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IMITATION: THOUGHTS ABOUT THEORIES

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Many behavioural features and psychological states can be transmitted between natural systems. A person or animal can acquire through observation of another a tendency to go to the same place, effect the same transformation of an object, perform the same body movements, make the same sounds, feel similar emotions or think similar thoughts. In our discussion of imitation we will focus on cases in which body movements are transmitted or 'copied' between model and observer, because these cases present a distinctive explanatory challenge.

The problem of producing a movement that matches one observed is made difficult due to the nature of the codes representing the observed and executed movements. The observer must formulate *motor* commands to match *visual* input. This is a special case of what has become known as the 'correspondence problem' (Alissandrakis, Nehaniv, & Dautenhahn, 2002; Nehaniv & Dautenhahn, 2001), and it is made particularly difficult when simple perceptual matching cannot be used to produce imitative movements, as in the following example. A tennis coach demonstrates a serve to a novice, which the novice then attempts to imitate. If the novice successfully imitates the coach's action[1] the two actions will not 'match' from the novice's perspective. The novice will perceive the coach's actions as a whole body movement, in which the back arches and one arm moves in an overhead arc. In contrast, the novice's own actions will be perceived as a movement of their arm and hand from an unseen position behind their head, to a position in front of their body. Similarly, the coach may be able to detect that the novice's action matched the movement they had demonstrated, even though the visual information they received from their own movement and that of the novice differed greatly. Thus, an important challenge for theories of imitation is to explain *how* observation of action facilitates production of matching movements. This chapter reviews three theories of imitation which approach this problem in very different ways.

1 Three Theories

The three theories to be examined in greater detail in this chapter are: Active Intermodal Mapping (e.g. Meltzoff & Moore, 1983, 1994, 1997); Associative Sequence Learning (Heyes, 2001; Heyes, in press; Heyes & Ray, 2000), and the theory of Goal-directed Imitation (Wohlschläger, Gattis, & Bekkering, 2003). These theories can be divided into two camps based on the information processing thought to occur during imitation. Both the Active Intermodal Mapping (AIM) and Goal-directed (GOADI) theories of imitation suggest that intermediate recoding occurs between observation and execution of an imitative body movement. They imply that, in addition to a visual representation of the observed movement and a motor representation that drives muscle movement, imitation involves a third kind of movement representation, which is neither sensory nor motor. In contrast, the Associative Sequence Learning (ASL) theory of imitation argues that observation of a body movement can prompt the preparation of a matching action directly, without the need for intermediate recoding. We will now give a brief overview of the theories, before discussing their success in explaining imitative phenomena.

1.1 Active Intermodal Mapping

The AIM model of imitation introduces three theoretical concepts. The first, ‘organ identification’, is the process by which infants come to identify parts of their body with parts of the bodies of others. Meltzoff and Moore argue that this is the first step in the imitative process. The second concept ‘organ relations’, refers to the capacity of the infant to parse an observed action into a series of relationships between organs (parts) of the body. The same capacity allows the infant to identify the organ relations of her own body using proprioceptive feedback, and through organ identification, to actively compare the organ relations of the model with her own organ relations. Organ relations provide a common content for the percept of an action to be compared to the action of the perceiver. The third concept, ‘body babbling’, refers to the process of learning the relationship between muscle movements and the organ relations which result. It is argued that this process leads to the formation of a ‘directory’ of muscle movements and associated organ relations. After such experience-dependent learning, the infant will have the ability to produce muscle movements leading to specified organ relations.

Thus far, AIM does not address the correspondence problem. Although the infant can identify the organ relations of her own body, and can identify the organ relations of the model’s body, the two representations are still in incommensurate coding systems. Visually coded organ relations must still be compared to proprioceptively coded organ relations in order for a mismatch to be detected. According to AIM, the problem is solved by the use of a supramodal representational system. This system encodes organ relations in a modality-general fashion. Visual and proprioceptive organ relations are translated into this common representational framework allowing them to be compared directly. Meltzoff and Moore suggest that AIM explains infant imitation and forms the basis of adult imitative competency. The major developmental change in imitation occurs after a few weeks of life when perceived actions are no longer coded as organ relations, but rather as goal-directed actions (organ relation transformations; Meltzoff & Moore 1997). Subsequently, imitation is not of perceived movements, but of inferred goals.

1.2 Goal Directed Imitation

The GOADI theory of imitation also denies a direct link between the perception and production of body movements. It suggests that perceived actions are decomposed into a series of ‘aspects’ (most grossly the goal of a movement and the means to achieve it). Capacity limitations mean that only some goal aspects are imitated; movement end-points and the manipulation of objects are more likely to be imitated than either the effector or the movement path. When the goal of the movement has been selected, the movement most commonly associated with this goal will be performed. Thus, there is no special relationship between matching movements under GOADI. If the observer’s most commonly associated movement is the same as that performed by the model, then imitation of the perceived movement will occur. Alternatively, if the movement most commonly associated with the perceived goal is different from the movement of the model, then goal, but not movement, imitation will occur.

GOADI focuses attention on cases of imitation in which an observer's behaviour has the same outcome as that of the model, and it has inspired a series of very interesting studies suggesting that, when they are given non-specific instructions such as 'Do this', observers are more likely to reproduce action outcomes than to reproduce the body movements used to achieve these outcomes (see Wohlschläger, Gattis, and Bekkering, 2003). However, GOADI does not deny that people sometimes imitate body movements. It allows that during dance instruction, for example, it may be the goal of the model to produce a certain body movement, and the goal of the imitator is to produce exactly the same body movement. Cases like this pose the correspondence problem, and yet GOADI is silent about how this problem may be solved.

Both AIM and GOADI suggest that the processes mediating imitation involve intermediate action representations which are neither sensory nor motoric. According to AIM, perceived actions are actively processed in order to infer the model's goals. These goals are then translated into supramodal representations which are used to produce motor commands. Under GOADI, goals are also extracted from perceived movements. The goal representation then activates its most commonly associated motor program, irrespective of whether this matches the movement performed by the model. In contrast to these theories, the ASL model argues that the perception of action typically prompts the performance of that action directly, without the need for intermediate representation.

1.3 Associative Sequence Learning

The ASL theory suggests that the correspondence problem is solved through the operation of bidirectional excitatory links, or 'vertical associations', between sensory and motor representations of action (see Figure 1). Sensory representations are activated when actions are perceived, and they contain information received through the distal senses (vision and audition). Motor representations contain motor commands needed to perform the action, and somatosensory (kinaesthetic and proprioceptive) information received when the movement is performed. Thus, roughly speaking, the sensory representation codes what the action 'looks like' and the motor representation codes what it 'feels like' to perform the action. When a sensory and a motor representation are linked by a vertical association, activation of the sensory representation is propagated to the motor representation. If the sensory and motor components represent the same action (a "matching vertical association"), this activation of the motor representation makes imitation possible.

According to the ASL model, whereas a few vertical associations may be innate, the majority are formed in a Hebbian fashion, through experience that provokes concurrent activation of sensory and motor representations of the same movement. This experience may consist of concurrent observation and execution of the same movement, leading to a 'direct' vertical association, or it may involve exposure to a common stimulus in conjunction with, on some occasions, observation of the movement, and on other occasions with its execution[2]. For example, a child may hear the sound of a word such as 'frown', sometimes when she is frowning and, at other times, when she sees another person frowning. As a consequence of this 'acquired equivalence' experience (Hall 1996), sensory and motor representations of frowning will each become linked to a representation of the word. This 'indirect vertical association' enables activation of the sensory representation to be propagated to the motor representation via the word representation, and, to the extent that it allows the sound of the word concurrently to activate sensory and motor representations of frowning, to the formation of a direct vertical association between them.

The ASL model does not specify a system which compares sensory and motor representations of movements. To generate imitative behaviour, the system does not have to 'decide' whether there is a match between the associated sensory and motor representations. Indeed, it is possible for associative links to be formed between sensory and motor representations of actions that do not match from a third-person perspective. The reason why associations are more likely to be formed between matching rather than non-matching movements is due to the environment. Heyes (in press) argues that natural systems develop in environments where matching sensory and motor action representations are more likely to be contiguously activated than non-matching representations, but that this is merely a contingent fact. If, in a wholly unethical experiment, a child was reared in an environment where, for example, every smile is greeted with a frown, and mirrors were replaced with time-delay video feedback devices, whenever other children imitate, this unfortunate child would show a systematic tendency to counter-imitate. This intuitively implausible suggestion becomes more plausible when one realises that, to support imitation, it is the sensory and motor action representations which must match, rather than the actions of two individuals. Hence, matching sensory and motor representations are activated during unaided and mirror self-observation; the sensory representation of a hand movement will always be activated concurrently with the motor representation of the same hand movement in normal development. Although it is more likely that non-matching movements will be performed at any time between two individuals, the range of possible non-imitative actions is so much larger than that of imitative actions. Thus, associations between specific non-matching actions are unlikely to be formed.

2. Contrasting the theories

The theories outlined above present differing views on whether imitation necessarily involves intermediate representation, i.e. representation of action that is neither sensory nor motoric. These views are empirically testable because they lead to different predictions concerning at least two questions. The first of these is whether observation can support effector-dependent learning, and the second is whether imitation learning can occur without awareness.

2.1 Effector-dependent observational learning

Learning is said to be effector-dependent to the extent that training of one set of muscles (e.g. those of the right hand) does not generalize to another (e.g. those of the left hand). Effector-dependence of practice-based learning has been demonstrated in both monkeys (Rand, Hikosaka, Miyachi, Lu, & Miyashita, 1998) and humans (Bapi, Doya, & Harner, 2000; Marcovitch & Flanagan, in press). For example, Marcovitch and Flanagan allowed human participants to learn a sequence of movements to spatial targets with one hand, and then tested performance of the other hand on the training sequence or a novel sequence.

The three theories reviewed in the previous section make different predictions regarding effector-dependent observational learning. AIM suggests that observational learning will always be effector-independent – that the effects of observational learning will *not* be confined to the effector observed during training. This is because, according to AIM, the perceptual representations formed during action observation are transformed into 'supramodal' representations, and these can be translated into a variety of motor outputs. GOADI suggests that observers preferentially encode and imitate more global or distal aspects of observed behaviour. For example, given a choice, they will imitate action effects rather than the body movements used to achieve these effects. Consequently, GOADI predicts that effector-dependent observational learning will be very rare. It will occur only when the observed action could not be encoded at a more global level.

In contrast with AIM and GOADI, ASL suggests that the formation of effector-dependent representations of observed action occurs, and is not unusual. More specifically, it proposes that observation-activated motor representations will be effector-dependent to the extent that prior visual experience of each movement component has been paired with activation of a distinct and constant muscle set. This condition is likely to be met by finger movements. When a person looks at their hands while performing finger movements, the sight of, for example, the left index finger lifting will be paired more reliably with activation of muscles in the left index finger than with activation of muscles in the left ring finger or the right index finger.

Effector-dependent learning by observation has been demonstrated in our laboratory (e.g. Bird & Heyes, in press; Heyes & Foster, 2002; Osman, Bird & Heyes, in press). In the learning phase of these experiments, observers watch a model performing finger movements on a keyboard. The keys are pressed repeatedly in the same sequence. Observers are then asked to perform a series of tests in which it is an advantage to know the sequence demonstrated by the model. The results of these tests show that observers are better able than controls to perform the finger movement sequence demonstrated by the model, but that they are no better than controls when the task requires expression of the same sequence knowledge using different effectors. For example, if the model used the fingers of her right hand, the observers can perform the sequence with the fingers of their right hands, but not with the fingers of their left hands, or using their thumbs.

These results are consistent with the ASL theory, but not with AIM, which suggests that observational learning should always be effector-independent, or even with GOADI. The GOADI theory would predict that, instead of engaging in effector-dependent observational learning, the observers in our experiments could have encoded the model's actions in terms of their (more distal) effects on the response keys. Thus, evidence of effector-dependent learning by observation provides support for a direct link between the perception and production of action.

2.2 Awareness and Imitation

Let us now turn to the second question which impacts upon the debate over whether imitation is direct, or mediated by flexible, higher-order goals. This relates to the role of awareness in imitation.

Both AIM and GOADI suggest that imitation occurs via intentional, rather than automatic, processes (Neumann, 1984). AIM makes this explicit when it states that imitation is "active" rather than passive. In the case of GOADI, intentional processing is implied the very name of the theory: "Goal-directed imitation". In contrast, ASL suggests that the intention to imitate is not necessary for imitative performance, that imitation can occur automatically.

Evidence of automatic imitation has been provided recently by electrophysiological studies of motor facilitation by action observation (e.g. Aziz-Zadeh, Maeda, Zaidel, Mazziotta, & Iacoboni, 2002; Maeda, Kleiner-Fisman, & Pascual-Leone, 2002; Strafella & Paus, 2000). In these studies, passive participants observed body movements while transcranial magnetic stimulation (TMS) induced motor evoked potentials (MEPs) were recorded from a range of muscles. It was found that MEPs recorded from muscles involved in execution of the observed movement were greater than those recorded at other muscle sites.

Further evidence of unintentional imitation comes from research examining the 'Chameleon effect' in relatively unconstrained social interaction (e.g. Chartrand & Bargh, 1999; Lakin & Chartrand, 2003). Participants in these studies are asked to interact freely with another individual whom they believe is a participant, but who is actually a confederate of the researchers. The confederate exhibits a target behaviour during the interaction (such as tapping their foot), and the tendency of the participant to perform the target behaviour during the interaction is compared to a baseline period when the participant is alone. Results consistently show an increase in performance of the target behaviour by the participant during the interaction. However, during post-test debriefing, participants report that they did not notice the target behaviour being demonstrated, that they had no intention to imitate the behaviour, and that they were unaware of doing so.

Research using stimulus-response compatibility (SRC) paradigms implies that movement observation can induce the observer to prepare to perform a matching movement even when performance of such a movement is counter-intentional (Brass, Bekkering, Wohlschläger, & Prinz, 2000; Craighero, Fadiga, Rizzolatti, & Umilta, 1998; Heyes, Bird, Johnson & Haggard, in press; Stürmer, Aschersleben, & Prinz, 2000). For example, Brass et al. (2000) asked participants to lift (in one test block), or lower (in another test block) their index finger as soon as they saw movement of a stimulus hand. Irrespective of the stimulus movement, participants were always required to perform the same movement throughout a block. Stimulus movements were either compatible (matching), or incompatible (non-matching), with respect to the response movement. Participants were faster to respond on compatible than incompatible trials suggesting that perception of an action primes production of that action even when the identity of observed movements is task-irrelevant.

The foregoing studies demonstrate unintentional activation and/or production of observed body movements that are already part of the observer's behavioural repertoire. It could be argued, therefore, that they are not the kind of phenomenon that AIM and GOADI are seeking to explain. Perhaps these theories are concerned exclusively with imitation *learning*, with cases in which an observer expands their behavioural repertoire by copying the actions of a model. However, the results of some of our recent experiments suggest that imitation learning can be automatic or unintentional. These studies indicate that healthy adults can learn to perform a sequence of finger movements fluently through imitation, without being able subsequently to recognise the sequence (Bird, Osman, Saggerson, & Heyes, submitted). Participants who had observed the sequence performed by a model executed it faster than controls, but when they were shown sequence segments and asked to rate their familiarity, observers were no better than controls at distinguishing segments of the observed sequence from segments of an unfamiliar sequence with the same, complex structure. This result suggests that participants were not aware of the information they had learned through imitation and, by inference, that imitation had occurred without intention.

3. Intentional and Incidental Imitation

ASL does not specify that imitation must involve a representation of the model's action goals, or assign a role to intermediate or amodal (non-sensory, non-motor) representations of action. And yet, introspection suggests that sometimes we *do* focus on goals during imitation, and form amodal representations of what we have observed. Returning to the example presented at the beginning of the chapter, as our novice tennis player watches his coach he may focus entirely on the angle the racquet makes with the ball, ignoring the position of the coach's head, trunk, and arms. Furthermore, the novice may formulate a linguistic description of the observed action in his mind, such as, "The racquet head is at 90 degrees to the ball and is rotated on contact". He may then re-run this verbal script as he tries to imitate the coach's serve, trying to use it to control his movements. The introspective plausibility of this kind of scenario implies that the ASL model does not capture some important features of our experience of imitation - features that *are* captured by AIM and GOADI. One day, ASL may be extended so that it makes better contact with introspective and experimental evidence relating to goal-directed imitation. For now, we simply offer some thoughts about the relationship between goal-directed or intentional processing and the vertical associations which, according to ASL, mediate imitation.

We suggest that, regardless of whether the observer intends to imitate, movement observation gives rise to motor activation in the manner described by ASL. Provided that the observer's past experience has been such as to provide them with vertical associations relevant to the currently observed movement, its perception will result in activation of the central and peripheral neural mechanisms that mediate performance of the same action. However, at least in humans, this activation is normally inhibited so that it does not result automatically in overt imitative performance. When the observer's intention is to be passive, or to perform a non-imitative movement, this inhibition allows the observer to discharge their intention with minimal interference from observation-induced motor activation. A healthy adult human may perform an echoing twitch when they intend to be still, or may be slower to perform an intended non-imitative movement than they would be in the absence of observation-induced activation (Stürmer et al 2000), but, unlike some frontal patients (Brass, Derrfuss, Matthes-von Cramon, & von Cramon, 2003) whose inhibition mechanisms are impaired, a healthy adult does not automatically perform the movements they see.

When movement observation occurs with the intention to imitate, one or both of two processes may occur. First, there may be disinhibition of the motor activation generated via vertical associations. That is, the inhibition which normally prevents matching motor activation from leading to overt performance of an imitative movement may be cancelled, 'releasing' imitative behaviour. Second, the observer may formulate a goal-related verbal description of the observed action, and try to achieve imitation by willing their body to move in a way that conforms to this description. To the extent that what the observer intends to imitate is an effect of a movement on an object (known as 'emulation' in the comparative and developmental literature) this strategy may be effective. However, if the observer's intention is to copy details of the model's body movements, vocabulary limitations are likely to thwart their efforts. Groups with special expertise, such as dancers and gymnasts, have vocabularies that distinguish subtly different body movements, but most of us lack such a facility. Furthermore, insofar as the strategy is effective, it may be due to indirect vertical associations, to bidirectional excitatory links between, on the one hand, acoustic representations of words, and, on the other, visual and motor representations of actions to which they relate.

In sum, it seems that representation of a model's goals may be important in explaining *what* is imitated, but that vertical associations are needed to explain *how* imitation is achieved.

Notes

1. The term ‘action’ is sometimes used to refer specifically to goal-directed or intentional body movements. We have not adopted this usage here; ‘action’ and ‘movement’ are used synonymously.

2. Although concurrent activation or 'contiguity' is emphasised here for clarity of exposition, the ASL model assumes, in line with contemporary theories of associative learning (see Hall 1994 for a review), that the formation of vertical associations depends on contingency in addition to contiguity.

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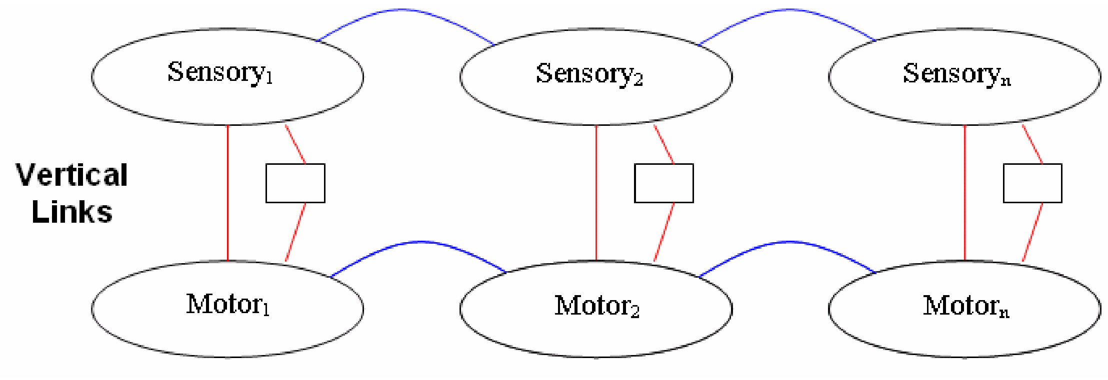
Figure Legends

Figure 1 - Schematic representation of the Associative Sequence Learning theory of imitation learning (see text for details).

Fig. 1


Sensory$_1$
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Vertical Links
Motor$_1$
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