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General Processes, Rather Than “Goals,” Explain Imitation Errors

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The goal-directed theory of imitation (GOADI) states that copying of action outcomes (e.g., turning a light switch) takes priority over imitation of the means by which those outcomes are achieved (e.g., choice of effector or grip). The object < effector < grip error pattern in the pen-and-cups task provides strong support for GOADI. Experiment 1 replicated this effect using video stimuli. Experiment 2 showed that shifting the color cue from objects to effectors makes imitation of effector selection more accurate than imitation of object and grip selection. Experiment 3 replicated this result when participants were required to describe actions. Experiment 4 indicated that, when participants are imitating and describing actions, enhancing grip discriminability makes grip selection the most accurately executed component of the task. Consistent with theories that hypothesize that imitation relies on task-general mechanisms (e.g., the associative sequence learning model, ideomotor theory), these findings suggest that imitation is no more or less goal directed than other tasks involving action observation.

Keywords: imitation, associative sequence learning (ASL), goal-directed theory of imitation (GOADI), pen and cups task, mirror neuron

It is often claimed that “goals” guide imitative performance, that when an observer copies the behavior of a model, the reproduction of action outcomes takes priority over imitation of the body movements through which they were achieved. According to this view, a child understands that it is more important to make a toy squeak than to squeeze it with the same hand as an adult, and a golfer wants to get the ball on the green more than he or she wants to copy a particular swing. The idea that imitation is goal directed has been central to the study of imitation in children (Bekkering, Wohlschläger, & Gattis, 2000; Carpenter, Akhtar, & Tomasello, 1998; Gergely, Bekkering, & Kiraly, 2002; Huang & Charman, 2005; Meltzoff, 1995) and in nonhuman primates (Byrne, 2003; Byrne & Byrne, 1991) for some time. In recent years, it has also become a prominent theme in research on the cognitive neuroscience of imitation and the *mirror system* (Chaminade, Meltzoff, & Decety, 2002; Iacoboni, 2005; Koski et al., 2002; Wohlschläger & Bekkering, 2002).

The *theory of goal-directed imitation* (GOADI) provides the most explicit, comprehensive, and well-supported statement to date of the view that goals guide imitative performance (Bekkering et al., 2000; Gattis, Bekkering, & Wohlschläger, 2002; Wohlschläger, Gattis, & Bekkering, 2003). GOADI consists of a number of postulates:

1. *Decomposition:* The perceived act is cognitively decomposed into separate aspects.

2. *Selection of goal aspects:* Owing to capacity limitations, only a few goal aspects are selected.

3. *Hierarchical organization:* The selected goal aspects are hierarchically ordered. The hierarchy of goals follows the functionality of actions. Ends, if present (e.g., objects and [their treatments]) are more important than means (e.g., effectors and movement paths).

4. *Ideomotor principle:* The selected goals elicit the motor programs with which they are most strongly associated. These motor programs do not necessarily lead to matching movements, although they might do so in many everyday cases.

5. *General validity:* There is no essential difference in imitation behavior between children, adults, and animals. Differences in accuracy are attributable to differences in working memory (Wohlschläger et al., 2003).

Several features of this theory are particularly important with respect to the experiments reported here. First, GOADI postulates that goals are priorities for imitative performance selected from a range of stimulus features already analyzed by the perceptual system. Second, regarding hierarchical organization, GOADI states clearly that the selection and treatment of objects has priority over choice of effectors and movement paths. Third, GOADI suggests that the processes mediating imitation have both general and special properties. The general properties relate to the ideo-

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motor principle and to the theory's range. GOADI assumes that, like other action plans, imitative goals produce body movement through activation of their most strongly associated motor programs (see Postulate 4 above) and that a single set of processes mediate imitation across species and throughout human development (see Postulate 5 above). However, GOADI implies that the processes mediating imitation are special—distinct from those mediating performance of other perceptual–motor tasks—in their reliance on decomposition, selection of goal aspects, and hierarchical organization. This claim about the distinctiveness of the goal selection processes mediating imitation is implicit in GOADI. It is presented as a theory of imitation; goal selection processes (see Postulates 1–3 above) are key features of the theory; and, unlike the ideomotor principle (see Postulate 4 above), they are not said to characterize performance in nonimitative tasks. Furthermore, the designs of some experiments conducted by the authors of GOADI indicate that it is intended to apply to imitative but not to nonimitative action (e.g., Wohlschläger et al., 2003, see below).

Evidence consistent with GOADI has come from studies of imitation in both children and adults. Developmental studies have typically used hand-and-ear tests (Head, 1920). In these tests, a child faces an adult as, on each trial, the adult touches his or her left or right ear with his or her left or right hand (four trial types). From 3 years of age, children who are either instructed to mirror imitate these actions (e.g., to copy movements of the model's right hand with their own [spatially compatible] left hand; Bekkering et al., 2000; Gleissner, Meltzoff, & Bekkering, 2000; Gordon, 1923; Schofield, 1976; Wapner & Cirillo, 1968) or allowed to imitate spontaneously (Wohlschläger et al., 2003) make a disproportionately large number of contralateral-to-ipsilateral errors. For example, if the adult touches their left ear with their right hand, the child touches their right ear, which is correct, but performs this action using their right hand in an ipsilateral movement path rather than their left hand in a contralateral movement path. Thus, children imitate object selection—choice of an ear to touch—more reliably than they imitate selection of an effector and movement path.

An earlier hypothesis suggested that rather than being a result of preferential imitation of object selection, children's contralateral-to-ipsilateral errors are attributable to the immaturity of neurological connections across the body's midline. This *lateral bifurcation* hypothesis has been discredited by evidence that in a speeded version of the hand-and-ear test, adults also make more contralateral-to-ipsilateral than ipsilateral-to-contralateral errors (Wohlschläger et al., 2003).

Variants of the hand-and-ear task have provided more specific evidence in support of GOADI. For example, children persist in making contralateral-to-ipsilateral errors when the model is wearing one black and one white glove, suggesting that these errors are attributable to postperceptual goal selection rather than a failure to discriminate between the model's hands (Gattis et al., 2002). In contrast, when children are shown photographs of the stimulus movements and asked to select matching photographs rather than to imitate, they do not make a disproportionate number of contralateral-to-ipsilateral errors, prompting Wohlschläger et al. (2003) to conclude that the errors "specifically occur under imitation and not in a more perceptually oriented task" (p. 504). This suggests both that children do not have difficulty in discriminating the hand used and that the goal selection processes postulated by GOADI are specific to imitation.

Further tests of GOADI have used the dots task and the pen-and-cups task. In the children's version of the dots task, the participant and the model/experimenter face one another across a table. On each trial, the model touches the table at a location on his or her left or right side using his or her left or right hand. In the dot condition, the target locations are marked with colored circles, and in the no-dot condition they are unmarked. As predicted by GOADI, contralateral-to-ipsilateral errors have predominated in the dot condition, in which objects (i.e., dots) are candidate goals but not in the no-dot condition, in which, in the absence of objects, effector or movement path selection can take priority (Bekkering et al., 2000, Experiment 3). Similarly, in an adult version of the dots task, in which participants were required to imitate contralateral and ipsilateral finger movements, more contralateral-to-ipsilateral errors were made when the movements were directed to dots than when they terminated at unmarked locations (Wohlschläger & Bekkering, 2002).

The pen-and-cups task, developed specifically to test GOADI with adults, allows three features of action to be manipulated independently: object selection, effector selection, and grip selection. On each trial in this speeded response procedure, the participant sees a model move a centrally located pen into one of two colored cups (object), using his or her right or left hand (effector), while grasping the pen with his or her thumb pointing up or down (grip). Both when they are required to mirror imitate and when they are required to transpose (e.g., right hand movements are copied with the spatially incompatible right hand), adults make fewer cup errors than hand errors and fewer hand errors than grip errors (Avikainen, Wohlschläger, Liuhanen, Hanninen, & Hari, 2003; Wohlschläger & Bekkering, 2002). Consistent with GOADI, this cup $<$ hand $<$ grip error pattern implies that when processing resources are limited, imitation of object selection takes priority over imitation of effector selection, which, in turn, takes priority over imitation of the details of response topography.

Using a variety of procedures, the foregoing studies have provided evidence that ends are imitated more accurately than means. GOADI states that this bias is attributable to goal selection processes, and it implies that these processes are imitation specific. In contrast with this proposal, "generalist" theories of imitation deny that imitation involves special-purpose mechanisms (Brass & Heyes, 2005). For example, ideomotor theory, which is invoked by the fourth postulate of GOADI, subsumes imitation within a general account of motor control (e.g., Prinz, 1997), and the associative sequence learning (ASL) model claims that the capacity to imitate is a product of task-general processes of associative learning (Heyes, 2001; Heyes & Ray, 2000). The details of these theories are unimportant for the present debate, but by denying that imitation involves special-purpose mechanisms, they encourage a reexamination of the evidence in favor of GOADI.

If generalist models are correct, the error patterns observed in the hand-and-ear, dots, and pen-and-cups tasks are a result of task-general mechanisms, such as perceptual processes, rather than of imitation-specific processes of goal selection. The present study tested this generalist hypothesis against GOADI using the pen-and-cups task. We chose this task because its results are the most difficult to explain with reference to the operation of general perceptual and attentional processes. It is plausible 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 over time (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 on which object selection is correct and effector selection is incorrect (contralateral-to-ipsilateral errors) will occur more frequently than, for example, trials on which effector selection is correct and object selection is incorrect (ipsilateral-to-contralateral errors). It is more difficult to see how perceptual and attentional factors could account for performance in the pen-and-cups task. because it examines three, rather than two, dimensions of object-directed action—object, effector, and grip selection—and the spatial codes distinguishing levels of two of these factors—effector and grip selection—change in the course of action sequences.

The generalist hypothesis tested against GOADI in the present study suggests that the error pattern observed in the pen-and-cups task depends on the relative discriminability of the three factors—cup, hand, and grip. In all implementations of the task to date, the cups, but not the hands or the grips, were of different colors. Thus, the cups were more readily discriminable than the hands or the grips. As a result, participants may have made fewer cup errors than hand or grip errors because it was easier for them to determine which of the cups had been selected on any given trial. Similarly, previous studies may have found more grip than cup or hand errors because, in all versions of the task used to date, the two grips were applied at approximately the same spatial location, and only one of them was present in the stimulus display at any given time. In contrast, the model's two cups and two hands were simultaneously present at distinct spatial locations. Therefore, the relatively high incidence of grip errors may have been a result of difficulty in perceiving which of the grips had been selected on each trial.

Experiment 1 used video stimulus presentation to replicate the cup < hand < grip error pattern observed in previous studies involving the pen-and-cups task (Avikainen et al., 2003). Experiment 2 examined the role of color coding by comparing error patterns when the cups or the hands were of different colors. Experiment 3 investigated whether color coding of the cups or the hands had the same effect in a nonimitative version of the pen-and-cups task. Using both imitative and nonimitative versions of the task, the final experiment asked whether stimulus factors explain not only the low incidence of cup errors but also the high incidence of grip errors observed in previous studies (Avikainen et al., 2003; Wohlschläger & Bekkering, 2002).

Experiment 1

In previous work using the pen-and-cups task, action sequences have been presented for imitation by a live model rather than on video (Avikainen et al., 2003; Wohlschläger & Bekkering, 2002). Consequently, stimulus parameters could not be standardized across trials and participants, and important features, such as sequence duration and intertrial interval (ITI), could not be recorded. The principal purpose of Experiment 1 was to replicate the cup < hand < grip error pattern observed in these studies using video stimuli with controlled parameters. Therefore, one group of participants was given the same pen-and-cups task, apparatus, and instructions as in the previous studies but presented with action stimuli on video rather than by a live model. This grip–cup group imitated action sequences in which a pen was grasped with the right or the left hand, using an up or a down grip, and then placed in one of two cups.

The secondary purpose of Experiment 1 was to find out whether the cup < hand < grip error pattern depends on the order of events in the pen-and-cups task. This was investigated by requiring a second group of participants (cup–grip) to imitate video-recorded action sequences in which the model moved their right or their left hand towards one of two cups, grasped the pen inside that cup using an up or a down grip, and then removed the pen to a central location. Thus, whereas participants in the grip–cup group, like those in previous studies, saw (and enacted) grip selection before cup selection, those in the cup–grip group observed (and enacted) cup selection before grip selection.

We manipulated the order of events simply to assess the robustness of the cup < hand < grip error pattern observed in previous studies; neither GOADI nor the generalist hypothesis would predict that the order of events would influence the error pattern. Thus, if video stimuli generate the same effects as live stimuli, both hypotheses predict fewer cup than hand errors and fewer hand than grip errors in the grip–cup group and in the cup–grip group.

To maximize the number of errors available for analysis, we required all participants to engage in transposition imitation—that is, to respond to the hand and cup components of modeled actions using anatomically compatible and egocentrically incompatible stimulus–response (S-R) mappings. For example, when the model, who was facing participants, used her left hand, participants were required to imitate the action using their left hand. A previous experiment, using a live model and grip–cup presentation, showed that typically developing adults make more errors with anatomically compatible than with egocentrically compatible mappings and that the cup < hand < grip error pattern is evident in both cases (Avikainen et al., 2003).

Method

Participants. Thirty-two students at University College London, London, United Kingdom (9 men and 23 women), participated in the experiment. They were randomly assigned in equal numbers to two groups, grip–cup and cup–grip. Their mean age was 21.6 years, and each was paid a small honorarium (~$5) for their participation. Two participants who did not make any errors were replaced. All had normal or corrected-to-normal vision and were naive with respect to the purpose of the experiment.

Stimuli and apparatus. Each video stimulus showed the hands, arms, and torso—but not the face—of a female adult as she performed an action sequence involving two cups and one or two pens. These objects were laid out on a table in front of the model. Figures 1a and 1b show their spatial arrangement and the location of the model's and the participant's hands at the beginning of each action sequence. There were two sets of eight action sequences. In the grip–cup set, the model grasped a centrally located pen and, reaching forward, placed it upside down in one of the two cups before returning the pen to its starting position. Thus, in this set, the model was seen to select a grip before she selected a cup. In the cup–grip set, in which cup selection preceded grip selection, the model reached forward and grasped one of two pens, lifted it out of its cup, placed it upside down at a central location, and then put it back in the same cup in the upright position.

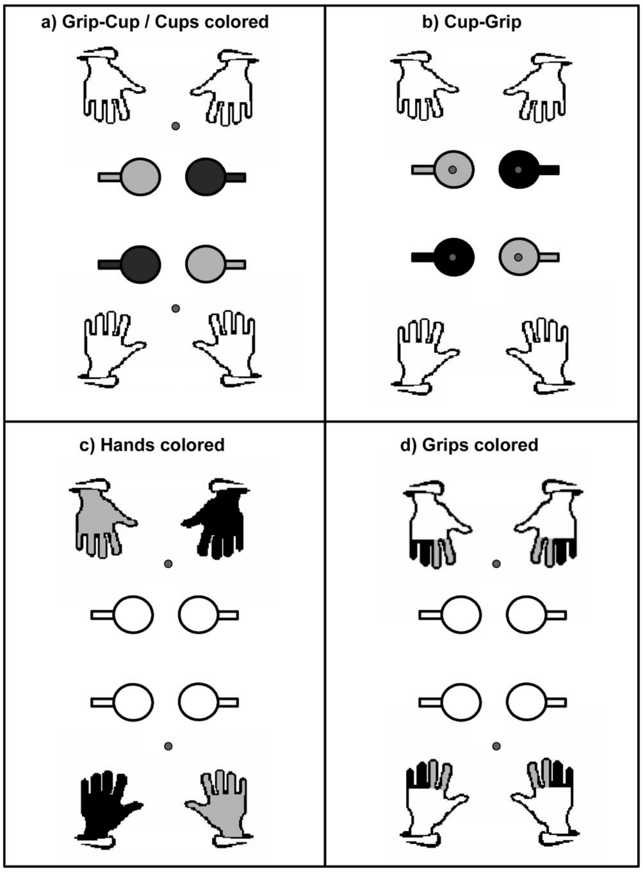

Figure 1. Diagrams indicating the spatial relationships between the objects and effectors at the beginning of each trial for a the grip–cup group in Experiment 1, the cups-colored groups in Experiments 2 and 3, and the cups-colored conditions in Experiment 4 (a); the cup–grip group in Experiment 1 (b); the hands-colored group in Experiments 2 and 3 (c); and the grips-colored conditions in Experiment 4 (d). The small dark circles represent pen locations. The larger circles represent cups with handles.

The eight sequences in each set were constructed by factorial combination of three variables: the color of the cup in which the pen was placed or from which it was retrieved (orange or green), the hand used to perform the action (left or right), and the grip applied to the pen (up or down). When the model used the up grip, her thumb pointed upward toward the cap of the pen, and when she used the down grip, her thumb pointed downward toward the base of the pen. The mean duration of each grip–cup action sequence was 5,255 ms (*SEM* = 165), and the mean duration of each cup–grip action sequence was 3,200 ms (*SEM* = 21) The mean ITI was 610 ms (*SEM* = 23) for the grip–cup sequences and 356 ms (*SEM* = 22) for the cup–grip sequences.

Video stimuli were digitally recorded and presented in color 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 per second and a viewing distance of approximately 90 cm.

To make their responses, participants used the same set of objects, in the same spatial configuration, as the model they observed (see Figures 1a and 1b). For the grip–cup group, which observed the grip–cup action sequences, 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. The layout for the cup–grip group, which saw the cup–grip action sequences, was the same except that at the start of each trial, each cup contained a pen in an upright (cap-upward) orientation. Each cup was 8 cm in diameter and 10 cm high. The pens (1.5 cm diameter and 14 cm high) were white with green caps. A transparent 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.

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 video stimuli were presented. They were told that they would be shown a video and that while watching it, they should imitate the movement sequences as simultaneously as possible, paying equal attention to three aspects: the hand (left/right), the grip (up/down), and the cup (orange/green). More specifically, participants were instructed (a) 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, (b) to grip the pen in the same thumb-up or thumb-down configuration as the model, and (c) to place the pen in (grip–cup group) or retrieve it from (cup–grip group) the cup of the same color as the model.

Each participant completed 10 practice trials followed by 80 test trials. The test trials comprised 10 presentations of each of the eight action sequences in the grip–cup or the cup–grip set, in random order.

Task performance was videotaped and subsequently scored by two independent observers. They recorded, for each trial, which hand, grip, and cup had been selected by the participant. An error was recorded if the participant's selection did not match that of the model, as specified in the instructions. Thus, there were three types of errors—relating to the hand, grip, and cup components of the task, respectively.

Results and Discussion

The cup–grip group, for which the ITI was shorter, made more errors ($M = 29$, $SEM = 3$) than the grip–cup group ($M = 7$, $SEM = 1$), $F(1, 30) = 38.5$, $p < .0001$. We analyzed the pattern of errors across the three features of the task—cup, hand, and grip—using a percentage measure. For example, percentage of cup error was calculated by dividing the number of trials on which a participant selected the wrong cup by the total number of cup, hand, and grip errors made by that participant across all trials.

As indicated in Figure 2, both groups showed the pattern of errors reported in previous studies using the pen-and-cups task; cup errors were less frequent than hand errors, and hand errors were less frequent than grip errors (Avikainen et al., 2003; Wohlschläger & Bekkering, 2002). Analysis of variance (ANOVA), in which the within-subject variable was error type (cup, hand, grip) and the between-subjects variable was group (grip–cup, cup–grip), was applied to the percentage error scores. There was a significant main effect of error type, $F(2, 60) = 26.6$, $p < .0001$, $\eta_p^2 = .47$, but the effects of group ($F < 1$, $\eta_p^2 = .03$) and the Error Type × Group interaction ($F < 1$, $\eta_p^2 = .00$), were not reliable. Within-subject contrasts, applied separately to the

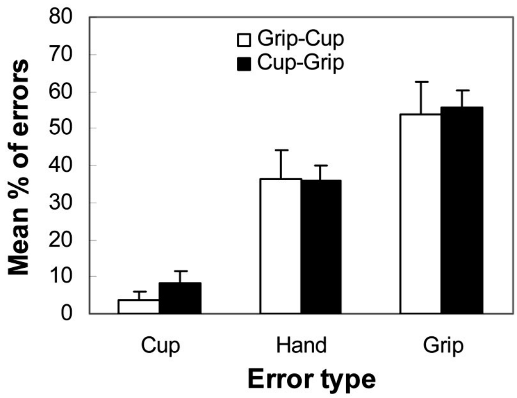

Figure 2. Mean percentages of cup, hand, and grip selection errors in Experiment 1. Participants imitated action sequences in which the model placed a pen in one of two cups (grip–cup) or removed a pen from one of two cups (cup–grip). Error bars represent standard errors of the mean.

data from each group, indicated that there was a linear increase in percentage error across the cup, hand, and grip categories in the grip–cup group, $F(1, 15) = 23.9$, $p < .0001$, $\eta_p^2 = .61$, and in the cup–grip group, $F(1, 15) = 51.8$, $p < .0001$ $\eta_p^2 = .78$.

These results indicate that the cup < hand < grip error pattern is robust in at least two respects. First, it occurs not only with a live model, as in previous studies, but also when the action sequence stimuli are presented on video. It is clear, therefore, that the pattern does not depend on social interaction between the participant and the model or even on seeing the model's face. Second, the error pattern occurs both when grip selection is observed prior to cup selection in each trial (grip–cup group) and when cup selection is observed prior to grip selection (cup–grip group). This evidence of the robustness of the cup < hand < grip error pattern provided a firm basis for the remaining experiments, in which video-based variants of the standard pen-and-cups task were used to examine the impact of stimulus factors on the distribution of errors.

Experiment 2

GOADI implies that the cup < hand < grip error pattern reflects an imitation-specific hierarchy of goals that assigns higher priority to object selection than to effector selection and higher priority to effector selection than to grip selection. The alternative, generalist hypothesis suggests that the error pattern depends on task-general mechanisms such as those involved in perceptual processing. In particular, the generalist hypothesis suggests that cup selection has been found to be more accurate than hand selection because coloring of the cups has made them more discriminable than are the hands. If the cups were more discriminable than the hands, it would have been easier to detect, on each trial, which cup the model had selected than to determine which hand the model had selected.

The purpose of Experiment 2 was to test this generalist account against the GOADI hypothesis: to find out whether the pattern of errors in the pen-and-cups task depends on color coding of action components. To this end, we gave two groups of participants the standard, grip–cup version of the task with video stimuli. As in previous experiments, the cups-colored group saw action sequences in which the two cups, but not the two hands or the two grips, were of different colors. In contrast, the hands-colored group saw action sequences in which the two hands, but not the two cups or the two grips, were of different colors. GOADI ascribes the cup < hand < grip error pattern to the operation of an imitation-specific hierarchy of goals and, therefore, would predict the occurrence of this pattern in both groups. In contrast, the generalist hypothesis, implicating task-general perceptual factors, predicts that whereas the cups-colored group will show the cup < hand < grip error pattern, the hands-colored group will make more cup than hand errors, generating a novel cup > hand < grip pattern.

Method

Participants. A further 32 University College London students (14 men and 18 women) participated in the experiment. Their mean age was 23.6 years, and each was paid a small honorarium (~$5) for their participation. They were randomly assigned in equal numbers to two groups, cups-colored and hands-colored. Their mean age was 23.6 years. Two participants who made no errors during the test trials and 1 who did not obey task instructions were replaced. All participants had normal or corrected-to-normal vision and were naive with respect to the purpose of the experiment.

Apparatus and stimuli. The stimuli and apparatus were the same as those of Experiment 1 except as noted. In line with previous experiments using the pen-and-cups task, and in contrast with Experiment 1, the colors used in Experiment 2 were red and blue. All participants saw grip–cup action sequences, in which a pen was grasped, inverted, and placed upside down in one of two cups (see Figures 1a and 1c). The model for the hands-colored group and the participants in this group wore a red glove on the left hand and a blue glove on the right hand. The cups presented to the hands-colored group were both a light beige, flesh-like color. As in previous studies, participants in the cups-colored group saw the model performing with ungloved hands and directing her movements to one red cup and one blue cup. The cups-colored participants were tested under the same conditions. The mean durations of action sequences were 4,660 ms (SEM = 128) for the cups-colored group and 4,650 ms (SEM = 45) for the hands-colored group. The mean ITIs were 1,250 ms (SEM = 37.48) for the cups-colored group and 1,213 ms (SEM = 36.37) for the hands-colored group.

Procedure. As in Experiment 1, participants in the cups-colored group were instructed (a) 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, (b) to grip the pen in the same thumb-up or thumb-down configuration as the model, and (c) to place the pen in the cup of the same color as the model. Participants in the hands-colored group were instructed (a) to use their red-colored hand when the model used her red-colored hand and to use their blue-colored hand when the model used her blue-colored hand, (b) to grip the pen in the same thumb-up or thumb-down configuration as the model, and (c) 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.

Results and Discussion

The mean total number of errors did not differ between groups (cups-colored = 5.9, *SEM* = 1.1; hands-colored = 6.3, *SEM* = 1.4; $F < 1$, $\eta_p^2 = .00$). As indicated in Figure 3, the cups-colored group showed the cup < hand < grip error pattern observed in Experiment 1 and in previous studies. However, as predicted by the generalist hypothesis, the hands-colored group showed a different pattern, with the frequencies of cup and grip errors both exceeding the frequency of hand errors. An ANOVA revealed a significant main effect of error type, $F(2, 60) = 15.7$, $p < .0001$, $\eta_p^2 = .34$, and a significant Error Type × Group interaction, $F(2, 60) = 12.3$, $p < .0001$, $\eta_p^2 = .29$. Within-subject contrasts, applied separately to the data from each group, indicated that in the cups-colored group there was a linear increase in percentage error across the cup, hand, and grip categories, $F(1, 15) = 92.2$, $p < .0001$, $\eta_p^2 = .86$, but in the hands-colored group the relationship between percentage error and error type was quadratic, $F(1, 15) = 6.3$, $p = .02$, $\eta_p^2 = .30$.

In this experiment, shifting the color cue from the cups to the hands was sufficient to alter the error pattern to one in which hand selection, rather than cup selection, was imitated most accurately. This suggests that the relative accuracy of cup and hand selection in the pen-and-cups task is determined not by a hierarchy of imitation-specific goals but by factors affecting perceptual processing such as the relative discriminability of cup and hand cues.

Experiment 3

Experiment 2 showed that participants in the pen-and-cups task make more hand than cup errors when the cups are of different colors and more cup than hand errors when the hands are of different colors. This was interpreted as evidence that the pattern of errors across components of the task is determined by task-general perceptual processes rather than by imitation-specific goal selection processes.

To investigate the specificity of the coloring effect on error patterns observed in Experiment 2, we presented participants in Experiment 3 with the same action sequences—cups-colored or hands-colored—but required them to describe, rather than to imitate, what they saw. GOADI implies that the processes that mediate imitation, goal selection processes, are specific to imitation and that, therefore, the error patterns seen in Experiment 2 were attributable to an interaction between the action sequences and the imitation task. Accordingly, GOADI is either silent with respect to the pattern of errors that will occur in the nonimitative version of the pen-and-cups task used in Experiment 3 or predicts that it will differ from that observed in Experiment 2. In contrast, the generalist hypothesis, which suggests that the error patterns found in Experiment 2 were attributable to task-general processes, predicts that the same error patterns will occur in Experiment 3.

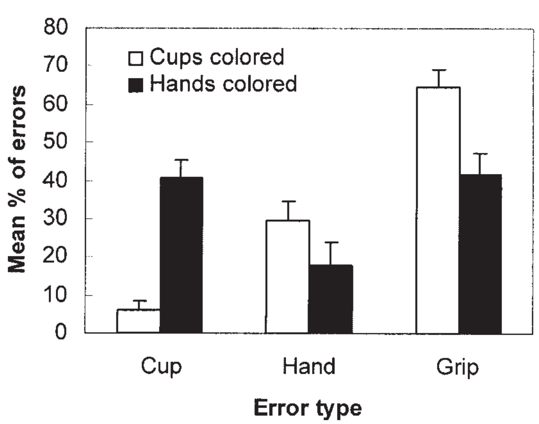

Figure 3. Mean percentages of cup, hand, and grip selection errors in Experiment 2. Participants imitated action sequences in which the model placed a pen in one of two cups when the cups (cups colored) or the hands (hands colored) were of different colors. Error bars represent standard errors of the mean.

Method

Participants. A further 32 University College London students (13 men and 19 women) participated in the experiment. Their mean age was 23.5 years, and each was paid a small honorarium (~$5) for their participation. They were randomly assigned in equal numbers to two groups, cups-colored and hands-colored. Their mean age was 23.5 years. Seven participants who made no errors during the test trials and 1 who did not obey task instructions were replaced. All participants had normal or corrected-to-normal vision and were naive with respect to the purpose of the experiment.

Apparatus and stimuli. The stimuli and apparatus were exactly the same as those of Experiment 2.

Procedure. The procedure was the same as that of Experiment 2 except as follows. All participants were instructed to describe, rather than to imitate, the model's movements. Thus, participants in the cups-colored group were told (a) to say "left hand" when the model used her left hand and to say "right hand" when the model used her right hand, (b) to say "up grip" or "down grip" according to the orientation of the model's thumb, and (c) to say "red cup" or "blue cup" in response to the model's object selection. Participants in the hands-colored group were instructed (a) to say "red hand" when the model used her red-colored hand and to say "blue hand" when she used her blue-colored hand, (b) to say "up grip" or "down grip" according to the orientation of the model's thumb, and (c) to say "left cup" or "right cup" in response to the model's object selection.

Results and Discussion

The mean total number of errors did not differ between groups (cups-colored = 3.4, *SEM* = 1.1; hands-colored = 1.6, *SEM* = 1.4), $F(1, 30) = 2.6$, $p = .12$, $\eta_p^2 = .08$. As indicated in Figure 4, the error patterns in this experiment, in which participants were required to describe the model's actions, were remarkably similar to those observed in Experiment 2, in which participants were required to imitate the model's actions. The cups-colored group showed the typical cup < hand < grip error pattern, whereas the hands-colored group showed the cup > hand < grip pattern first observed in the hands-colored group in Experiment 2. An ANOVA revealed a significant main effect of error type, $F(2, 60) = 8.9$, $p < .001$, $\eta_p^2 = .23$, and a significant Error Type × Group interaction, $F(2, 60) = 5.5$, $p < .05$, $\eta_p^2 = .15$. Within-subject contrasts, applied separately to the data from each group, indicated that in the

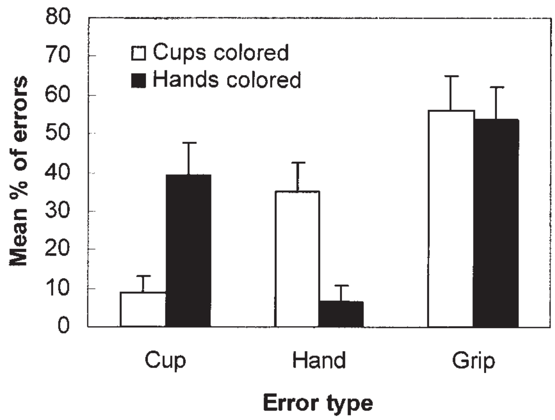

Figure 4. Mean percentages of cup, hand, and grip selection errors in Experiment 3. Participants described action sequences in which the model placed a pen in one of two cups when the cups (cups colored) or the hands (hands colored) were of different colors. Error bars represent standard errors of the mean.

cups-colored group there was a linear increase in percentage error across the cup, hand, and grip categories, $F(1, 15) = 15.6$, $p < .001$, $\eta_p^2 = .51$, but in the hands-colored group the relationship between percentage error and error type was quadratic, $F(1, 15) = 48.3$, $p < .0001$, $\eta_p^2 = .76$.

Experiments 2 and 3 were identical except that in Experiment 2, participants imitated, and in Experiment 3, they described the model's actions. To assess any effect of this task variation more directly, we combined the data from the two experiments and subjected them to an ANOVA in which the within-subject variable was error type (cup, hand, grip), and the between-subjects variables were task (imitate, describe) and group (cups-colored, hands-colored). The main effect of error type, $F(2, 120) = 22.0$, $p < .0001$, $\eta_p^2 = .27$, and the Error Type × Group interaction, $F(2, 120) = 13.8$, $p < .0001$, $\eta_p^2 = .19$, were significant. However, confirming that the results of Experiments 2 and 3 did not differ, there was no evidence of an Error Type × Task interaction ($F < 1$, $\eta_p^2 = .00$) or of an Error Type × Group × Task interaction, $F(2, 120) = 1.5$, $\eta_p^2 = .02$.

In combination, the results of Experiments 2 and 3 show that highly accurate object selection in the pen-and-cups task depends on color coding of the objects and does not depend on whether participants are indicating their object selections by imitation or by description. These findings were predicted by the generalist hypothesis but not by GOADI, which implies that accurate imitation of object selection is attributable to imitation-specific processes of goal selection.

Experiment 4

Experiments 2 and 3 provided evidence that the accuracy of object selection depends on task-general factors and can be exceeded by the accuracy of effector selection when the discriminability of hand use is increased using a color cue. Experiment 4 investigated whether similar factors also modulate the accuracy of grip selection.

In the standard pen-and-cups task, grip selection may be relatively difficult to discriminate for three reasons. First, the thumb-up and thumb-down grips are not as spatially distinct as are the cups or the hands. For example, at the beginning of each trial, the model's left and right hands are approximately 10 cm apart on the computer screen, whereas the thumb positions for up and down grips are approximately 1 cm apart. Second, the two cups and the two hands are continuously visible in the stimulus display, but only the selected grip is presented on any given trial. Therefore, cups and hands, but not grips, are available for simultaneous discrimination. Finally, on every trial, grip direction is reversed. For example, in an action sequence involving the up grip, the model's thumb points upward when she first grasps the pen, but rotates through 180° as she moves the pen toward the cup and points downward when the pen enters the cup. In contrast, the cups do not move at all, and the egocentric spatial location of the selected hand is reversed only on 50% of trials, when the model places the pen in the cup contralateral to the selected hand.

To enhance grip discriminability, in Experiment 4 we used a new grip manipulation in the pen-and-cups task. As before, the model was observed in each trial using one of her two hands to place a pen in one of two cups using one of two grips. However, instead of applying an up or a down grip, the model positioned her hand so that the palm was facing downward and, with fingers extended, clamped the pen between her index and middle fingers (inside grip) or between her ring and little fingers (outside grip). The alternative grips used in Experiment 4 were more discriminable than those used previously in three respects. First, although the two grips were still closer together in space than the two cups or the two hands, both grips were now continuously available for visual comparison. Second, in Experiment 4, the pen was transferred to the cup without inversion; the model's palm faced downward throughout the movement. Finally, in two of the four conditions tested in Experiment 4, the inside and the outside grips were of different colors.

In Experiment 4, we used a within-subject design for greater power. Each participant performed the inside/outside grip variant of the pen-and-cups task under four conditions: when the cups were colored and imitation was required (imitate/cups-colored), when the grips were colored and imitation was required (imitate/grips-colored), when the cups were colored and description was required (describe/cups-colored), and when the grips were colored and description was required (describe/grips-colored).

The purpose of the imitate/cups-colored condition was to find out whether the cup < hand < grip error pattern would emerge in a task identical to that used in previous studies with the exception that the two grips were more discriminable. GOADI predicts the occurrence of this error pattern because it claims that the pattern is a result of goal selection processes that should not be influenced by alteration of the grip variable. In contrast, the generalist hypothesis predicts that the frequencies of cup, hand, and grip errors will be approximately equal in this condition. There may be more hand errors than cup and grip errors because, relative to hand discrimination, cup discrimination is facilitated by the presence of a color cue, and grip discrimination is facilitated by the absence of spatial cue reversal on any trial. However, because it reduces the complexity of the movement path traversed by the hand, the inside/outside grip manipulation may also facilitate hand discrimination. Therefore, one would not expect marked differences between cup, hand, and grip errors.

The purpose of the imitate/grips-colored condition was to find out whether enhancing grip discriminability using a color cue would enable participants to be more accurate in grip selection than in cup and hand selection: the inverse of the pattern reported in previous studies. This is predicted by the generalist hypothesis, which assumes that accuracy in the pen-and-cups task depends primarily on the discriminability afforded by color cues. In contrast, GOADI claims that grip selection lies at the bottom of the hierarchy of goals and should, therefore, be the most error-prone component of the task.

Following the same logic as Experiment 3, the describe/cups-colored and describe/grips-colored conditions were included to investigate the task generality of the factors modulating accuracy in the imitation conditions. If the generalist hypothesis is correct, one would expect the error patterns in these conditions to be the same as those observed in the corresponding imitation conditions.

Method

Participants. A further 14 University College London students (6 men and 8 women) participated in the experiment. Their mean age was 30.9 years, and each was paid a small honorarium (~$5) for their participation. Two participants were replaced, 1 who made no errors and 1 who did not obey task instructions. All participants had normal or corrected-to-normal vision and were naive with respect to the purpose of the experiment.

Apparatus and stimuli. The stimuli and apparatus were the same as those of Experiment 2 except as noted. Instead of using an up or down grip and inverting the pen to place it in a cup, the model held the pen between her index and middle fingers (inside) or between her ring and little fingers (outside) and placed it in a cup in the upright position. In the cups-colored conditions, the model wore flesh-colored gloves and directed her movements to one red cup and one blue cup. In the grips-colored conditions, the fingers of the gloves worn by the model were colored; the index and middle fingers were blue, and the ring and little fingers were red. In this condition, the cups were both of the same light beige, flesh-like color (see Figure 1a and 1d). In the cups-colored conditions, the mean trial duration was 4,660 ms (*SEM* = 128), and in the grips-colored conditions, it was 6,210 ms (*SEM* = 126.7). The mean ITI was 1,230 ms (*SEM* = 24) in the cups-colored conditions and 1,422 ms (*SEM* = 44.9) in the grips-colored conditions.

Procedure. The procedure was the same as those of Experiments 2 and 3 except as follows. Each participant was tested under four conditions: imitate/cups-colored, imitate/grips-colored, describe/cups-colored, and describe/grips-colored. The two imitation conditions and the two description conditions were completed consecutively. Half of the participants completed the imitation conditions first, and half completed the description conditions first. The order of cups-colored and grips-colored conditions was counterbalanced within each of these groups.

In the cups-colored conditions, the instructions distinguished cups by their color and distinguished hands and grips using spatial codes. Thus, participants were told (a) to use their left hand, or to say "left hand," when the model used her left hand and to use their right hand, or to say "right hand," when the model used her right hand; (b) to use or to name the same inside or outside grip as the model; and (c) to place the pen in the cup of the same color as the model or to describe that cup by its color. In the grips-colored conditions, the instructions distinguished grips by their color and distinguished hands and cups using spatial codes. Thus, participants were told (a) to use their left hand, or to say "left hand," when the model used her left hand and to use their right hand, or to say "right hand," when the model used her right hand; (b) to use or to name the grip of the same color as the model; and (c) to use or name the cup on their left if the model placed the pen in the cup on her left and to use or name the cup on their right if the model placed the pen in the cup on her right. There were 80 test trials in each condition, immediately preceded by 10 practice trials.

Results and Discussion

On average, participants made 6.1 (*SEM* = 1.4) errors in the imitate/cups-colored condition, 7.3 (*SEM* = 2.1) errors in the imitate/grips-colored condition, 2 (*SEM* = 0.7) errors in the describe/cups-colored condition, and 2 (*SEM* = 0.6) errors in the describe/grips-colored condition. An ANOVA, in which task (imitate, describe) and colored (cup, grip) were within-subject factors, indicated that participants made more errors when imitating than when describing the action sequences, $F(1, 13) = 9.23$, $p = .01$, $\eta_p^2 = .42$. This difference is likely to have been a result of the fact that imitative responses took longer to execute than verbal responses, and therefore, participants were under greater time pressure and carried a larger working-memory load in the imitation conditions. The main effect of color ($F < 1$, $\eta_p^2 = .02$) and the Task × Colored interaction ($F < 1$, $\eta_p^2 = .01$) were not reliable. These data indicate that the main effect of color did not significantly influence the total number of errors made over the four conditions. Although errors were generally lower when participants described rather than imitated the action sequences, color had similar effects on both the imitate and describe conditions.

The results of principal interest are the error patterns in each of the four conditions (see Figure 5). The percentage error score for each component (cup, hand, 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 all conditions. For example, the imitation hand error percentage score was obtained by dividing the number of hand errors made when the participant was required to imitate, by the total number of cup, hand, and grip errors made by the participant in both the imitation and description conditions. Calculation of percentage error scores in this way allows comparison across the imitate and describe tasks and reflects the within-subject design of Experiment 4, but it does not alter the pattern of errors within each condition. The error patterns observed in the imitation and description conditions were very similar. As predicted by the generalist hypothesis, the error pattern in the cups-colored conditions tended toward the quadratic, with hand errors slightly exceeding both cup and grip errors, whereas the error pattern in the grips-colored conditions was the inverse of that observed in previous studies; there were fewer grip than hand or cup errors. An ANOVA in which task (imitate, describe), colored (cup, grip), and error type (cup, hand, grip) were within-subject factors yielded a significant main effect of task, $F(1, 13) = 6.5$, $p = .02$, $\eta_p^2 = .33$; a significant main effect of error type, $F(2, 26) = 7.6$, $p = .003$, $\eta_p^2 = .37$; and a significant Colored × Error Type interaction, $F(2, 26) = 4.9$, $p = .02$, $\eta_p^2 = .28$. No other effects or interactions were reliable (all Fs < 1, all η_p^2s $< .08$).

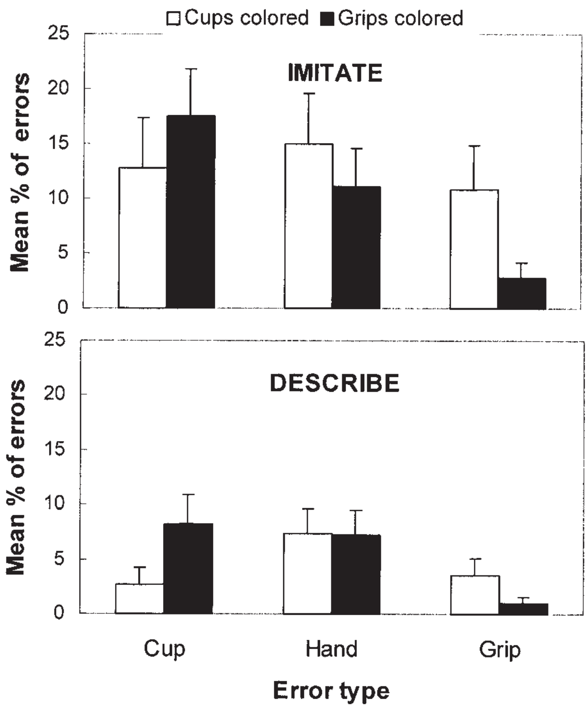

Figure 5. Mean percentages of cup, hand, and grip selection errors in Experiment 4. Participants imitated and described action sequences in which the model placed a pen in one of two cups when the cups (cups colored) or the grips (grips colored) were of different colors. Error bars represent standard errors of the mean.

Within-subject contrasts, applied separately to the data from each condition, indicated a linear decrease in percentage error across the cup, hand, and grip categories in the imitate/grips-colored, $F(1, 13) = 12.6$, $p < .004$, $\eta_p^2 = .49$, and describe/grips-colored, $F(1, 13) = 6.8$, $p = .02$, $\eta_p^2 = .34$, conditions. In the describe/cups-colored condition, the relationship between percentage error and error type was quadratic, $F(1, 13) = 4.7$, $p < .05$, $\eta_p^2 = .27$, and in the imitate/cups-colored condition, there was neither a linear ($F < 1$, $\eta_p^2 = .01$) nor a quadratic trend ($F < 1$, $\eta_p^2 = .03$).

The results of this experiment suggest that, like object and effector selection, the accuracy of grip selection in the pen-and-cups task is modulated by task-general processes.

General Discussion

GOADI provides an explicit statement of the view that ends take priority over means in the reproduction of observed actions. It suggests that imitation-specific goal selection processes assign higher priority to reproduction of the effects of body movements on objects than to imitation of the body movements themselves. The present study reexamined an imitative phenomenon that provides some of the strongest support for GOADI: the cup < hand < grip error pattern in the pen-and-cups task. Experiment 1 replicated this phenomenon using video stimuli, and the results of Experiments 2–4 indicated that the cup < hand < grip error pattern is attributable not to imitation-specific processes of goal selection but to task-general mechanisms. Experiment 2 showed that shifting the color cue from the cups to the hands is sufficient to make imitation of hand selection more accurate than imitation of cup and grip selection. Experiment 3 replicated this effect when participants were required to describe, rather than to imitate, the action sequences they observed. Experiment 4 consolidated these findings by showing that in both the imitation and the description versions of the task, enhancing the discriminability of the alternative grips through the addition of a color cue and by other means improved grip selection to the point where it was the most accurately executed component of the task.

Taken together, the results of the present study suggest that imitative behavior is much more flexible than was previously assumed. Rather than being consistently biased toward the reproduction of action outcomes, the mechanisms that mediate imitation are plastic with respect to the processing of ends and means. Furthermore, the factors influencing which aspects of an action are imitated are task general; they apply whether an individual is performing an imitative or nonimitative task. This flexibility and generality is not consistent with GOADI, which implies that imitation is governed by a special-purpose hierarchy of goals. It is compatible with both the ASL model and ideomotor theory, which suggest that imitation is mediated by task-general processes and is, therefore, no more or less goal-directed than other reactions to external stimuli.

The present experiments showed that a stimulus variable, color, modulates accuracy of performance in the pen-and-cups task. The color cue could have improved performance in several ways. First, differential coloring of the two levels of an action variable (cup, hand, or grip) could have enhanced their discriminability directly, making it easier to see on each trial which variant had been selected by the model. Second, coloring of an action variable may have enhanced discriminability indirectly by making that component of the model's behavior a focus of spatial attention. Third, nonspatial color coding may be easier to remember and apply than are the complicated location-based mappings inherent in the task. If so, the information load on the S-R mapping relevant to the colored action component may be lower than on those mappings distinguished by location alone. Finally, the color cue may have facilitated more automatic processes of response selection; a blue stimulus code may activate a blue response code more strongly than a left (anatomical) stimulus code activates a left (anatomical) response code. Although not strictly "perceptual," all of these processes are task general. Perceptual discrimination, attentional selection, S-R translation, and response selection occur in a range of perceptual–motor tasks, not just in those requiring imitation. Therefore, whatever range and combination of these processes was responsible for the effects observed in the present experiments, our results support the view that general mechanisms, rather than imitation-specific processes of goal selection, explain imitation errors.

In contrast with the results of Experiment 2, Gattis et al. (2002) found that performance in the hand-to-ear task did not improve when the model's hands were colored. Children continued to imitate object (ear) selection more accurately than hand selection when the model wore a white glove on one hand and a black glove on the other. Although the results were obtained from different tasks, the contradiction between the results of Gattis et al. and the present results must be explained. Two empirically testable hypotheses are that (a) children are more likely than adults to bias their attention toward objects than toward effectors, and (b) objects that are body parts (rather than cups, as in the present experiment) may be especially salient and, therefore, continue to be accurately imitated. A third, more disturbing possibility is that the variations on the standard pen-and-cups task used in the present experiments (requiring participants to imitate in a transposed rather than mirror fashion and specifying the three aspects of the action to be imitated) may have in some way altered the effect of applying a color cue to the hands. If so, the present results would not be applicable to the preceding empirical work supporting GOADI.

This third hypothesis is incompatible with the data obtained by Avikainen et al. (2003). In their experiment, the cup < hand < grip error pattern was preserved in the pen-and-cups task when participants were explicitly instructed to copy each aspect of the task, both when mirror and when transposition imitation was required. Both groups in Experiment 1 also showed the standard cup < hand < grip error pattern with explicit instructions to copy each aspect of the task and when imitating in a transposed fashion. However, to test whether the instructions and transposed mapping altered the effect of the color cue, we replicated Experiment 2 but changed the instructions to the less explicit "copy the actions shown on the computer" (equivalent to the "do as I do" instructions used in the preceding experiments) and arranged the color cues in such a way as to encourage mirror responding. The results were identical to those obtained in Experiment 2; the cups-colored group showed the cup < hand < grip error pattern, whereas the hands-colored group showed the hand < cup < grip error pattern first observed in Experiment 2. The difference in the relative proportions of cup and hand errors between the groups was significant: Error Type × Group interaction, $F(1, 22) = 33$, $p < .001$, $\eta_p^2 = .60$. Therefore, the effect of moving the color cue on error patterns was replicated with the instructions and imitation mapping used in the majority of studies using the pen-and-cups task. The results of this additional experiment rule out an explanation of the present results based on either of these two factors and make clear their applicability to previous experiments supporting GOADI.

To make GOADI consistent with the results of the present experiments, it would be necessary to assume that (a) color coding enhanced performance by inducing revision of the goal hierarchy, and (b) goal selection processes play the same role in imitative and nonimitative tasks. The first of these assumptions is consistent with previous research by the authors of GOADI, which they have interpreted as evidence of flexibility in the goal hierarchy (Gattis et al., 2002), and it is consistent with their suggestion that a goal is a "mental state representing the desired state of the world" (Gattis et al., 2002, p. 185). However, a version of GOADI that postulates a flexible goal hierarchy rather than priority of ends over means, or one that defines goals as mental states rather than observable features of action, would be very different from, and much weaker than, the version of the theory specified by Wohlschläger et al. (2003) and quoted in the introduction to this article. Such a flexible and/or mentalistic version of the theory would be weak because it is not clear how it could be tested. If one allowed that the goal hierarchy can change across imitation tasks and that imitative performance (indexed by errors or reaction times) is the only way of finding out how the hierarchy is configured in any given task, then it would become true by definition that imitative performance depends on a (flexible) hierarchy of goals.

The second assumption that would make GOADI consistent with the present findings, that goal selection processes play the same role in imitative and nonimitative tasks, is also problematic for the theory. The results reported here can be explained with reference to established perceptual, attentional, and response selection processes. These processes are not characterized with reference to "goals" when they are used to explain nonimitative performance, and therefore, it is not clear they should be thus characterized in the case of imitation. Furthermore, if the processes postulated by GOADI were assumed to apply equally to imitative and nonimitative tasks, it would not be clear in what sense GOADI is a theory of imitation rather than, for example, of voluntary action. Explicitly generalist theories, such as the ASL model and ideomotor theory, assume that the same processes mediate performance in imitative and nonimitative tasks, but they constitute theories of *imitation* because they address the *correspondence problem*; they explain how perception of an action encoded as a pattern of light across the retina can be used to generate muscle commands to produce a matching movement (Brass & Heyes, 2005). It has been argued that the correspondence problem is the unique explanatory challenge posed by imitative action (Heyes, 2001), but GOADI addresses this problem only by referring to ideomotor theory (Postulate 4; Wohlschläger et al., 2003).

The ASL model offers a simple, functional solution to the correspondence problem (Heyes, 2001; Heyes & Ray, 2000). It proposes that in common with other perceptual–motor tasks, imitation is mediated by perceptual and motor representations becoming associated through repeated coactivation. Under ASL, imitation is made possible through associative links being formed between, for example, the perceptual representation of a hand opening ("what it looks like") and the motor representation of performing the hand-opening movement. Once an association has been formed, sight of an opening hand will cause the perceptual representation of hand opening to be activated, which will in turn activate the motor representation of hand opening and enable imitation. Within ASL's characterization of the mechanisms of imitation, there are no imitation-specific processes or structures. The only difference between imitative and nonimitative perceptual–motor associations is that in the former, the perceptual and motor representations are of matching movements. The ASL model offers an account of the conditions in which matching vertical associations are learned, which applies both to perceptually transparent actions, such as finger movements, in which the imitator can use perceptual matching to guide imitation and to perceptually opaque actions, such as facial expressions, in which the lack of visual feedback from performance means that perceptual matching cannot be used to guide imitation (Bird & Heyes 2005; Heyes, Bird, Johnson, & Haggard, 2005; Press, Bird, Flach, & Heyes, 2005).

The correspondence problem is trivial when one is trying to understand reproduction of action outcomes such as cup selection. Vision alone is sufficient to determine whether the cup one is selecting is of the same color as, or at a location corresponding to, the cup selected by a model. The problem becomes much more challenging when one tries to explain imitation of body movements, because many of these are not perceived in the same modality or coordinate frame during observation and execution. For instance, the visual input received when one performs a tennis serve is very different from that received when one watches an opponent serving; indeed, the two actions may only match visually from a third-person perspective. Despite this mismatch, the visual input received during an opponent's serve can still be used to improve performance of one's own serve.

In claiming that object selection takes priority over effector and path selection, GOADI suggests that body-movement imitation is relatively infrequent and, therefore, that the correspondence problem is unimportant in ecological terms. By challenging this claim, the results of the present study underline the importance of the correspondence problem, suggesting that it is not merely a theoretical conundrum but a challenge inherent in a much larger proportion of imitative behavior than GOADI implies. To solve this problem, GOADI invokes ideomotor theory to explain how the correspondence problem is solved. It is clear then that the unique contribution of GOADI is to explain *what* is imitated (e.g., object, effector, or grip selection in the pen-and-cups task) rather than *how* imitation occurs. The results of the present experiments challenge GOADI's explanation of what is imitated and suggest that task-general processes are responsible for selecting which aspects of the action are imitated.

One of the strengths of GOADI is that it makes an explicit link between imitation and the ideomotor framework, a general account of action representation that has substantial empirical support (Hommel, Müsseler, Aschersleben, & Prinz, 2001). The ideomotor framework suggests that at the cognitive level, actions are represented and controlled exclusively in terms of their sensory effects. In contrast, the ASL model says rather little about the content of motor representations. However, the ASL model is compatible with the ideomotor principle; it is consistent with the idea that "motor" representations of action consist primarily of somatosensory information, but it is not consistent with the suggestion, made by GOADI, that imitation is mediated by a specialized system that assigns priority to processing of the effects of action on objects. There is no doubt that during the observation of action, processing of the effects of body movements, such as object displacements, can dominate processing of body movements features, such as effector, grip, and trajectory (Mataric & Pomplun, 1998). However, the ASL model suggests that this is no more likely to occur during observation for imitation than during passive observation or observation prior to the performance of complementary, nonimitative actions. In the absence of any evidence to the contrary, it seems appropriate to assume that either ends or means can dominate action processing, depending on the way in which the stimulus array and context engage task-general processes (Kunde & Weigelt, 2005).

We have suggested that action processing may not be biased in favor of its effects on objects. This is implausible if one assumes that the sole function of action is to change the relationship between the individual and objects in their environment—to wield instruments, remove obstructions, and bring objects closer to the body for shelter, ingestion, or destruction. It is more plausible when one remembers that body movements also fulfill communicative functions that are essential for effective social interaction. The kinematics and dynamics of body movement can signal the identity, condition, reproductive state, group membership, expertise, disposition, and intentions of an actor. When body movements can carry this much information, it would be unwise for the cognitive system consistently to treat them as subordinate goals.

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