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12 Imitation: Associative and Context Dependent

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Introduction

Imitation has been taking a walk on the wild side. Until the mid-1990s, imitation was studied in paradigms where it was either known or believed to be occurring deliberately. Adult human participants were politely instructed to copy observed body movements, and whenever infants or nonhuman primates imitated actions, it was assumed that they had intended to do so. In the last 10 to 15 years, attention has shifted to more wayward forms of imitation. These include unconscious behavioral mimicry, in which people copy the incidental gestures of others, apparently without awareness (Chartrand & Van Baaren, 2009); mirror effects, showing that the passive observation of actions can elicit neural responses associated with the execution of similar actions (Iacoboni, 2009); and automatic imitation, stimulus-response compatibility (SRC) effects in which the observation of task-irrelevant body movements facilitates the performance of similar movements and interferes with the performance of dissimilar movements (Heyes, 2011). This chapter focuses on automatic imitation because it is through studies of this phenomenon that imitation has become for the first time a central focus of action science. Previous research was primarily concerned with the developmental, social, and evolutionary consequences of imitation. It used imitation as an instrument to measure human cognitive and social development, as well as the intelligence of animals. Through the use of automatic imitation paradigms, it has become possible to study the core mechanisms of imitation—the cognitive processes that solve the "correspondence problem" (Brass & Heyes, 2005). These processes allow the perception of an action to be translated into the performance of a topographically similar action, an action in which parts of the observer's body move in the same way, relative to one another, as the parts of the model's body.

Evidence of automatic imitation comes from studies using a special kind of SRC procedure in which the stimulus set includes photographic images of the actions in the response set. For example, in one of the original studies, Stuermer, Aschersleben, and Prinz (2000) asked participants to open and close their hands in response to a color cue (red or blue; the task-relevant stimulus dimension) superimposed on a video of an opening or closing hand (the task-irrelevant stimulus dimension). Correct responses were initiated faster when the irrelevant action stimulus was response compatible (e.g., when an open hand response was made in the presence of an opening hand stimulus) than when the irrelevant action stimulus was response incompatible (e.g., when an open hand response was made in the presence of a closing hand stimulus). In other words, response times (RTs) were shorter in compatible than in incompatible trials. Subsequent studies have reported similar robust effects for a range of finger (Brass, Bekkering, Wohlschlaeger & Prinz, 2000; Brass, Bekkering & Prinz, 2001; Catmur & Heyes, 2011), arm (Gowen, Stanley & Miall, 2008; Kilner, Hamilton & Blakemore, 2007; Kilner, Paulignan & Blakemore, 2003), foot (Bach & Tipper, 2007; Gillmeister, Catmur, Liepelt, Brass & Heyes, 2008), and mouth (Leighton & Heyes, 2010) actions.

Effects of this kind have been called not only "automatic imitation" (Heyes, Bird, Johnson & Haggard, 2005; Liepelt & Brass, 2010; Longo & Bertenthal, 2009; Longo, Kosobud & Bertenthal, 2008; Press, Bird, Walsh & Heyes, 2008) but also "motor priming" (Liepelt, von Cramon & Brass, 2008); "visuomotor priming" (Craighero, Fadiga, Umiltà & Rizzolatti, 1996); "body part priming" (Bach & Tipper, 2007); "effector priming" (Gillmeister et al., 2008); "imitation inhibition" (Brass, Derrfuss & von Cramon, 2005); "imitative compatibility" (Catmur & Heyes, 2011); "movement compatibility" (Brass et al., 2000); "movement interference" (Gowen, Stanley & Miall, 2008); "motor facilitation by action observation" (Edwards, Humphreys & Castiello, 2003); and "motor mimicry" (Spengler, Brass, Kuehn & Schütz-Bosbach, 2010). I prefer the term "automatic imitation" because the word "automatic" captures more vividly than "priming" the apparently involuntary or unintentional nature of the phenomena; and in contrast with "motor" or "visuomotor," "imitation" indicates the topographic specificity of the relationship between visual stimulus and motor response (Heyes, 2011).

Regarding automaticity, several factors suggest that participants in automatic imitation experiments do not intend their behavior to be influenced by the task-irrelevant action stimuli. First, and by definition, participants are not instructed to respond to these stimuli. For example, in the hand

opening/closing paradigm outlined earlier, participants were instructed to respond to the color of the hand stimulus (Stuermer et al., 2000), not to the stimulus dimension that generated the RT difference between compatible and incompatible trials, that is, to the opening or closing properties of the hand stimuli. Second, automatic imitation effects can occur when participants do not intend to direct spatial attention to the action stimuli that generate the effects. For example, hand opening/closing and mouth opening/closing automatic imitation effects have been observed when the imperative cues were presented at fixation, and irrelevant action images appeared in the periphery of the visual field (Leighton & Heyes, 2010). Third, automatic imitation occurs under conditions where it interferes with performance, preventing participants from doing what they have been asked to do—to respond swiftly and accurately to the task-relevant cue. For example, responding is slower in imitatively incompatible trials than in baseline trials where the task-relevant cue is presented in the absence of a task-irrelevant movement stimulus (Bertenthal, Longo & Kosobud, 2006; Brass et al., 2000; Gillmeister et al., 2008). Finally, automatic imitation effects occur when participants are not prepared to perform a response of the incompatible kind. At the beginning of each trial in choice RT paradigms, participants are prepared—they have an active intention—to make each of the responses that could be cued in the trial. However, automatic imitation effects occur not only in choice RT tasks but also in simple RT paradigms where participants are making the same prespecified response in each successive trial (e.g., Heyes et al., 2005).

If we turn to the specificity of the relationship between stimulus and response, ample evidence now indicates that, like intentional imitation, automatic imitation effects depend on topographic features of action—the way in which parts of the body move or are located relative to other parts of the body. For example, the sight of hand opening facilitates the performance of hand opening, not because the stimulus and response actions involve a similar change in relative position (e.g., a movement to the right, or to the left, in external spatial coordinates) but because they both involve movement of the thumb and fingers away from one another and from the palm (Heyes et al., 2005). Thus the hand opening/closing automatic imitation effect is not merely a spatial compatibility effect.

Eleven pairs of action types have been used in experiments on automatic imitation. In seven of these cases, the majority, the evidence clearly shows that automatic imitation effects are not due solely to spatial compatibility: power/precision grip (Chong, Cunnington, Williams & Mattingley, 2009); index finger lifting/tapping (Brass, Bekkering & Prinz, 2001); index/

middle finger movement (Bertenthal et al., 2006); index/little finger abduction (Catmur & Heyes, in press); hand opening/closing (Heyes et al., 2005; Press et al., 2008); mouth opening/closing (Leighton & Heyes, 2010); hand/mouth movement (Leighton & Heyes, 2010). These studies report automatic imitation effects when left–right, up–down, and orthogonal spatial compatibility have been controlled. In 1 of the 11 cases, variables relevant to spatial compatibility have been examined, but the results are not yet conclusive: horizontal/vertical arm movement (Kilner et al., 2003, 2007; Gowen et al., 2008; Stanley et al., 2007). In three cases, the role of spatial compatibility in generating the observed effects has not been investigated systematically: left/right grip orientation (Craighero, Bello, Fadiga & Rizzolatti, 2002; Craighero et al., 1996; Craighero, Fadiga, Rizzolatti & Umiltà, 1998); horizontal/vertical grip orientation (Vogt, Taylor & Hopkins, 2003); and hand/foot movement (Bach, Peatfield & Tipper, 2007; Gillmeister et al., 2008; Wiggett, Hudson, Tipper & Downing, 2011; see Heyes, 2011, for a review).

"Imitation" typically refers to overt behavioral execution of actions that are topographically similar to those observed, but automatic imitation rarely involves overt behavioral execution of topographically matching responses. Automatic imitation effects usually consist of response time, rather than accuracy, differences between compatible and incompatible trials. Therefore automatic imitation appears to be a covert form of imitation—to be related to intentional imitation and overt motor mimicry in much the same way that silent reading is related to reading aloud. In other words, automatic imitation appears to be a phenomenon generated by the same core processes as overt behavioral imitation, but in which the impulse or capacity to copy an action is not fully expressed. If this is correct, automatic imitation paradigms provide an unprecedented opportunity for analytic investigation of the core processes of imitation. In contrast with most intentional imitation paradigms, they permit tight control of stimulus variables, and precise measurement of response characteristics, under conditions where the effects of linguistic and motivational variables are likely to be minimal.

This chapter reviews studies of automatic imitation that bear on an important, long-standing question (Heyes & Bird, 2007): are the core mechanisms of imitation associative or conceptual? Broadly speaking, associative models (fig. 12.1, left side) assume that these mechanisms consist of durable and direct excitatory connections between visual and motor representations of the same topographic features of actions. For example, a visual representation of hand opening is connected to a motor representation of hand opening, so that observation of hand opening directly
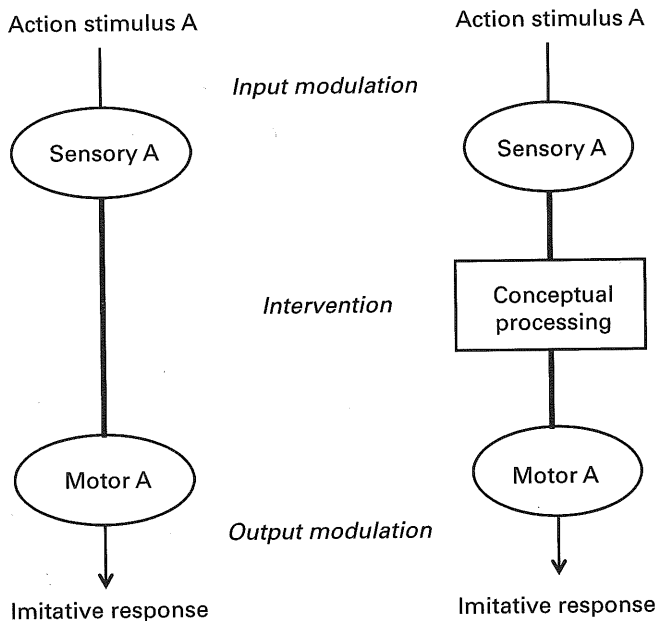
Figure 12.1
Schematic representations of associative (*left*) and conceptual (*right*) models of imitation, showing the loci of input modulation, output modulation, and intervention. In each case, observation of an action, *A*, initially activates a sensory (typically visual) representation of the topographic features of *A*. Associative models suggest that this results directly in the activation of a motor representation of the topographic features of *A*, whereas conceptual models suggest that motor activation occurs only after higher-order processing of some sort. Both types of model allow that context-dependent higher-order processing can modulate imitative performance by influencing the activation of sensory representations (input modulation) and the extent to which motor activation gains control of behavior (output modulation). Conceptual models predict that this kind of processing can also influence the extent to which activation of sensory representations is propagated to corresponding motor representations (intervention).

activates an imitative response. In the associative sequence learning model (Heyes 2001), these connections are described as "matching vertical associations," and in the ideomotor account of imitation (Prinz, 2005) they are known as "common codes." In contrast, conceptual models (fig. 12.1, right side) suggest that when an imitative response occurs, some kind of higher-level processing intervenes in a causal chain between stimulus processing and matching response activation. The nature of this higher-level processing is not specified, but it has been described variously as semantic (Tessari & Rumiati, 2004), symbolic (Bandura, 1986), supramodal (Meltzoff & Moore, 1997), cognitive (Goldenburg, 2006), reconstructive (Csibra, 2008), goal directed (Gattis, Bekkering & Wohlschlaeger, 2002), and conceptual (Jansson, Wilson, Williams & Mon-Williams, 2007).

Both associative and conceptual accounts are consistent with context specificity. They both predict that the occurrence and magnitude of imitative responses will vary with the internal state of the imitator (internal context), and the situation in which the model's behavior is observed (external context), and anticipate that at least some of this variation will be due to the modulation of imitative responses by higher-order cognitive processes. For example, both associative and conceptual accounts are consistent with the modulation of imitative behavior by instruction-specific or situation-specific beliefs about the action stimuli. However, associative models imply that broadly intentional processes can modulate imitative performance only by influencing the processing of the action stimulus (input modulation) or by influencing the extent to which activation of a motor representation is either inhibited or allowed to influence overt responding (output modulation). In contrast, conceptual models suggest that higher-order processes can also "intervene," that is, modulate imitation by changing the extent to which activation of the stimulus representation results in activation of the response representation. Associative models are not consistent with intervention because they suggest that imitation depends on direct links in long-term memory between sensory and motor representations of the same action, and it is the nature of such links that their strength cannot be changed by higher-order processes. In contrast, conceptual models predict intervention because they suggest that imitation depends on a cognitive architecture in which some kind of higher-order cognitive process always occurs after activation of a sensory representation of the action stimulus and before activation of a motor representation of the same action. This kind of intermediate cognitive process would provide a natural locus for contextual factors to influence imitative performance.

The first section of this chapter reviews evidence that automatic imitation is subject to input modulation. This evidence currently consists of studies showing that contextual variables can influence the magnitude of automatic imitation effects by modulating attentional variables. The second section examines studies that have been interpreted as demonstrating output modulation. These suggest that social cognitive variables can influence automatic imitation, not by changing the properties of a long-term sensorimotor link but by inhibiting motor activation after that link has operated. The third section discusses studies of conceptual compatibility and counterimitative task set, which have been interpreted as evidence of intervention: evidence that contextual variables can modulate automatic imitation by altering the process that translates activation of a stimulus representation into activation of a response representation. The final part of the chapter suggests potentially productive directions for future work on the mechanisms of imitation, including examination of the role of conditional learning in generating context effects.

Input Modulation

Automatic imitation has been reported when task-irrelevant movement stimuli were presented in the periphery of the visual field (Leighton & Heyes, 2010). This suggests that automatic imitation can occur when participants are not directing their attention to the stimuli that are generating the effect. However, evidence also suggests that top-down variations in spatial attention and feature selection can influence the magnitude of automatic imitation effects.

Several studies of animacy—comparing the magnitude of automatic imitation effects generated by natural human movements and by artificial, impossible, or robotic movements—have pointed to this conclusion (Liepelt & Brass, 2010; Longo & Bertenthal, 2009; Longo et al., 2008). For example, Longo et al. (2008) asked participants to respond to the left–right spatial position of index and middle finger tapping movements that were either possible (normal joint movements) or impossible (abnormal joint movements). When the task instructions made no reference to the possibility variable, the automatic imitation effect (e.g., faster index finger responses to index than to middle finger stimuli) was of equal magnitude in the possible and impossible conditions. However, in another experiment, where participants were told that they would see both natural and impossible movements, an automatic imitation effect occurred only in the blocks where possible actions were presented.

These results were interpreted as effects of instructions on attention (Longo & Bertenthal, 2009; Longo et al., 2008). When the instructions did not mention the impossible or computer-generated character of the stimuli, participants attended to the end point of each movement, and both possible/photographic and impossible/computer-generated movements produced an automatic imitation effect. When the instructions alluded to the possibility variable, participants shifted their attention from movement end points to movement kinematics, and the impossible/computer-generated stimuli failed to produce a substantial automatic imitation effect because their kinematics were unfamiliar or dissimilar to those of the tapping responses.

Other animacy studies have examined the magnitude of automatic imitation effects produced by natural human movement stimuli as a function of participants' beliefs about the origins of those stimuli. For example, before testing participants with index and middle finger movements of a gloved human hand, Liepelt and Brass (2010) told one group of participants, with an illustration, that the movements had been generated by a wooden hand. This group showed a smaller automatic imitation effect than the group that believed they were observing human movements. As the authors acknowledged (Liepelt & Brass, 2010), like the animacy effects reported by Longo and colleagues (Longo, Kosobud & Bertenthal, 2008; Longo & Bertenthal, 2009), this result could have been due to closer attention to movement kinematics in the wooden hand group. If the index/middle finger automatic imitation effect depends on effector priming, rather than movement priming, focusing attention on movement kinematics would be expected to erode the magnitude of the effect.

In experiments similar to those of Longo et al. (2008; Longo & Bertenthal, 2009) and Liepelt et al. (2008; Liepelt & Brass, 2010), Press, Gillmeister, and Heyes (2006) found that hand open/close automatic imitation effects were not modulated by instructions concerning the human or robotic origins of the movement stimuli or by whether the stimulus movements were performed by a hand with a natural human wrist or a robotic wire wrist. These negative results are unlikely to have been due to test insensitivity because the same paradigm has shown that automatic imitation can be modulated by intrinsic properties of the movement stimuli (Press, Bird, Flach & Heyes, 2005; Press et al., 2006). Therefore they imply that for reasons that are yet to be established, automatic imitation of hand opening/closing, assessed in a simple RT task, is less susceptible to the influence of attention than automatic imitation of index/little finger movements, assessed in a choice RT task.

More direct evidence that automatic imitation can be modulated by attention comes from a study that varied the location of the imperative cue relative to the action stimuli eliciting the effect (Bach et al., 2007, experiment 1). Participants were instructed to respond with their foot or their hand, depending on the color of a dot presented near the head, hand, or foot in whole-body images depicting hand or foot action. An automatic imitation effect (e.g., faster foot responses when the actor was performing a foot than a hand action) occurred when the imperative stimuli appeared close to the acting effector, but not when the dots appeared close to the actor's head.

In another study designed explicitly to examine the effect of attention on automatic imitation, Chong et al. (2009, experiment 2) presented a red or blue diamond superimposed on a hand in a power or precision grip posture. An automatic imitation effect (e.g., faster execution of power grip with a power than a precision grip cue) occurred when participants were instructed to use stimulus grip as the go/no go signal (i.e., to decide whether or not a prespecified response should be made in that trial), but not when they were instructed to use color as the go/no go signal.

This brief review shows that both direct (Bach et al., 2007) and indirect (Liepelt & Brass, 2010; Longo & Bertenthal, 2009; Longo et al., 2008) evidence indicates that the magnitude of automatic imitation effects can be modulated by attention. This evidence of input modulation is consistent with both associative and conceptual models of imitation.

Output Modulation

Research relevant to output modulation has been dominated by studies showing, through a variety of methods, that the magnitude of automatic imitation effects can be influenced by social cognitive processes. For example, Spengler, Brass et al. (2010) found that the index/middle finger automatic imitation effect was attenuated when self-focus was encouraged by allowing participants to view their own body in a mirror during testing or by requiring them to make evaluative self-referential judgments between trials. Similarly, Leighton, Bird, Orsini, and Heyes (2010) tested participants in the hand open/close paradigm immediately after they had completed a scrambled-sentence task. The automatic imitation effect was attenuated if the sentence task included antisocial words (e.g., rebel, independent, disagreeable, alone) and enhanced if it included prosocial words (e.g., affiliate, friend, cooperate, together), relative to a condition in which the sentence task included only neutral words. Also using the hand open/close procedure,

Wang, Newport, and Hamilton (2011) found a larger automatic imitation effect when the movement stimulus was preceded by the actor making direct eye contact with the participant than when it was preceded by averted gaze or by a centrally located flash of light.

These findings from behavioral studies involving neurologically intact participants support those of previous research involving functional imaging and patients with brain lesions. The imaging studies have shown consistently that two cortical areas associated with social cognitive functions, the anterior fronto-median cortex (aFMC) and the temporo-parietal junction (TPJ), are more active during incompatible than during compatible trials in the index lift/tap (Brass, Zysset & von Cramon, 2001) and index/middle finger (Brass et al., 2005; Spengler, von Cramon & Brass, 2010) automatic imitation paradigms. The neuropsychological studies have indicated that, in patients with frontal lesions and in controls, the magnitude of the index/middle finger automatic imitation effect is correlated with performance on an advanced theory-of-mind task, and in patients with TPJ lesions, it is correlated with indices of empathy, visual perspective taking, and theory of mind (Spengler, Von Cramon & Brass, 2010). In all cases, a larger automatic imitation effect predicted weaker performance on measures of social cognitive functioning.

Studies involving participants with autism spectrum condition (ASC), who are known to have impairments in social cognitive functioning, also suggest that social cognitive processes can modulate automatic imitation. Compared with controls, adults with ASC show an enhanced automatic imitation effect in the hand open/close procedure (Bird, Leighton, Press & Heyes, 2007). Furthermore, in the index/middle finger procedure, the magnitude of their automatic imitation effects is not influenced by prosocial and antisocial priming using a scrambled-sentence task (Cook & Bird, 2012). Similarly, Bach and Tipper (2007) found a correlation between Autism Spectrum Quotient scores and the extent to which completion of a hand/foot automatic imitation procedure influenced participants' judgments about the personality characteristics of the actors observed during the procedure. For example, participants with high scores were more inclined to judge as "sporty" an actor who had been observed kicking a ball, rather than typing on a keyboard, when the participant was making foot responses.

These findings have been interpreted as examples of output modulation, suggesting that social cognitive processes modulate the magnitude of automatic imitation effects by influencing the extent to which corresponding motor activation is either inhibited or allowed to influence overt

behavioral performance (Bien, Roebroeck, Goebel & Sack, 2009; Brass, Ruby & Spengler, 2009). More specifically, Brass et al. (2009) have proposed that two social cognitive functions are involved in the modulation of automatic imitation. The first function, associated with the TPJ, makes "agency" judgments; it classifies an observed body movement as either self-generated or other generated. The second function, associated with the aFMC, "is required to enforce one's own motor intention against the externally triggered response tendency." In other words, the aFMC mediates higher-order intentional processes that oppose the behavioral expression of motor activation generated by a direct sensorimotor association. Factors influencing the efficiency of either or both functions—durably, as in the cases of brain injury and ASC, or transiently, via self-focus and social priming procedures—could have an impact on the magnitude of automatic imitation effects. For example, weak enforcement of the participant's own intentions (based on task instructions) could be a direct effect of brain injury or social priming, or secondary to a reduction in the efficiency with which body movement stimuli are classified as other generated rather than self-generated. In either case, weak enforcement of a participant's own intentions would be expected to result in faster responding in imitatively compatible trials and slower responding in imitatively incompatible trials, because it would leave associatively activated motor representations relatively unopposed in gaining control of behavior.

We still have much to learn about the interaction between automatic imitation and other social cognitive functions. However, at present, research in this area suggests that higher social cognitive functions modulate automatic imitation, not by changing the process that normally generates corresponding motor activation but by regulating the behavioral output from this process. Thus, consistent with both associative and conceptual models of imitation, higher social cognitive processes appear to contribute to output modulation rather than intervention.

Intervention

Studies of conceptual compatibility and counterimitative task set have been interpreted as evidence of intervention: context-related intentional processes can modulate automatic imitation, not only at input and output but also by changing the process that translates activation of a stimulus representation into activation of a response representation. If this is correct, it is unlikely that the translation process is mediated by long-term sensorimotor associations.

Jansson et al. (2007) have suggested that automatic imitation effects may be due to "conceptual compatibility." For example, the sight of hand opening may activate a verbal or semantic representation of "opening," rather than a motor representation of hand opening, that is, a specific, topographically similar response. In this case, the process producing "automatic" imitation effects would be mediated by higher-order representations, and therefore it would be likely that higher-order processes could intervene to prevent it from running its course.

In support of their proposal, Jansson et al. (2007, experiment 2) showed that a compatibility effect could be obtained with hand opening/closing responses not only when the stimuli depicted opening and closing hand actions but also when they consisted of two dots moving apart (opening) or together (closing). However, this result is ambiguous. It could be that the hand and dot compatibility effects were mediated by the same conceptual process, but it is at least equally plausible that the dot effect was mediated by a conceptual process (or by orthogonal spatial compatibility; see Press et al., 2008), whereas the hand effect was due to direct activation of motor responses by action stimuli.

An experiment by Leighton and Heyes (2010) provided a stronger test of the conceptual compatibility hypothesis proposed by Jansson et al. (2007). If the sight of hand opening activates an abstract verbal or semantic representation of "opening," rather than a specific motor representation of hand opening, one would expect hand opening stimuli to be equally effective in priming hand opening and mouth opening responses. However, the results reported by Leighton and Heyes (2010, experiment 3) were contrary to this prediction. They used a procedure in which color stimuli cued one of four responses in each trial—hand open, hand close, mouth open, mouth close—and this imperative cue was accompanied by an irrelevant stimulus depicting one of the same four actions. They found that the open/close compatibility effect was significantly greater when the stimulus effector was response compatible than when it was response incompatible. For example, open mouth responses were faster in the presence of open hand than of close hand stimuli, but the effect of the irrelevant hand stimuli was greater when participants were making open hand, than open mouth, responses. This pattern of results suggests that, rather than being conceptually mediated, the hand open/close compatibility effect is due to direct, associative activation by movement observation of motor representations coding topographically similar responses.

In another study that has been interpreted as providing evidence of intervention, Van Schie, Van Waterschoot, and Bekkering (2008) showed

that an automatic imitation effect can be reversed when trials in which the action cue is task irrelevant are embedded in a counterimitation task (for similar effects, see Heyes & Ray, 2004; Ocampo & Kritikos, 2009). In each trial in these experiments, participants saw an actor grasping either the base of an object with a power grip or the upper part of the object using a precision grip. In imitation blocks, participants were asked to do the same as the actor (e.g., to respond to a power grip using a power grip), and in counterimitation blocks they were instructed to perform the opposite action (e.g., to respond to a power grip using a precision grip). The findings of interest were from probe trials presented in each of these block types. In probe trials, a component of the stimulus video (hand, object, or table) was colored green, indicating that the participant should make a prespecified response—for example, use a power grip, regardless of the grip type applied by the model. In imitation blocks, probe trial responding was faster when the action stimulus was compatible with the prespecified response, but in counterimitation blocks, probe trial responding was slower when the action stimulus was compatible with the prespecified response.

This striking reversal effect has been taken to indicate that higher-order processes can intervene to determine whether perceptual analysis of action stimuli results in the activation of topographically similar or topographically dissimilar motor representations. This interpretation has two problems. First, in this experiment, grip type (power versus precision) was confounded with the part of the object grasped (large base versus small top), and therefore there is a risk that responses were primed not by topographic features of body movement but by spatial properties of the object part (Heyes, 2011). Second, the reversal effect is formally identical to the Hedge and Marsh effect (Hedge & Marsh, 1975) and can be explained in terms of "logical recoding," which is a form of output modulation (De Jong, Liang & Lauber, 1994).

The output modulation account of the reversal effect reported by Van Schie et al. (2008) assumes that standard (nonreversed) spatial compatibility and automatic imitation effects can be explained by "dual route" processing in the following way. Once it has been identified through perceptual analysis, the task-relevant stimulus activates the correct response via an intentional route. This route is often modeled as a short-term stimulus-response (S-R) connection: an excitatory link between a stimulus representation and a response representation, which is established on the basis of task instructions and held in short-term memory for the duration of the task (Barber & O'Leary, 1997; Zorzi & Umiltà, 1995). In addition, the task-irrelevant stimulus activates a similar or "corresponding" response via an

automatic route. This route is typically modeled as a long-term S-R connection: an excitatory link between a stimulus representation and a response representation, which is held in long-term memory. If the intentional and automatic routes activate the same response representation (compatible trials), the correct response is executed rapidly. However, if the two routes activate different response representations (incompatible trials), the incorrect response, activated via the automatic route, must be inhibited in favor of the correct response. This takes extra time, and therefore responding is slower in incompatible trials.

The output modulation account of the reversal effect reported by Van Schie et al. (2008) assumes that incongruent mapping instructions are logically recoded, or overgeneralized, from the task trials, in which location and grip are response relevant, to the probe trials, in which color is response relevant. Consequently, if we take counterimitation blocks as an example, the intentional route includes response rules, or short-term S-R links, connecting incompatible stimuli and responses. These compete with the long-term sensorimotor associations that connect compatible stimuli and responses and constitute the automatic route. Unless responses are made very fast, when automatic activation is strong, performance is dominated by the short-term intentional links that promote incompatible responding, and a reversal of the usual compatibility effect is observed (De Jong et al., 1994). If this account is correct, the reversed automatic imitation effect reported by Van Schie and colleagues does not show that contextual variables can modulate imitative performance by acting on a conceptual process that reliably occurs between stimulus processing and activation of a corresponding motor representation. In other words, their reversal effect is not an example of intervention.

Thus research on conceptual compatibility and the influence of a counterimitative task set does not currently provide compelling evidence that higher-order cognition can intervene in the process mediating automatic imitation. The conceptual compatibility hypothesis is inconsistent with the effector dependence of automatic imitation, and the effect of counterimitative task set could be due to logical recoding, that is, output modulation by intentional processes.

Conditional Learning

This chapter has distinguished three ways in which aspects of the social and nonsocial context could, in principle, have an impact on automatic imitation via higher-order processing: input modulation, where broadly

attentional processes influence the extent of action stimulus processing; output modulation, where imitative motor representations are inhibited or allowed to gain control of overt behavior; and intervention, where context-dependent intentions have a direct effect on the process that converts activation of an action stimulus representation into activation of a topographically similar response representation. As predicted by associative models of imitation, the review found evidence of input modulation and output modulation, but not of intervention. This tripartite scheme could be useful in future studies of imitation and related phenomena such as unconscious behavioral mimicry and mirror effects (Heyes, 2011).

However, to make further progress in understanding the core mechanisms of imitation—those that translate sensory representations of action into topographically similar motor representations—we need empirical studies designed explicitly to distinguish input and output modulation from intervention. To design such studies, it will almost certainly be necessary to develop conceptual models that specify the kind of higher-order processing that may constitute a core mechanism of imitation. Without this specification—without a clear picture of the kind of process in which intervention is supposed to intervene—it will remain extremely difficult for conceptual models to make testable predictions.

Associative models of imitation also require further elaboration, both to exploit more fully the wealth of information about associative learning accumulated through research on conditioning and to accommodate the full range of context effects likely to emerge in the next decade (Massen & Prinz, 2009). As a first step, the remainder of this section suggests that it would be fruitful for associative models of imitation to incorporate what is known about conditional learning (e.g., Bonardi, 1998).

It will be helpful for associative models of imitation to borrow theoretical and empirical resources from associative learning theory only if the long-term sensorimotor links that mediate imitation are predominantly learned, and learned via the same processes that produce Pavlovian and instrumental conditioning phenomena. A substantial body of evidence now suggests that the long-term sensorimotor links are learned (see Heyes, 2011, for a review). For example, this evidence shows that automatic imitation and mirror effects can be enhanced (Press, Gillmeister & Heyes, 2007), abolished (Heyes et al., 2005; Gillmeister et al., 2008; Wiggett et al., 2011), and even reversed (Catmur et al., 2008; Catmur, Mars, Rushworth & Heyes, 2011; Catmur, Walsh & Heyes, 2007) by novel sensorimotor experience. Some of the clearest evidence that this learning depends on the same processes as conditioning comes from a study showing that, like the acquisition of

conditioned responses (Dickinson & Charnock, 1985; Elsner & Hommel, 2004), it is sensitive to the contingency or predictive relationship between events (Cook, Press, Dickinson & Heyes, 2010).

Cook et al. (2010) followed up an experiment in which participants were tested for automatic imitation of hand opening/closing in a simple RT task 24 hours after they had performed 432 trials of a choice RT task in which closing hand responses were made to opening hand stimuli and opening hand responses were made to closing hand stimuli (incompatible group), or vice versa (control group). In this experiment, a significant automatic imitation effect (e.g., faster hand opening responses in the presence of hand opening than of hand closing stimuli) was observed in the control group, but not in the incompatible group (Heyes et al., 2005). Using the same procedure, Cook et al. (2010) found that incompatible sensorimotor experience abolished automatic imitation only when there was a positive contingency between hand movement stimuli and hand movement responses during training. When this contingency was eroded, for example, by including additional training trials in which responses occurred in the absence of movement stimuli, the effect of training was significantly reduced.

Research on conditional learning within the associative tradition has shown that contextual variables—known as "discriminative stimuli" or "occasion setters"—can modulate the learned behavior of animals such as rats and pigeons. For example, Colwill and Rescorla (1990, experiment 2) trained rats in an environment where they could make two responses, lever pressing (R1) and chain pulling (R2), for two kinds of outcomes, sucrose solution (O1) and dry food pellets (O2), in the presence of two contextual stimuli, a noise (S1) and a light (S2). When a noise sounded (S1), lever pressing produced sucrose (R1 > O1), and chain pulling produced pellets (R2 > O2); but when the light was presented, lever pressing produced pellets (R1 > O2), and chain pulling produced sucrose (R2 > O1). (The design was fully counterbalanced.) One of the two outcomes was then devalued by pairing with lithium chloride. In a subsequent test, where no outcomes were available, the rats' behavior was precisely modulated by the contextual stimuli: guided by these stimuli, they preferred to make the response that would have yielded the nondevalued outcome. For example, rats that had been averted to sucrose pulled the chain more than they pressed the lever in the presence of the noise, and pressed the lever more than they pulled the chain in the presence of the light.

Experiments of this kind demonstrate that complex contextual modulation of behavior can occur in relatively "simple" animals. They have also

provided information about the way in which associative mechanisms can produce contextual modulation. Two models—hierarchical and configural—have substantial empirical support. In the hierarchical model (Holland, 1983; Bonardi 1998), binary associations between a response and an outcome (e.g., R1 > O1) function as a unit that itself becomes associated with a contextual cue (e.g., S1). In other words, the contextual cue acts as an "and-gate" allowing activation of the response representation to be propagated to the outcome representation, or vice versa. In the configural model (Brandon & Wagner, 1998; Wilson & Pearce, 1992), the learner encodes the response-in-context (e.g., R1-in-C1), and this configural representation becomes associated with an outcome (e.g., O1). For example, lever-pressing-in-noise becomes associated with sucrose, whereas lever-pressing-in-light becomes associated with pellets.

Thus studies of conditioning in animals suggest that if it is based on learned sensorimotor associations, the contextual specificity of imitative performance could be due not only to input modulation and output modulation but also to conditional learning. As this chapter indicates, all the context effects reported to date in the literature on automatic imitation can be explained in terms of input and output modulation; they do not yet call for an explanation in terms of conditional learning. However, it is likely that training effects on automatic imitation depend, at least in part, on conditional learning. Consider the case, described earlier, where a relatively brief period of incompatible sensorimotor training (hand opening responses to hand closing stimuli, and vice versa) abolished the hand opening/closing automatic imitation effect (Heyes et al., 2005; Cook et al., 2010). It is possible that this training left intact the sensorimotor links that previously generated automatic imitation—links between topographically corresponding sensory and motor representations (open-open, close-close)—and established a new pair of noncorresponding associations (open-close, close-open) that were under the control of the training context. To test this hypothesis, it would be necessary to conduct incompatible sensorimotor training in a distinctive context and to compare its effects on automatic imitation in the training context and in an alternative context. If the effects of training are mediated by conditional learning, one would expect them to be stronger in the training context (Cook, Dickinson & Heyes, 2012).

More speculatively, conditional learning may also play a part in producing context effects on behavioral mimicry. For example, the physical characteristics of in-group members (e.g., accents, clothing) may act as occasion setters for the sensorimotor links underlying the enhanced mimicry of

in-group members in naturalistic social settings (Yabar, Johnston, Miles & Peace, 2006). Similarly, in the case of tool use actions, pivot points may act as occasion setters for sensorimotor associations relating simple spatial properties of action (e.g., toward versus away) to lever movements (e.g., up versus down) (Massen & Prinz, 2009).

Conclusion

Automatic imitation is a type of stimulus-response compatibility effect in which the topographical features of task-irrelevant action stimuli facilitate similar, and interfere with dissimilar, responses. This chapter has reviewed research on automatic imitation indicating that it is subject to input modulation by attentional processes, and output modulation by inhibitory processes, but not to intervention; higher-order cognition does not act directly on the processes that convert visual into motor representations of action. The lack of evidence of intervention suggests that even when automatic imitation effects are context dependent, they are mediated by associative rather than conceptual processes—by learned, long-term associations between sensory and motor representations of the same actions. This conclusion is consistent with the associative sequence learning (ASL) (Heyes, 2001) and ideomotor accounts of imitation (Prinz, 2005).

Automatic imitation is one of several "wayward" or unintentional forms of imitation that have been investigated intensively in the last 10 to 15 years. Others include unconscious behavioral mimicry and mirror effects. Drawing on evidence that lies beyond the scope of this chapter (e.g., Leighton, Bird & Heyes, 2010), both the ASL model and ideomotor theory suggest that these wayward forms of imitation are mediated by the same core processes as intentional imitation. If so, the research reviewed here suggests that both when we are trying to imitate and when imitative responses are elicited by body movement stimuli, the infamous correspondence problem (Brass & Heyes, 2005) is solved by associative processes. Higher-order cognitive processes can influence imitative performance, but the core competence—the ability to convert the sight of a body movement into matching motor output—depends on learned, long-term sensorimotor associations.

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