool in the same way they saw it being used by a model. In contrast, mother-reared chimpanzees ignored the model's specific method of tool use, which led to the suggestion that a human-like sociocultural environment is an essential component in the development of imitative behaviour (Tomasello, Savage-Rumbaugh, & Kruger 1993). Byrne and Russon (1998), in contrast, argue that it is not the means themselves but rather the complexity of the goal hierarchy that distinguishes the highest form of imitation (program level imitation) from lower forms of imitation (action level imitation), arguing that some animals keep track of goals and several subgoals, and others do not. The present study also indicates that the ability to keep track of goals is a relevant aspect in imitation, and that the actual number of goals that can be tracked may be limited early in development (see also Wohlschläger, Gattis, & Bekkering, 1998). However, the present study also suggests that it is likely that more than one mechanism determines imitative behaviour and that the goal-directed aspects of imitation might emerge later in human ontogeny.

Another important implication of our goal-directed imitation hypothesis is that it may shine some new light on how infants learn to initiate actions in general. It can be argued that not only is imitative behaviour guided by goals, but all voluntary actions are preceded by goals or intentions about the action to be undertaken. That is, infants may learn how to build the necessary motor structures by an active matching-to-goal process instead of an active matching-to-target perspective as postulated in AIM. In a goal-directed perspective, imitation may help motor learning by curtailing the learning process, increasing information about goals, and decreasing reliance on the proprioceptive feedback loop and trial-and-error learning. Of course, in order to fulfil the goal of an imitative act, imitators need to construct a motor output. Importantly, however, the present experiments support the view that what is extracted from a model's movement is not so much the motor command or the kinematic primitives, but the desired goal of the action (see also Jeannerod, 1994, for a similar view).

An important question that remains to be resolved is how goals are extracted from the visual input. In the present experiments, for instance, is it difficult to separate goals such as objects and agents from other notions such as the action's final end state or the saliency of a specific aspect of an action. Further research (see also Wohlschläger, Gattis, & Bekkering, 1998) is necessary to establish the goal-directed perspective on imitative behaviour and also to determine the nature of the goal hierarchy guiding the mediation between perception and action in imitation.

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