Cognition 114 (2010) 423–435

Contents lists available at ScienceDirect

Cognition

journal homepage: www.elsevier.com/locate/COGNIT

'Goals' are not an integral component of imitation

Jane Leighton [a], Geoffrey Bird [a,b], Cecilia Heyes [a,c,*]

[a] Department of Psychology, University College London, Gower Street, London WC1E 6BT, United Kingdom
[b] School of Psychology, Birkbeck, University of London, Malet Street, London WC1E 7HX, United Kingdom
[c] All Souls College, University of Oxford, Oxford OX1 4AL, United Kingdom

ARTICLE INFO

Article history:
Received 1 July 2008
Revised 28 October 2009
Accepted 1 November 2009

Keywords:
Imitation
Pen-and-cups task
Goal
GOADI
ASL

ABSTRACT

Several theories suggest that actions are coded for imitation in terms of mentalistic goals, or inferences about the actor's intentions, and that these goals solve the *correspondence problem* by allowing sensory input to be translated into matching motor output. We tested this intention reading hypothesis against general process accounts of imitation using the pen-and-cups task. The task has three components: participants place a pen in one of two cups, using their right or left hand, and one of two grips. Previous research has revealed a colour minimum error pattern; when one of the components is differentially coloured (e.g., one cup is red and the other blue), accuracy is greatest on the coloured dimension. We found the colour minimum error pattern, not only in the standard version of the task, where participants imitate the actions of a human model, but also in three novel variants of the task, in which participants responded on the basis of spatial or arbitrary stimulus–response mappings to 'geometric', non-biological stimuli. These stimuli do not afford the attribution of intentions, and therefore our results support generalist theories of imitation by showing that the colour minimum error pattern is due, not to intention reading, but to the operation of task-general processes of perception, attention and motor control.

1. Introduction

Imitation is regarded as one of the most important means whereby skills and behaviour are transferred between agents; it is thought to play a significant role in language acquisition, skill learning, socialization, and enculturation (e.g., Byrne & Russon, 1998; Meltzoff & Gopnik, 1993; Trevarthen, 1984, 1994). A growing body of evidence suggests that imitation also makes a major contribution to our understanding of ourselves and others (e.g., Meltzoff, 2002; Tomasello, Kruger, & Ratner, 1993). Given the functional significance of imitation, it is important to understand how we are able to imitate. This question raises a fundamental problem because successful imitation requires the translation of sensory information received from observing an action into the motor commands necessary to carry out a matching action (the correspondence problem, Brass & Heyes, 2005).

Many researchers have suggested that 'goals' mediate imitative behaviour (e.g., Byrne, 1993, 2003; Meltzoff, 1995; Meltzoff & Moore, 1997; Wohlschläger, Gattis, & Bekkering, 2003). Goals and their relationship to imitation may be relevant when trying to explain how the correspondence problem is solved. Goal-directed theories of imitation suggest that intermediate recoding occurs between observation and execution of a body movement (Bekkering & Wohlschläger, 2002; Byrne, 1993, 1999, 2003; Byrne & Russon, 1998; Meltzoff & Moore, 1997; Perra & Gattis, 2008). These theories imply that, in addition to the visual representation of the observed movement and the motor representation that drives muscle movement, imitation involves a third kind of representation. This third type of representation is neither sensory nor motor, but is

* Corresponding author. Address: Department of Psychology, University College London, Gower Street, London WC1E 6BT, United Kingdom. Tel.: + 44 (0) 1865 279394.
E-mail address: cecilia.heyes@all-souls.ox.ac.uk (C. Heyes).

0010-0277/$ - see front matter © 2009 Elsevier B.V. All rights reserved.
doi:10.1016/j.cognition.2009.11.001

rather at the level of the goal of the act. When we observe an action, we do not try to parse what we observe into specific movements; rather we extract the goal of the action. Consequently, such action goals make it possible for a relevant motor programme to be activated. According to this view, goals represent the link between the "seen but unfelt" and the "felt but unseen", and thereby provide a solution to the correspondence problem (e.g., Bekkering & Wohlschläger, 2002; Byrne, 1993; Byrne & Russon, 1998; Meltzoff & Moore, 1997, p.180).

A number of authors have highlighted the importance of goals in imitation. The most explicit statement of this view has been provided by the theory of goal directed action (GOADI) (e.g., Bekkering & Wohlschläger, 2002; Bekkering, Wohlschläger, & Gattis, 2000; Gleissner, Meltzoff, & Bekkering, 2000; Wohlschläger & Bekkering, 2002). GOADI consists of a number of postulates: "(i) *Decomposition.* The perceived act is cognitively decomposed into separate aspects. (ii) *Selection of goal aspects*. Owing to capacity limitations, only a few goal aspects are selected. (iii) *Hierarchical organisation.* The selected goal aspects are hierarchically ordered. The hierarchy of goals follows the functionality of actions. Ends, if present (e.g., objects and treatments of the latter) are more important than means (e.g., effectors and movement paths). (iv) *Ideomotor principle*. The selected goals elicit the motor programme with which they are most strongly associated. These motor programmes do not necessarily lead to matching movements, although they might do so in many everyday cases. (v) *General validity*. There is no essential difference in imitation behaviour between children, adults and animals. Differences in accuracy are due to differences in working memory." (Wohlschläger et al., 2003, p. 503). Thus, according to GOADI, goals are extracted from perceived movements, and the goal representation then activates its most commonly associated motor program, irrespective of whether this matches the movement performed by the model (e.g., Bekkering & Wohlschläger, 2002; Bekkering et al., 2000; Gleissner et al., 2000; Wohlschläger & Bekkering, 2002).

A number of findings have been argued to provide specific support for GOADI. These findings demonstrate that, when required to imitate, instead of faithfully reproducing all aspects of a movement, children and adults frequently reproduce the goal of that movement. Bekkering and colleagues have investigated how the goal of an action, such as touching a dot on a table, or placing a pen in a cup, affects the translation from perception to action (Bekkering et al., 2000; Wohlschläger et al., 2003). For example, the pen-and-cups task allows three components of action to be manipulated independently: object selection, effector selection and grip selection. On each trial, the participant sees a model move a centrally located pen into one of two coloured cups (object), using his right or his left hand (effector), while grasping the pen with his thumb pointing up or down (grip). Adults typically make fewer cup errors than hand errors and fewer hand errors than grip errors (Avikainen, Wohlschläger, Liuhanen, Hanninen, & Hari, 2003; Leighton, Bird, Charman, & Heyes, 2007; Wohlschläger & Bekkering 2002). If one supposes that the primary goal of each action is to place the pen into a cup, then this cup < hand < grip error pattern supports the view that participants code an action in terms of its goal, and when processing resources are limited, this goal is more accurately reproduced than the means by which the goal is achieved. This view has been supported by a number of other similar findings (Gattis, Bekkering, & Wohlschläger, 2002; Gleissner et al., 2000; Head, 1963; Want & Gattis, 2005).

However, a critical issue is the exact meaning of the term 'goal', because this term has been used in a variety of contexts across the literature. While some authors assume that it refers to an observable, physical, end-state or outcome, others imply that it is a mental state; an intention. Under the latter view, theory of mind abilities are needed to infer a model's goals. For example, Wohlschläger and colleagues suggest that goals are action outcomes or end-states, stating that "although using action goals as the core concept, GOADI does not say anything about the representation of the intentions of the model in the imitator. In our view the representation of intentionality or any theory of mind is not necessary to explain imitation" (Wohlschläger et al., 2003, p. 513). However, a contrasting claim was made by Gattis and colleagues who explicitly stated that "goals are mental states" (p. 202, Gattis et al., 2002). Under this view, a goal is understood to be the inferred intention of the model. We will refer to the broad category of models and hypotheses which assume that mentalistic goal processing is an integral component of imitation as 'intention reading' accounts of imitation (e.g., Bellagamba & Tomasello, 1999; Carpenter, Akhtar, & Tomasello, 1998; Carpenter, Call, & Tomasello, 2005; Carpenter, Nagell, & Tomasello, 1998; Johnson, Booth, & O'Hearn, 2001; Meltzoff, 1995; Sanefuji, Hashiya, Itakura, & Ohgami, 2004).

Thus, according to goal-directed theories, any recoding between perception and action may involve the representation of physical, end-state goals or mentalistic goals. Some recent evidence bears on the first but not on the second of these hypotheses. In a series of experiments using the pen-and-cups task, Bird, Brindley, Leighton, and Heyes (2007) found that the cup < hand < grip error pattern could be altered such that the outcome of an action was not always the most accurately imitated component. Whereas in the original version of the pen-and-cups task, the cup component is the only component that is differentially coloured (i.e. one cup was coloured blue and the other red), Bird and colleagues manipulated the colour coding such that either the cup, hand or grip component was differentially coloured. For example, in one condition, the cups were both a neutral colour but the model and participant each wore coloured gloves, making one hand blue and the other red. Altering which component was coloured resulted in a modification of the error pattern; the coloured component was always the most accurately reproduced component ('colour minimum error'). Thus, when the means were differentially coloured, they were more accurately imitated than the end-state or *goal* (cup selection) of that action.

If goals are understood to be physical end-states, then the findings of Bird et al. are inconsistent with the hypothesis that observed actions are coded as goals for imitation. However, if goals are understood to be intentions, the findings of Bird et al. do not bear directly on the goal-directed hypothesis. It is possible that shifting the colour cue in the pen-and-cups task induces a revision of the imitator's inferences about the model's intentions. For example, adding colour to the hand may have resulted in the observed action being coded as, "The model intends to grasp the pen with his *red hand* and put it in a cup", rather than, "The model intends to place the pen in the *red cup*" when the cups are coloured. Therefore, the colour minimum error pattern reported by Bird et al. may have been due to intention reading; to inferences about the model's mentalistic goals.

A study by Meltzoff (1995) seems to provide strong support for the idea that imitation involves intention reading. In this study, infants either observed a model successfully carrying out a target action on an object or attempting to carry out the action but failing to do so. For example, the model attempted to pull apart a dumbbell-shaped toy but their hand 'accidentally' slipped off one end of the dumbbell. Meltzoff found that 18-month-old infants produced target acts (e.g., separating the parts of the dumbbell toy) as frequently following observation of these "failed attempts" as they did following observation of the model successfully completing the target actions. Meltzoff concluded that 18-month-old infants represent an action in terms of the intended goal and it is this goal that is imitated rather than specific movements.

In a second experiment pointing to the same conclusion, infants were shown a mechanical device with two pincers that mimicked the way the model had acted on the dumbbell toy in the failed attempt display (Meltzoff, 1995). The pincers grasped the dumbbell at the two ends and pulled them outwards, but one pincer slipped off. After watching the unsuccessful movements of the mechanical device, infants pulled the dumbbell apart less frequently than when the same action was demonstrated by a human actor. Given that the attribution of intentions is unlikely when observing a mechanical device, this finding apparently represents further evidence that infants' imitation of target acts under both full-demonstration and failed attempt conditions is due to the tendency to code actions in terms of the model's underlying intention and to imitate that intention, rather than faithfully to copy the demonstrated action.

In contrast with intention reading accounts of imitation, the 'associative sequence learning' (ASL) model assumes that mentalistic goal representations do not play an integral role in imitation (Brass & Heyes, 2005; Heyes, 2001, 2003; Heyes & Ray, 2000). This model assumes that the correspondence problem is solved by direct connections between sensory and motor representations of action, and that task-general psychological processes – rather than processes that are specific to imitation or to the processing of social stimuli – are responsible for the formation and operation of these sensorimotor links. Therefore, in common with other 'generalist' theories of imitation (Brass & Heyes, 2005), the ASL model suggests that the results of the studies reviewed above are due, not to intention reading, but to the operation of general processes; to the mechanisms that mediate perception, attention, learning, memory and motor control, not just in imitation tasks, but in tasks where the individual is required to respond to biological and non-biological stimuli with actions that do not resemble those stimuli.

For example, infants may reproduce target actions after observing failed attempts as well as successful demonstrations (Meltzoff, 1995), not because they are intention reading in both cases, but because both failed attempts and successful demonstrations draw their attention to important parts of the object set, and enable them to learn how those parts can be separated and conjoined. Some evidence in support of this general process account has been provided by Huang, Heyes, and Charman (2002) in their study using the failed attempts paradigm. They replicated Meltzoff's (1995) study and included two additional conditions. First, in an emulation learning condition, infants were exposed to the initial and end-states of the target display but not to the experimenter's manipulations of the test objects, which were occluded by a screen. Second, in the spatial contiguity condition, the experimenter moved the two parts of the object set into close proximity. The results showed that infants in the emulation learning and spatial contiguity conditions produced as many target acts as infants in the full demonstration and failed attempt conditions. These findings indicate that the performance of infants in the latter conditions could be due, not to intention reading, but to learning by observation – and via general processes – about the properties of the stimulus objects.

Thus, behaviour which seems to indicate that mentalistic goals are intrinsic to imitation can also be explained with reference to general processes. The purpose of the present study was to find out whether performance in the pen-and-cups imitation task is more likely to be due to intention reading or to general processes. As indicated above, performance in this task is characterised by a colour minimum error pattern; when the cups are of different colours, participants imitate cup selection more accurately than hand selection, and when the hands are of different colours, they imitate hand selection more accurately than cup selection (Bird et al., 2007). The intention reading hypothesis suggests that the colour minimum error pattern is due to inferences about the model's goals (e.g., Gattis, Bekkering & Wohlschläger, 2002). For example, when the cups are coloured, the participant may infer that the model's primary intention is to place the pen in a particular cup, or to communicate to the participant that selection of the correct cup should be the participant's primary goal. (In the former case the participant would be ascribing a first order intention to the model, and in the second case a higher order intention.) In contrast, the general process account suggests that the colour minimum error pattern is due the same perceptual, attentional and motor control processes that would mediate performance in a comparable task which does not involve biological stimuli or imitation. It suggests, for example, that cup selection is more accurate when one cup is blue and the other red because colouration draws the participant's attention to the cup component of the task, makes it easier to discriminate which of the cups the model has selected on any given trial, and/or facilitates stimulus–response mapping because the model's and the participant's cups are of corresponding colours.

We tested the intention reading hypothesis against the general process account by comparing performance on the standard 'naturalistic' pen-and-cups task, in which participants imitate the actions of a model, with performance in novel versions of the task, in which participants responded on the basis of spatial or arbitrary stimulus–response mappings to 'geometric', non-biological stimuli. The stimuli used in the geometric tasks were matched with those used in the naturalistic task in terms of their low-level visual and spatial features, but the geometric stimuli should not support the attribution of intentions. Therefore, if the colour minimum error pattern is due to intention reading, it should emerge in the naturalistic task but not in the geometric tasks, but if this pattern is due to general processes, it should characterise performance in all versions of the task.

2. Experiment 1

In Experiment 1, participants either carried out a naturalistic or a geometric version of the pen-and-cups task. On each trial in both tasks, participants grasped a pen using either their left or right hand, with a thumbs-up or thumbs-down grip, and placed the pen into one of two cups. In the naturalistic version, participants copied actions carried out by a human model. In the geometric task, their hand, cup and grip selections were cued by moving, abstract, geometric shapes. Each participant completed the naturalistic or the geometric task under two conditions; one where the cups were differentially coloured (one red and one blue) and one where the hands were differentially coloured (one red and one blue). If imitation is mediated by general processes, one would expect to see the colour minimum error pattern in both the naturalistic and the geometric tasks, i.e. cup selection should be the most accurately performed component when the cups are coloured, and hand selection when the hands are coloured. However, if imitation is mediated by intention reading, this colour minimum error pattern should emerge only in the naturalistic task where the stimuli afford the attribution of intentions.

2.1. Method

2.1.1. Participants

Twenty-four consenting, healthy participants with an average age of 22.5 years, 13 male, were recruited from the UCL Department of Psychology database and paid a small honorarium for their participation. All were right-handed, had normal or correct-to-normal vision, and were proficient in the English language. They were naïve with respect to the purpose of the experiment. Participants were randomly assigned to two groups; naturalistic and geometric. Each participant was tested under both colour conditions (hands-coloured and cups-coloured) in a counterbalanced order. One participant who did not make any errors was replaced. This experiment was performed with local ethical committee approval and in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki.

2.1.2. Stimuli and apparatus

Participants were required to respond to stimuli by performing an action involving grasping a pen and inserting it into one of two cups. Factorial combination of the three components (cup, hand and grip) resulted in eight possible responses. Participants could make a response using either their left or right hand, using a thumbs-up or thumbs-down grip, and to place the pen into one of the two cups.

Participants in the naturalistic group responded to videos of a model carrying out the actions. For participants in the geometric group the correct response on each trial was indicated by a short stimulus animation. In these animations, the hands were replaced by squares, the grips by short rectangles attached to the squares, and the cups by ellipses. Further details of the naturalistic and geometric stimuli can be found in Appendix A.

The geometric shapes were matched to the naturalistic videos in terms of their spatial and temporal characteristics. Each geometric shape was approximately the same size as the corresponding component in the naturalistic videos. Topographical spatial locations of the shapes were equivalent to spatial locations in the naturalistic stimuli. Each shape moved for approximately the same amount of time and with a trajectory similar to that of the corresponding naturalistic component. Fig. 1 depicts the starting positions of the stimuli in the naturalistic (a and b) and the geometric conditions (c and d).

In the naturalistic task, in the cups-coloured condition, participants saw the model performing with ungloved hands, and directing her movements to one red cup and one blue cup. The model in the hands-coloured condition wore a red glove on their left hand, and a blue glove on their right hand. The cups presented in the hands-coloured condition were both a light beige, flesh-like colour. In the geometric task, in the cups-coloured condition the squares (and small rectangles attached to them) were a neutral off-white colour and the ellipses were coloured, one red and one blue. In the hands-coloured condition the ellipses were a neutral off-white colour and the squares (and small rectangles attached to them) were coloured, one red and one blue. In all conditions the blue component was on the left hand side of the stimulus set and the red component was on the right.

To make their responses participants sat at a table upon which was placed a pen and two cups, in the same spatial configuration as used in previous versions of the pen-and-cups task (Bird et al., 2007; Leighton et al., 2008; Wohlschläger et al., 2003). Fig. 2 depicts the spatial relationships between the objects and the effectors at the beginning of a trial in the naturalistic condition.

The cups were placed 35 cm from the front of the participant's body, 30 cm apart, and equidistant from the participant's midline. At the beginning of each trial, the pen was placed on a marker, a black dot, directly in front of the participant and 23 cm from their body. Each cup was 8 cm in diameter and 10 cm high. The pens (1.5 cm diameter, 14 cm high) were white with green caps. A transpar-

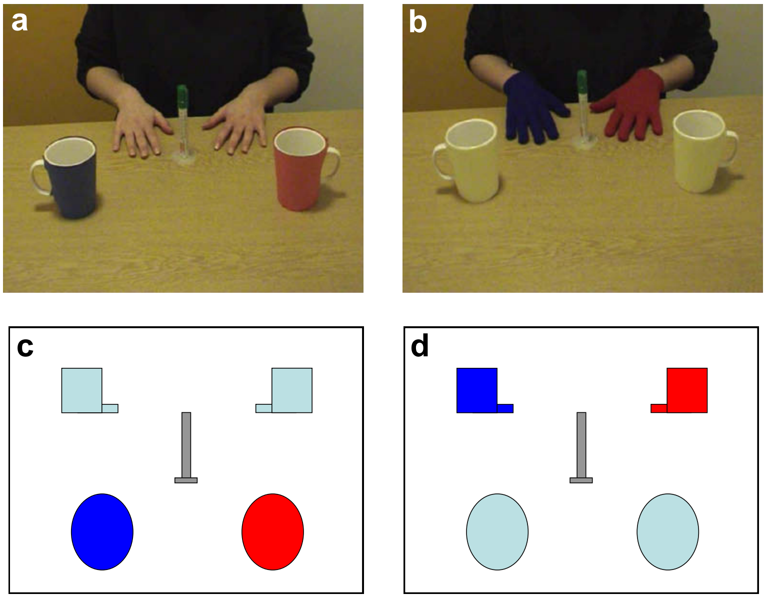

Fig. 1. Experiment 1. Images depicting the starting position of the stimuli for (a) the cups-coloured and (b) the hands-coloured condition in the naturalistic task and (c) the cups-coloured and (d) the hands-coloured condition in the geometric task. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

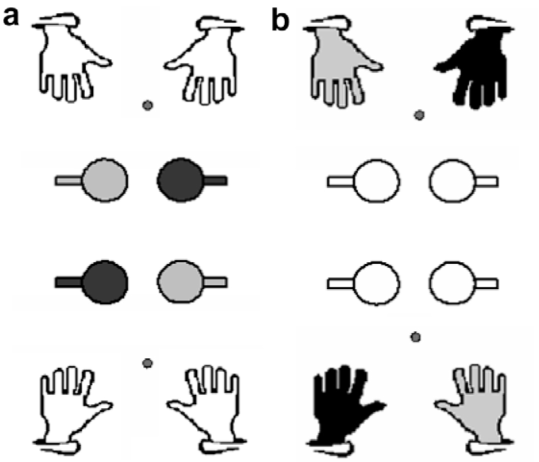

Fig. 2. Experiment 1. Diagrams indicating the spatial relationships between the model's and observer's objects and effectors at the beginning of each trial for (a) the cups-coloured condition and (b) the hands-coloured condition in the naturalistic condition. The small dark circles represent pen locations. The larger circles represent cups with handles. There were equivalent spatial relationships between the shape stimuli and the response objects and effectors in the geometric condition.

ent plastic disk, 4.8 cm in diameter, was attached to the base of each pen to increase its stability when at rest in the upright position. In the cups-coloured condition one cup was blue and one red. In the hands-coloured condition subjects wore a red glove on their left hand and a blue glove on their right hand. The cups were both a neutral off-white colour. The red cup or glove was placed on the participant's left hand side and the blue cup or glove on their right hand side.

2.1.3. Procedure

Participants were tested individually in a quiet room. Each sat at a table bearing the object set and, beyond it, the laptop computer on which the stimulus animations were presented. They were told that they would be required to make some movements involving placing a pen into one of the cups.

Participants in the naturalistic group were told that they should copy the movements shown on the screen and participants in the geometric group were told that they would see shapes moving on the screen that would indicate which movement to make in each trial. Participants were asked to pay equal attention to three aspects of their response: in the cups-coloured condition these were the hand (left/right), the grip (up/down) and the cup (red/blue) and in the hands-coloured condition these were the hand (red/blue), the grip (up/down) and the cup (left/right). Details of the specific task instructions can be found in Appendix B.

In both tasks participants' responses were spatially incompatible with the movements of the stimuli. For example, in the naturalistic task, if the model used their left hand, which was located on the right side of the screen, participants were required to use their spatially incompatible left hand. Similarly, in the geometric condition, if the shape on the right moved, participants were required to use their spatially incompatible left hand. Spatially incompatible stimulus–response mappings were used here, as in several previous pen-and-cups experiments (Bird et al., 2007; Wohlschläger & Bekkering, 2002), because this arrangement yields more errors, and therefore reduces the risk of ceiling effects in this task (Avikainen et al., 2003; Leighton et al., 2008).

Each participant completed 10 practice trials followed by 80 test trials in each of the two conditions. The test trials comprised 10 presentations of each of the eight action sequences in the cups-coloured or the hands-coloured set, in random order.

Performance was videotaped and the experimenter recorded, for each trial, which hand, grip and cup had been selected by the participant. An error was recorded if the participant selected the incorrect hand or cup or used the incorrect grip as specified by the instructions. Thus, there were three types of errors, relating to the hand, grip and cup components of the task.

2.2. Results and discussion

The percentage error score for each component (cup, hand and grip) in each condition was calculated by dividing the number of errors made when responding to the target component in the target condition by the total number of errors made across all components in both conditions. For example, percentage cup error was calculated by dividing the number of trials on which the participant selected the wrong cup by the total number of cup, hand and grip errors made by that participant across all trials in both colour conditions.

As indicated in Fig. 3, similar error patterns were observed for the naturalistic and geometric tasks. In the cups-coloured condition participants showed the cup < hand < grip error pattern, while errors in the hands-coloured condition followed a different pattern, with the

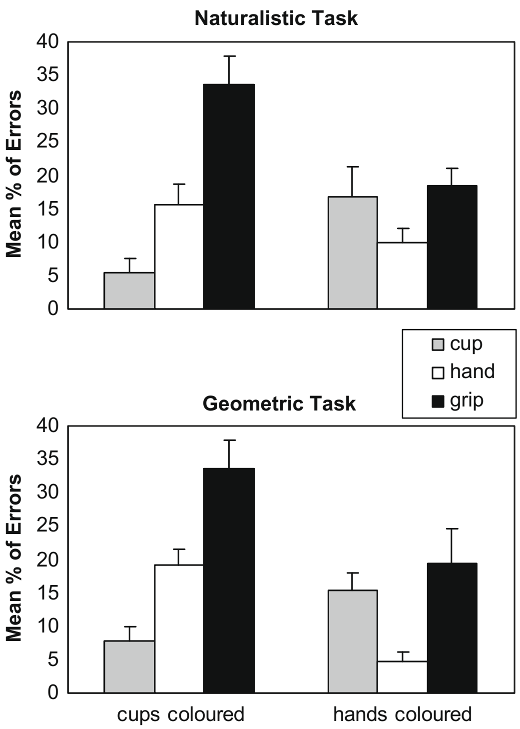

Fig. 3. Experiment 1. Mean percentage of errors in the naturalistic and geometric versions of the task. Grey bars represent errors on the cup component, white bars represent errors on the hand component and black bars represent errors on the grip component. Vertical bars indicate the standard error of the mean.

frequencies of cup and grip errors both exceeding the frequency of hand errors. Thus, a colour minimum error was observed in both the naturalistic and geometric tasks.

Analysis of Variance (ANOVA) with colour (cups-coloured, hands-coloured), and error type (cup, hand, grip) as within-subjects factors and task (naturalistic, geometric) as a between-subjects factor revealed significant main effects of colour, $F_{2,22} = 6.80$, $p = .016$, and error type, $F_{2,22} = 19.78$, $p < .001$. Participants made more errors in the cups-coloured condition than in the hands-coloured condition (cups-coloured, Mean: 19.13, SEM: .95; hands-coloured, Mean: 14.21, SEM: .95). Participants also made more hand errors than cup errors and more grip errors than hand errors (cup, Mean: 11.37, SEM: 1.34; hand, Mean: 12.23, SEM: 1.21; grip, Mean: 26.40, SEM: 1.97). There was a significant colour $\times$ error type interaction, $F_{2,22} = 13.11$, $p < .000$; in the cups-coloured condition, participants made fewer cup errors than hand or grip errors (cup, Mean: 6.52, SEM: 1.59; hand, Mean: 17.10, SEM: 2.04; grip, Mean: 33.77, SEM: 3.08) and in the hands-coloured condition participants made fewer hand errors than cup or grip errors (cup, Mean: 16.23, SEM: 2.51; hand, Mean: 7.36, SEM: 1.26; grip, Mean: 19.03, SEM: 2.92). There were no significant effects or interactions involving the task variable (all $F < 1$). Within-subjects contrasts, applied separately to the data from each condition, indicated that for the naturalistic task, in the cups-coloured condition there was a linear increase in percentage error across the cup, hand and grip categories, $F_{1,11} = 33.11$, $p < .001$, and in the hands-coloured condition the relationship between percentage error and error type was quadratic, $F_{1,11} = 11.77$, $p = .006$. In the cups-coloured condition, participants made fewer cup errors than hand or grip errors (cup, Mean: 5.37, SEM: 2.26; hand, Mean: 15.03, SEM: 3.20; grip, Mean: 34.05, SEM: 4.25) and in the hands-coloured condition participants made fewer hand errors than cup or grip errors (cup, Mean: 16.94, SEM: 4.32; hand, Mean: 10.05, SEM: 1.98; grip, Mean: 18.57, SEM: 2.62). Similarly, for the geometric task, in the cups-coloured condition, there was a linear increase in percentage error across the cup, hand and grip categories, $F_{1,11} = 18.60$, $p = .001$, and in the hands-coloured condition the relationship between percentage error and error type was quadratic, $F_{1,11} = 25.62$, $p < .000$. In these analyses no other polynomial contrasts approached significance. In the cups-coloured condition, participants made fewer cup errors than hand or grip errors (cup, Mean: 7.67, SEM: 2.24; hand, Mean: 19.16, SEM: 2.56; grip, Mean: 33.48, SEM: 4.45) and in the hands-coloured condition participants made fewer hand errors than cup or grip errors (cup, Mean: 15.52, SEM: 2.57; hand, Mean: 4.69, SEM: 1.55; grip, Mean: 19.48, SEM: 5.21).

In summary, the same pattern of performance was observed in the naturalistic and geometric versions of the task where abstract geometric stimuli, rather than observation of human action, specified the target response. In both tasks a colour minimum error pattern emerged. According to an intention reading account, this error pattern is due to inferences about the model's intentions. Since the stimuli used in the geometric task were unlikely to support the attribution of intentions, an intention reading account would not predict a colour minimum error in the geometric task. Therefore, the present results are inconsistent with the predictions made by an intention reading account. They are, however, consistent with the general process hypothesis which suggests that imitative performance is guided by task-general processes. According to this view, the colour minimum error pattern is due to perceptual and attentional processes that do not rely on the attribution of intentions and should, therefore, function in the same way when participants are responding to naturalistic human stimuli and geometric stimuli.

3. Experiment 2

The results of Experiment 1 suggest that imitation does not necessarily involve representation of the model's mentalistic goals or intentions. However, this conclusion rests on the assumption that abstract geometric shapes do not support the attribution of intentions, and this assumption may not be valid for the dynamic geometric stimuli used in Experiment 1.

It has been shown that viewing animated sequences of simple shapes conveys the impression of intentional goal-directed movements in typically developing individuals (Heider & Simmel, 1944). More recent studies investigating theory of mind abilities have shown that typically developing participants engage in mentalising when asked to describe the movements of geometric shapes (Castelli, Frith, Happe, & Frith, 2000; Castelli, Happe, Frith, & Frith, 2002). It has also been demonstrated that the attribution of agency is based on the type of motion or on interaction between objects (Heider & Simmel, 1944; Tremoulet & Feldman, 2000; Scholl & Tremoulet, 2000); shapes that do not move, and do not interact with one another, are less likely to support the attribution of mental states.

Therefore, in Experiment 2, static geometric stimuli were used to minimise the possibility that participants would attribute intentions to the shapes. If in Experiment 1 the colour minimum error pattern emerged in the geometric task because participants attributed mentalistic goals to the moving geometric stimuli, then this error pattern should not recur in Experiment 2 where the geometric shape cues were static rather than dynamic and interactive. In contrast, if the colour minimum error pattern in the geometric task in Experiment 1 was due to task-general perceptual and attentional processes, it should persist when the geometric cues are static.

Experiment 2 also contrasted movement responses to the static geometric stimuli, in which participants moved a pen into a cup, with verbal responses to the same stimuli. When responding verbally, participants named the task components, for example, by saying red when the red shape flashed, and blue when the blue shape flashed. The verbal task was introduced as an additional test of the hypothesis that mentalistic goal processing is an integral component of imitation. Some researchers have suggested that goal processing is an integral component of imitation in the sense that it occurs only, or plays a more important role, when participants are imitating – making isomorphic responses to action stimuli – than when they are responding symbolically or in a non-isomorphic way to action stimuli (Meltzoff, 1995; Wohlschläger et al., 2003). If this is correct, then even if participants attribute intentions to the static geometric stimuli in the movement task, they should not do so in the verbal task. Therefore, a colour minimum error pattern in the movement task and not in the verbal task, would suggest that mentalistic goals were attributed to the static geometric stimuli in the movement task, and that this generates the colour minimum error pattern. In contrast, a colour minimum error pattern in both movement and verbal tasks would confirm that this pattern is due to general perceptual and attentional processes, rather than to mentalistic goal attribution.

Finally, a grips-coloured manipulation was added to Experiment 2 to check the robustness of the finding, predicted by the general processes account and reported in Experiment 1, that the smallest proportion of errors will be made on the coloured component. If this is a robust principal, then one would expect, not only minimum cup errors in the cups-coloured condition and minimum hand errors in the hands-coloured condition, but also minimal grip errors in the grips-coloured condition. In order to vary grip colour in a manner analogous to that in which cup and hand colour were varied, the grip variable was changed such that, instead of a thumbs-up or thumbs-down grip, participants used an inside or outside grip. For an inside grip, participants held the pen between their index and middle fingers and for the outside grip they held the pen between their ring and little fingers.

3.1. Method

3.1.1. Participants

A further 24 consenting, healthy participants with an average age of 22.6 years, eight male, were recruited from the UCL Department of Psychology database and paid a small honorarium for their participation. All were right-handed, had normal or correct-to-normal vision, and were proficient in the English language. They were naïve with respect to the purpose of the experiment. Participants were randomly assigned to two groups; movement task and verbal task. Each participant was tested under all three conditions (hands-coloured, cups-coloured and grips-coloured) in a counterbalanced order. Two participants, who made no errors during the test trials, were replaced.

3.1.2. Apparatus and stimuli

The apparatus and stimuli were similar to those in the geometric condition of Experiment 1 except that the shapes on the screen did not change their positions in the course of each trial. Instead, they flashed to indicate the correct response. Fig. 4 depicts the layout of the new stimuli. The spatial configuration of the objects on the screen and the temporal properties of the flashing were matched to the movements from Experiment 1, i.e. each shape flashed for the same amount of time as it had moved in Experiment 1. Further details of the stimuli used in Experiment 2 can be found in Appendix A.

To enhance grip discriminability, Experiment 2 used a new grip manipulation. Instead of being required to perform an up or down grip, participants were required to

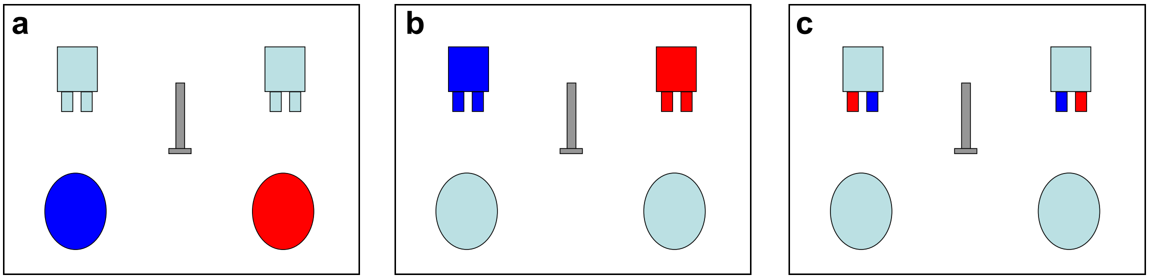

Fig. 4. Experiment 2. Images depicting the starting position of the stimuli in: (a) the cups-coloured condition, (b) the hands-coloured and (c) the grips-coloured condition. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

use an inside or outside grip. For an inside grip the participant held the pen between their index and middle fingers and for the outside grip they held the pen between their ring and little fingers. The new grip manipulation was represented in the stimulus layout by two rectangles attached to the bottom of the square. These indicated the use of either an inside or outside grip.

For participants in the movement group, the response apparatus was the same as that used in Experiment 1 for the cups-coloured and hands-coloured conditions except that in the grips-coloured condition the participant wore gloves with coloured fingers. The gloves were an off-white neutral colour except for blue index and middle fingers and red ring and little fingers. There was no pen and cup apparatus present for participants in the verbal group.

3.2. Procedure

The procedure was the same as in Experiment 1 except as follows. Each participant was tested under three conditions: cups-coloured, hands-coloured and grips-coloured. The order of cups-coloured, hands-coloured and grips-coloured conditions was counterbalanced across participants. Details of the specific task instructions can be found in Appendix B.

3.3. Results and discussion

As in Experiment 1, the percentage error score for each component (cup, hand and grip) in each condition was calculated by dividing the number of errors made when responding to the target component in the target condition by the total number of errors made across all components in both conditions.

As indicated in Fig. 5, the colour minimum error pattern was observed in all three colour conditions in both the movement and the verbal task.

ANOVA was applied to the percentage error scores, with colour (cups-coloured, hands-coloured, grips-coloured), and error type (cup, hand, grip) as within-subjects factors and task (movement, verbal) as a between-subjects factor revealed a significant main effect of colour $F_{2,22} = 4.23$, $p = .021$; overall, participants made fewest errors in the hands-coloured condition, more errors in the cups-coloured condition, and most errors in the grips-coloured condition (cups-coloured, Mean: 11.15, SEM: 1.18; hands-coloured, Mean: 8.10, SEM: 1.09; grips-coloured,

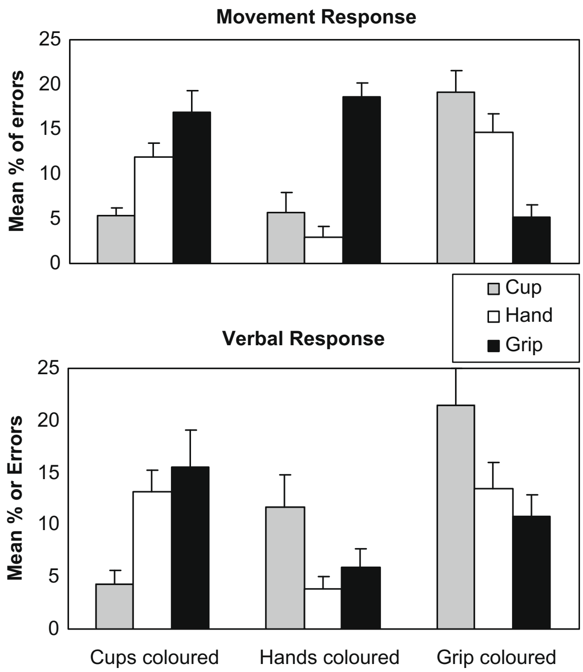

Fig. 5. Experiment 2. Mean percentage of errors in the movement and verbal response versions of the task. Grey bars represent errors on the cup component, white bars represent errors on the hand component and black bars represent errors on the grip component. Vertical bars indicate the standard error of the mean.

Mean: 14.09, SEM: 1.29). There was a significant colour × error type interaction, $F_{2,22} = 16.712$, $p < .001$; in the cups-coloured condition, participants made fewer cup errors than hand or grip errors (cup, Mean: 4.75, SEM: 1.11; hand, Mean: 12.52, SEM: 2.02; grip, Mean: 16.18, SEM: 2.79), in the hands-coloured condition they made fewer hand errors than cup or grip errors (cup, Mean: 8.67, SEM: 1.70; hand, Mean: 3.40, SEM: .74; grip, Mean: 12.21, SEM: 2.62 and in the grips-coloured condition they made fewer grip errors than cup or hand errors (cup, Mean: 20.25, SEM: 2.17; hand, Mean: 14.04, SEM: 2.04; grip, Mean: 7.99, SEM: 1.22). Finally, the analysis revealed a significant colour × error type × task interaction, $F_{2,22} = 3.98$, $p = .005$. The means and standard errors for this analysis are shown in Table 1. Inspection of the means suggests that the three-way interaction was due to different proportions of cup and grip errors, across tasks, in the

Table 1
Experiment 2. Means and standard errors for the colour × error × task interaction.

Task	Condition	Error	Mean	SEM
Movement	Cups-coloured	Cup	5.261	1.572
		Hand	11.819	2.856
		Grip	16.812	3.951
	Hands-coloured	Cup	5.620	2.406
		Hand	2.936	1.045
		Grip	18.568	3.714
	Grips-coloured	Cup	19.096	3.064
		Hand	14.654	2.881
		Grip	5.233	1.722
Verbal	Cups-coloured	Cup	4.229	1.572
		Hand	13.211	2.856
		Grip	15.552	3.951
	Hands-coloured	Cup	11.714	2.406
		Hand	3.873	1.045
		Grip	5.857	3.714
	Grips-coloured	Cup	21.404	3.064
		Hand	13.423	2.881
		Grip	10.736	1.722

hands-coloured condition. In the movement task participants made more cup errors than hand errors and more grip errors than cup errors (cup, Mean: 5.62, SEM: 2.41; hand, Mean: 2.93, SEM: 1.05; grip, Mean: 18.57, SEM: 3.71), and in the verbal task they made more grip errors than hand errors and more cup errors than grip errors (cup, Mean: 11.71, SEM: 2.40; hand, Mean: 3.87, SEM: 1.05; grip, Mean: 5.80, SEM: 3.71). Importantly, however, performance was most accurate with respect to the hand component in the hands-coloured condition of both tasks, and therefore the three-way interaction does not represent a departure from the colour minimum error pattern.

Within-subjects contrasts, applied separately to the data from each condition, indicated that for both tasks, in the cups-coloured condition, there was a linear increase in percentage error across the cup, hand and grip categories, (movement: $F_{1,11} = 2.64$, $p = .018$, verbal: $F_{1,11} = 13.63$, $p = .004$), in the hands-coloured condition the relationship between percentage error and error type was quadratic (movement: $F_{1,11} = 21.71$, $p = .001$, verbal: $F_{1,11} = 7.75$, $p = .018$), and in the grips-coloured condition there was a linear decrease in percentage error across the cup, hand and grip categories (movement: $F_{1,11} = 37.63$, $p < .000$, verbal: $F_{1,11} = 5.11$, $p = .045$). The means and standard errors for this analysis are shown in Table 1.

Thus, as predicted by the general process hypothesis, but not by an intention reading account, Experiment 2 found the colour minimum error pattern when participants made both movement and verbal responses to static geometric stimuli.

4. General discussion

Several theories suggest that actions are coded for imitation in terms of their goals, and that these goal representations solve the correspondence problem by mediating the translation of sensory representations into matching motor outputs (e.g., Gattis et al., 2002; Meltzoff & Moore, 1997; Wohlschläger et al., 2003). Goal representations are understood to encode either observable action end-states or the mental states of the model. The purpose of the present study was to test the latter, intention reading hypothesis against an alternative, general process account, which suggests that imitative performance is mediated by task-general, perceptual, attentional and motoric processes. In common with previous studies testing goal-directed accounts of imitation, we examined error patterns in the pen-and-cups task. This task has three dimensions: hand, grip and cup. On each trial, participants must decide whether to use their right or left hand, in one of two grips, to place a pen in one of two cups.

We used several variants of the pen-and-cups task, in which hand, grip and cup selection were all cued by a video recording of a human model performing the required movements (naturalistic, Experiment 1), by moving geometric shapes (geometric, Experiment 1), or by static geometric shapes (geometric, Experiment 2). In each version of the task, we varied the task dimension that was differentially coloured – either the hands, the cups or the grips were of different colours – and found a colour minimum error pattern; in all three task variants participants made fewer errors on the coloured task dimension than on the other, non-coloured dimensions.

In the naturalistic version of the task, this colour minimum error pattern could have been due the effects of differential colouring on participants' inferences about the model's mental states. For example, when the cups are coloured, participants' performance may be most accurate on the cup dimension because they infer that the model's primary intention is to ensure that she selects the correct cup. However, the emergence of the same colour minimum error pattern in the geometric versions of the task, where responses were cued by stimuli that do not support mental state attribution, suggests that this was not the case. The pervasiveness of the colour minimum error pattern across tasks implies that it is due, not to inferences about mental states, but to task-general processes. For example, when the cues for hand selection and the participants' own hands are differentially coloured, it is likely to be easier to detect which of the two hand cues is being presented on any given trial, and to map that cue to the appropriate response.

The colour minimum error pattern was clearly evident in all tasks and conditions used in the present study; it was observed ten times in total. However, a minor anomaly emerged in the hands-coloured condition of Experiment 2: when movement responses were required, participants made more grip than cup errors, but when verbal responses were required, they made more cup than grip errors. This interaction effect is likely to have been driven by the difficulty that participants experienced in executing the unfamiliar inside and outside grips used in Experiment 2. (Note that the grip error data in Experiments 1 and 2 are not directly comparable because in Experiment 1 we used a different – thumb-up versus thumb-down – grip manipulation.) In the verbal task in Experiment 2, participants were required to name but not to execute the inside and outside grips; thus, the requirements for correct responding on the grip component were less demanding in the verbal than in the movement task. Therefore, in the hands-coloured condition, where accuracy on the hand component was promoted by colour coding, verbal responding incurred a lower proportion of grip errors and a correspondingly higher proportion of cup errors than movement responding.

It has been suggested that error patterns in tasks, like the pen-and-cups task, provide support for the view that goals guide imitation. However, the results of the present study suggest that, contrary to this hypothesis, it is not necessary to invoke goal processing to explain imitation performance on this task. Consequently, the error patterns seen in the pen-and-cups task do not provide specific support for goal-directed theories. Rather the results from this study support the idea that imitation is guided by general processes.

General processes may also be responsible for other error patterns that have been interpreted as evidence that imitation is intrinsically goal-directed. For example, it has been suggested that contralateral-to-ipsilateral error patterns observed in the dots and hand-to-ear tasks demonstrate goal-directedness in imitation (e.g., Bekkering, 2002). In these tasks, the participant faces a demonstrator who touches one of two objects (ears or dots) with either their left or right hand, by making an ipsilateral or contralateral movement. Children and adults make a disproportionate number of contralateral-to-ipsilateral errors. That is, they make an ipsilateral movement to reach the correct goal, thus using the incorrect hand and movement. Like the error patterns in the pen-and-cups task, these results can be explained with reference to general processes. It is likely that, in the hand-to-ear and dots tasks, contralateral-to-ipsilateral errors are common because, during the trials in which they occur, the locations of the two objects (ears or dots) are fixed, whereas the locations of the two effectors (hands or fingers) change in the course of the trial (e.g., from left to right hemispace and back again). Consequently, effector selection is likely to be harder to discriminate than object selection, and therefore trials in which object selection is correct and effector selection incorrect (contralateral-to-ipsilateral errors) will occur more frequently than, for example, trials in which effector selection is correct and object selection incorrect (ipsilateral-to-contralateral errors).

The present findings have implications for research which uses performance on imitation paradigms as an indicator of theory of mind skills. For example, Want and Gattis (2005) argued that children with impaired theory of mind should also demonstrate impaired goal-directed imitation, that is, they should not show the typical error patterns in the dots task. They tested the imitative abilities of late-signing deaf children with suspected theory of mind impairments and found their performance to be equivalent to that of control children. This finding prompted Want and Gattis to conclude that late-signing deaf children had inferred the goals of the demonstrator, and therefore that an early form of mental state understanding was intact in these children. In contrast with this view, the results of the present study suggest that an understanding of mental state goals is not necessary for imitation, and therefore that one cannot validly infer theory of mind ability from imitative performance.

The results of the present study are consistent with the associative sequence learning model (ASL) of imitation (Brass & Heyes, 2005; Heyes, 2001, 2003; Heyes & Ray, 2000). This model assumes that the correspondence problem is solved by direct connections between sensory and motor representations of action, that these connections are forged by task- and species-general processes of associative learning, and that their operation is subject to the influence of general processes of perception, attention and motor control. (For evidence that attention plays a critical role in imitation, see Mattingley, Brander, Tan, Chong, & Cunnington, 2008.) Supported by the results of Experiments 1 and 2, the ASL model implies that imitation is made possible by a system in which sensory and motor representations are connected with one another directly, not via intermediate goal representations. Accordingly, it suggests that mentalistic goals do not solve the correspondence problem, and therefore do not explain how imitation is made possible by the neurocognitive system.

The results of the present study are also consistent with ideomotor theory (Brass, Bekkering, & Prinz, 2001; Brass, Bekkering, Wohlschläger, & Prinz, 2000; Prinz, 1997, 2002). This theory suggests that actions are represented in terms of their sensory consequences, and that action observation primes performance of the same action to the extent that the observed and executed actions have similar sensory consequences. This view can readily explain imitation of cup, hand and grip selection because these actions are perceptually transparent (Heyes & Ray, 2000), i.e. they yield similar visual effects when observed and executed. However, unlike the ASL model, ideomotor theory does not specifically address the imitation of perceptually opaque actions, such as facial expressions and whole body movements, which yield dissimilar sensory input when observed and executed (Leighton & Heyes, in press).

Of course, imitative behaviour, like non-imitative behaviour, is sometimes intentional: goals – representations of action end-states and of the intentions of others – sometimes play a role in determining which of a range of potential imitative and non-imitative actions are selected for overt performance. However, the results of the present study provide no evidence for a 'special relationship' between goals and imitation. Rather, they are consistent with the ASL model's suggestion that goals do not play a different or more important role in the generation of imitative than of non-imitative behaviour. According to this model goals do not explain the distinctive and defining feature of imitative action – the similarity between the behaviour of the model and that of the observer.

Appendix A

A.1. Stimuli – Experiment 1

In the naturalistic task, each video stimulus showed the hands, arms and torso of an adult female as she performed an action sequence. At the beginning of the action sequence, the pen stood upright on a black marker that was fixed to the table. The model grasped the pen using either her left or right hand, with a thumbs-up or thumbs-down grip, and placed the pen into one of two cups. Following these movements, the model carried out the actions described above in reverse to return the pen to the black marker.

The mean duration of naturalistic action sequences was 4660 ms (SEM = 128) for the cups-coloured condition and 4650 ms (SEM = 45) for the hands- coloured condition. The mean ITI was 1250 ms (SEM = 37.48) for the cups-coloured condition, and 1213 ms (SEM = 36.37) for the hands-coloured condition. Video stimuli were digitally recorded and presented in colour on an IBM compatible laptop computer with a 38-cm screen (resolution 1024×678 pixels), at approximately one third of life size. Video clips (720×576 pixels) were presented at a frame rate of 25 fps and a viewing distance of approximately 90 cm.

In the geometric task, at the beginning of each trial one of the squares moved downwards with a curved trajectory until it reached a long rectangle. While moving toward the long rectangle the square rotated 45° either clockwise or anticlockwise so that the short rectangle attached to it either pointed upwards to the top of the screen (i.e. was positioned on the top of the square) or downwards to the bottom of the screen (i.e. was positioned on the bottom of the square) as it reached the long rectangle. After it had reached the rectangle, both the long rectangle and square moved downwards together with a curved trajectory to one of the ellipses. While moving towards the ellipse, the objects rotated 90° either clockwise or anticlockwise so that the long rectangle, and the direction in which the small rectangle was pointing (up or down), were inverted when they reached the ellipse. Once the objects had reached the ellipse they paused momentarily and then followed the above steps in reverse until they had reached their starting state. The reverse movements were the equivalent of those used by the human model in the naturalistic task to replace the pen on the black marker.

The mean duration of the geometric action sequence, from shape movement onset until the shapes returned to their initial configuration, was 5255 ms (SEM = 165). The animation stimuli were presented in colour on an IBM compatible laptop computer with a 38 cm screen (resolution 1024×678 pixels), at a viewing distance of approximately 90 cm.

A.2. Stimuli – Experiment 2

In this experiment, consecutive stimulus flashes indicated which response to make. Initially, one of the squares flashed on and off the screen (specifying which hand was to be used), followed by the long rectangular object (corresponding to the pen in the naturalistic task) and finally one of the two ellipses (specifying the target cup). While the square flashed, one of the small rectangles attached to the squares disappeared briefly so that only one remained visible (specifying which grip to select). After the ellipse flashed, the shapes then followed the above steps in reverse, finishing with the square flashing. The reverse sequence corresponded to the reverse sequence used by the human model in the naturalistic task to replace the pen on the black marker.

Appendix B

B.1. Task instructions – Experiment 1

The instructions for those in the naturalistic group were as follows: in the cups-coloured condition, participants were instructed: (1) to use their left hand when the model used her left hand, and to use their right hand when the model used her right hand; (2) to grip the pen in the same thumb-up or thumb down configuration as the model; and (3) to place the pen in the cup of the same colour as the model.

In the hands-coloured condition, participants were instructed: (1) to use their red-coloured hand when the model used her red-coloured hand, and to use their blue-coloured hand when the model used her blue-coloured hand; (2) to grip the pen in the same thumb-up or thumb down configuration as the model; and (3) to place the pen in the cup on their left when the model placed the pen in the cup on her left, and to place the pen in the cup on their right when the model placed the pen in the cup on her right.

Instructions for those in the geometric group were as follows: in the cups-coloured condition, participants were instructed: (1) to use their left hand when the square on the right moved, and to use their right hand when the square on the left moved; (2) to grip the pen in the thumbs-up position when the small rectangle was positioned on the top of the square and to use the thumbs-down position when the small rectangle was positioned on the bottom of the square; and (3) to place the pen in the red cup when the objects moved to the red ellipse and in the blue cup when the objects moved to the blue ellipse.

In the hands-coloured condition, participants were instructed: (1) to use their red hand when the red square moved, and to use their blue hand when the blue square moved; (2) to grip the pen in the thumbs-up position when the small rectangle was positioned on the top of the square and to use the thumbs-down position when the small rectangle was positioned on the bottom of the square; and (3) to place the pen in the cup on their left when the objects moved to the ellipse on the right of the screen and in the cup on their right when the objects moved to the ellipse on the left of the screen.

B.2. Task instructions – Experiment 2

Instructions for those in the movement group were as follows: in the cups-coloured condition, participants were instructed: (1) to use their left hand when the square on the right flashed, and to use their right hand when the square on the left flashed; (2) to use an inside grip when the rectangle on the inside remained visible or an outside grip when the rectangle on the outside remained visible; and (3) to place the pen in the red cup when the red ellipse flashed and in the blue cup when the blue ellipse flashed.

In the hands-coloured condition, participants were instructed: (1) to use their red hand when the red square flashed, and to use their blue hand when the blue square flashed; (2) to use an inside grip when the rectangle on the inside remained visible or an outside grip when the rectangle on the outside remained visible; and (3) to place the pen in the cup on the left when the square on the right flashed, and in the cup on the right when the square on the left flashed.

In the grips-coloured condition, participants were instructed: (1) to use their left hand when the square on the right flashed, and to use their right hand when the square on the left flashed; (2) to use their red fingers to grip when the red rectangle remained visible and their blue fingers when the blue rectangle remained visible; and (3) to place the pen in the cup on the left when the square on the right flashed, and to place the pen in the cup on the right when the square on the left flashed.

Instructions for those in the verbal group were as follows: in the cups-coloured condition, participants were instructed: (1) to say "left", when the square on the right flashed, and to say "right" when the square on the left flashed; (2) to say "inside" when the rectangle on the inside remained visible and "outside" when the rectangle on the outside remained visible; and (3) to say "red" when the red ellipse flashed and "blue" when the blue ellipse flashed.

In the hands-coloured condition, participants were instructed: (1) to say "red" when the red square flashed, and to say "blue" when the blue square flashed; (2) to say "inside" when the rectangle on the inside remained visible and "outside" when the rectangle on the outside remained visible; and (3) to say "left" when the ellipse on the right flashed, and "right" when the ellipse on the left flashed.

In the grips-coloured condition, participants were instructed: (1) to say "left" when the square on the right flashed, and to say "right" when the square on the left flashed; (2) to say "red" when the red rectangle remained visible and "blue" when the blue rectangle remained visible; and (3) to say "left" when the ellipse on the right flashed, and "right" when the ellipse on the left flashed.

References

Avikainen, S., Wohlschläger, A., Liuhanen, S., Hanninen, R., & Hari, R. (2003). Impaired mirror-image imitation in Asperger and high-functioning autistic subjects. *Current Biology, 13*, 339–341.

Bekkering, H. (2002). Imitation: A tool to study the underlying mechanisms of intentional action control. Paper presented to the European society for philosophy and psychology, Lyon, July 2002.

Bekkering, H., & Wohlschläger, A. (2002). Is human imitation based on a mirror-neurone system? Some behavioural evidence. *Experimental Brain Research, 143*, 335–341.

Bekkering, H., Wohlschläger, A., & Gattis, G. (2000). Imitation of gestures in children is goal-directed. *Quarterly Journal of Experimental Psychology, 53*, 153–164.

Bellagamba, F., & Tomasello, M. (1999). Re-enacting intended acts: Comparing 12- and 18-month-olds. *Infant Behaviour and Development, 22*, 277–282.

Bird, G., Brindley, R., Leighton, J., & Heyes, C. M. (2007). General processes, rather than 'goals', explain imitation errors. *Journal of Experimental Psychology: Human Perception and Performance, 33*, 1158–1169.

Brass, M., Bekkering, H., & Prinz, W. (2001). Movement observation affects movement execution in a simple response task. *Acta Psychologica, 106*, 3–22.

Brass, M., Bekkering, H., Wohlschläger, A., & Prinz, W. (2000). Compatibility between observed and executed finger movements: Comparing symbolic, spatial, and imitative cues. *Brain and Cognition, 44*, 124–143.

Brass, M., & Heyes, C. M. (2005). Imitation: Is cognitive neuroscience solving the correspondence problem? *Trends in Cognitive Sciences, 9*, 489–495.

Byrne, R. (1993). Hierarchical levels of imitation. Commentary on M. Tomasello, A.C. Kruger, & H.H. Ratner "Cultural learning". *Behavioral and Brain Sciences, 16*, 516–517.

Byrne, R. (1999). Imitation without intentionality: Using string-parsing to copy the organization of behaviour. *Animal Cognition, 2*, 63–72.

Byrne, R. (2003). Imitation as behavior parsing. *Philosophical Transactions of the Royal Society of London B, 358*, 529–536.

Byrne, R. W., & Russon, A. E. (1998). Learning by imitation: A hierarchical approach. *Behavioral and Brain Sciences, 21*, 667–721.

Carpenter, M., Akhtar, N., & Tomasello, M. (1998). Fourteen-through-18-month-old infants differentially imitate intentional and accidental actions. *Infant Behaviour and Development, 21*, 315–330.

Carpenter, M., Call, J., & Tomasello, M. (2005). Twelve- and 18-month-olds copy actions in terms of goals. *Developmental Science, 8*, 13–20.

Carpenter, M., Nagell, K., & Tomasello, M. (1998). Social cognition, joint attention and communicative competence from 9 to 15 months of age. *Monographs of the Society for Research in Child Development, 63*, 1–143.

Castelli, F., Frith, C., Happé, F., & Frith, U. (2002). Autism, Asperger syndrome and brain mechanisms for the attribution of mental states to animated shapes. *Brain, 125*, 1839–1849.

Castelli, F., Happé, F., Frith, U., & Frith, C. (2000). Movement and mind: A functional imaging study of perception and interpretation of complex intentional movement patterns. *Neuroimage, 12*, 314–325.

Gattis, M., Bekkering, H., & Wohlschläger, A. (2002). Goal-directed imitation. In A. N. Meltzoff & W. Prinz (Eds.), *The imitative mind* (pp. 183–205). Cambridge University Press.

Gleissner, B., Meltzoff, A. N., & Bekkering, H. (2000). Children's coding of human action: Cognitive factors influencing imitation in 3-year-olds. *Developmental Science, 3*, 405–414.

Head, H. (1963). *Aphasia and kindred disorders of speech* (Vol. 1). Cambridge: Cambridge University Press.

Heider, F., & Simmel, M. (1944). An experimental study of apparent behavior. *American Journal of Psychology, 57*, 243–259.

Heyes, C. M. (2001). Causes and consequences of imitation. *Trends in Cognitive Sciences, 5*, 253–261.

Heyes, C. M. (2003). Four routes of cognitive evolution. *Psychological Review, 110*, 713–727.

Heyes, C. M., & Ray, E. D. (2000). What is the significance of imitation in animals? *Advances in the Study of Behavior, 29*, 215–245.

Huang, C.-T., Heyes, C. M., & Charman, T. (2002). Infants' behavioral re-enactment of 'failed attempts': Exploring the roles of emulation learning, stimulus enhancement and understanding of intentions. *Developmental Psychology, 38*, 840–855.

Johnson, S. C., Booth, A., & O'Hearn, K. (2001). Inferring the goals of a non-human agent. *Cognitive Development, 16*, 637–656.

Leighton, J., & Heyes, C. M. (in press). Hand to mouth: Automatic imitation across effector systems. *Journal of Experimental Psychology: Human Perception and Performance*.

Leighton, J., Bird, G., Charman, T., & Heyes, C. M. (2008). Weak imitative performance is not due to a mirroring deficit in adults with autism spectrum disorders. *Neuropsychologia, 46*, 1041–1049.

Mattingley, J. B., Brander, C., Tan, D., Chong, T., & Cunnington, R. (2008). Activity within the human mirror system during imitation of unseen hand actions: An fMRI study using continuous flash suppression. Paper presented at the annual meeting of the cognitive neuroscience society.

Meltzoff, A. N. (1995). Understanding the intentions of others: Re-enactment of intended acts by 18-month-old children. *Developmental Psychology, 31*, 838–850.

Meltzoff, A. N. (2002). Elements of a developmental theory of imitation. In A. N. Meltzoff & W. Prinz (Eds.), *The imitative mind: Development, evolution, and brain bases* (pp. 19–41). Cambridge: Cambridge University Press.

Meltzoff, A. N., & Gopnik, A. (1993). The role of imitation in understanding persons and developing a theory of mind. In S. Baron-Cohen, H. Tager-Flusberg, & D. J. Cohen (Eds.), *Understanding other minds: Perspectives from autism* (pp. 335–366). New York: Oxford University Press.

Meltzoff, A. N., & Moore, M. K. (1997). Explaining facial imitation: A theoretical model. *Early Development and Parenting, 6*, 179–192.

Perra, O., & Gattis, M. (2008). Reducing the mapping between perception and action facilitates imitation. *British Journal of Developmental Psychology, 26*, 133–144.

Prinz, W. (1997). Perception and action planning. *European Journal of Cognitive Psychology, 9*, 129–154.

Prinz, W. (2002). Experimental approaches to imitation. In A. N. Meltzoff & W. Prinz (Eds.), *Imitative mind: Development, evolution, and brain bases* (pp. 143–162). New York: Cambridge University Press.

Sanefuji, W., Hashiya, K., Itakura, S., & Ohgami, H. (2004). Emergence of the understanding of the other's intention: Reenactment of intended acts from "failed-attempts" in 12- to 24-month olds. *Psychologia: An International Journal of Psychology in the Orient, 47*, 10–17.

Scholl, B. J., & Tremoulet, P. D. (2000). Perceptual causality and animacy. *Trends in Cognitive Sciences, 4*, 299–309.

Tomasello, M., Kruger, A., & Ratner, H. (1993). Cultural learning. *Behavioural and Brain Sciences, 16*, 495–592.

Tremoulet, P. D., & Feldman, J. (2000). Perception of animacy from the motion of a single object. *Perception, 29*, 943–951.

Trevarthen, C. (1984). How control of movement develops. In H. Whiting (Ed.), *Human motor actions: Bernstein reassessed* (pp. 223–261). Amsterdam: North-Holland.

Trevarthen, C. (1994). Infant semiosis. In W. Noth (Ed.), *Origins of semiosis* (pp. 219–252). Berlin: Mouton de Gruyter.

Want, S., & Gattis, M. (2005). Are "late-signing" deaf children "mindblind"? Understanding goal directedness in imitation. *Cognitive Development, 20*, 159–172.

Wohlschläger, A., & Bekkering, H. (2002). Is human imitation based on a mirror-neurone system? Some behavioural evidence. *Experimental Brain Research, 143*, 335–341.

Wohlschläger, A., Gattis, M., & Bekkering, H. (2003). Action generation and action perception in imitation: An instance of the ideomotor principle. *Philosophical Transactions of the Royal Society of London B, 358*, 501–515.