

Action understanding and social learning in Autism: a developmental perspective

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Abstract

Social cognitive development in humans is grounded on a set of “hard-wired” skills that enable children to (1) pay attention to relevant aspects of the environment in order to make sense of other people’s behaviour (2) incorporate the actions they observe into their own behavioural repertoire (i.e., social learning). This phenomenon, which allows individuals to take advantage of other people’s knowledge and avoid the costs of trial-and-error learning, are likely to reflect the interplay of uniquely human social-cognitive biases (e.g., drive to orient attention toward other people) and higher-level cognitive processes (e.g., strategic selection of what to imitate). Difficulties in understanding and imitating others’ actions, as well as difficulties in learning, are frequently documented in children with autism, a neurodevelopmental disorder characterized, by multiple deficits in the areas of social communication, and reciprocity and by behavioural rigidity. A set of recent experimental studies based on the eye-tracking technologies (Vivanti, McCormick, Young, Abucayan, Hatt, Nadig et al., 2011; Vivanti, Nadig, Ozonoff, & Rogers, 2008) provide us with new insight on the nature of imitative learning and its disruption in children with autism. In particular, mechanisms such as joint attention, gaze following and “reading” referential cues appear to be crucially involved in the ability to understand, predict and copy others’ actions. We will discuss these find-

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ings and their relevance for clinical practice, future research and theoretical debate on the neurocognitive mechanisms subserving social learning in children with and without autism.

Keywords: Autism, Imitation, Social Learning, Eye-Tracking, Mirror Neurons

1. Introduction

Most learning takes place in a social context (Vygotsky, 1978). This type of learning is particularly relevant in infancy and childhood and it's facilitated by specific cognitive and attentional biases that lead children to preferentially attend to social stimuli and to experience the participation in social exchanges as intrinsically rewarding (Legerstee, Anderson, & Schaffer, 1998).

Mechanisms involved in social reciprocity and social learning appear to be disrupted or inefficient in persons affected with Autism Spectrum Disorders (ASDs), a group of conditions characterized by multiple deficits in the areas of social communication and reciprocity and behavioural rigidity (Kanner, 1943; Volkmar, Lord, Bailey, Schultz, & Klin, 2004).

Most adults with Autism Spectrum Disorders are unable to live independently and need continuous assistance in their everyday life (Howlin, 2005). According to several scholars in the field, such disability, rather than being intrinsic to an Autism Spectrum condition, appears to be a consequence of being affected by such condition (Rogers & Dawson, 2010). In other words, the disability in autism might reflect the failure to learn skills that are crucial for cognitive development and adaptive functioning. In this view, specific differences in the way others' actions are attended, processed and learned might give rise to developmental sequelae resulting in cognitive and adaptive delays.

From infancy, children with autism show a diminished attention to social stimuli compared to peers (possibly because they don't experience the same level of social reward that is associated with participating in social exchanges in typical development; Dawson, 2008); they also show difficulties in understanding and imitating the actions they observe (Vivanti, McCormick, Young, Abucayan, Hatt, Nadig, Ozonoff, & Rogers, 2011). How is this affecting the learning processes that contribute to shape the developing brain during early developmental stages? We will focus our discussion on the nature of such phenomena in a developmental perspective.

2. Imitation and social learning in autism

Social learning is a type of learning that occurs as a function of observing and replicating novel behavior executed by others (Bandura, 1962). The most commonly observed social learning process in humans is imitation (Tennie, Call, & Tomasello, 2009; Whiten, McGuigan, Marshall-Pescini, & Hopper, 2009).

The centrality of imitation as a general learning mechanism in early childhood (Uzgiris, 1981; Meltzoff, 1985; Tomasello, 1999) is supported by

evidence that, in typically developing young children, a variety of key developmental accomplishments demonstrate strong relationships with imitation skills, including general cognitive abilities (Strid, Tjus, Smith, Meltzoff, & Heimann, 2006), language development (Bates, Thal, Whitesell, Fenson, & Oakes, 1989; Masur & Eichorst, 2002), sharing of affect (Uzgiris, 1999), cooperation (Colombi, Liebal, Tomasello, Young, Warneken, & Rogers, 2009), and social responsiveness (Heimann, 1998; 2002), although the nature of these relationships is not fully understood.

Because of the relationship between imitation and several other developmental domains, it is plausible that an early imitation deficit in autism may contribute to impairments in cognition, social communication, and adaptive skills (DeMyer, Hintgen, & Jackson, 1981; Rogers & Pennington, 1991; Hepburn & Stone, 2006). Imitative difficulties in children with autism were first identified and studied almost 40 years ago by DeMyer and colleagues (DeMyer, Alpern, Barton, DeMyer, Churchill, & Hingtgen, 1972). Subsequently the imitation deficit in autism has been confirmed by many methodologically rigorous studies using comparison groups of developmentally matched children with typical development, as well as matched groups involving children or adults with other developmental disorders, and several systematic reviews, including a meta-analysis (e.g., Sigman & Ungerer, 1984; Rogers & Pennington, 1991; Smith & Bryson, 1994; Charman, Swettenham, Baron-Cohen, Cox, Baird, & Drew, 1997; Stone Ousley, & Littleford, 1997; Rogers, 1999; Rogers, Stackhouse, Hepburn, & Wehner, 2003; Williams, Whiten, & Singh, 2004; Vivanti, Nadig, Ozonoff, & Rogers, 2008).

Interestingly, not all aspects of imitation seem to be equally impaired in ASD. While both frequency of imitation and precision of imitation appear to be affected, people with autism show relatively better performance in imitating goal-directed actions on objects than gestural and facial movements (Vivanti *et al.*, 2008; Colombi, Vivanti & Rogers, 2011).

3. Neuropsychology of imitative learning

Crucial insights on the neuro-cognitive processes involved in imitative learning have been provided by Rothi, Ochipa and Heilman (1991) and Tessari, Canessa, Ukmar and Rumiati (2007). Both their models include three main phases:

Encoding phase. This step involves the formation of a representation of the action based on the imitator's visual attention to relevant properties of the demonstrator's action.

Cross-modal or transformation/matching phase: in this process, the imitator's previous knowledge of the meaning and motor aspects of the action

is recruited, allowing for an efficient transfer from a perceptual code to a semantic and motor code. When the observed action is novel and cannot be mapped onto the imitator's motor vocabulary, the action, rather than being processed as a unit, is decomposed in a series of chunks that are each maintained "online" in working memory. In this case, imitation relies on a direct mapping from the perceptual to the motor features of the action, without a "semantic" mediation.

Execution phase: during this phase, the action is executed and the perceptual analysis of the performed action is compared to the representation of the action to provide online feedback and corrections on the motor plan.

The process begins with an observation of an action. The occipital cortex maps the observed action, and projects to the superior temporal sulcus (STS) region. The STS is a high-level visual-processing area that is selectively activated by the perception of biological movements (Decety & Grezes, 1999; Allison, Puce, & McCarthy, 2000; Pelphrey, Adolphs, & Morris, 2004). Recent findings suggest that the STS is specialized in interpreting dynamic social signs, such as gaze and head directions, and in processing social information conveyed by biological motion. Moreover, this region provides a somatotopic representation of the observed actions (Pelphrey, Morris, & McCarthy, 2005). Therefore, one role of STS is to distinguish social/biological motion, to translate perceived information into body knowledge, and possibly to detect intentionality in the perceived movement (Castelli, Happé, Frith, & Frith, 2000; Castelli, Frith, Happé, & Frith, 2002; Pelphrey, Singerman, Allison, & McCarthy, 2003; Schultz, Chawarska, & Volkmar, 2006). The STS then projects to the inferior parietal lobule (IPL).

The inferior parietal lobule has "mirror properties neurons." in this area are activated by both observing an action and executing it (Gallese, Fadiga, Fogassi, & Rizzolatti, 1996). This mirroring capacity is believed to mediate an "automatic" understanding of the action, based on the direct matching of the visual information onto the imitator's motor repertoire (Fogassi & Luppino, 2005). The inferior parietal lobule projects to the inferior frontal gyrus (Broca's area).

The inferior frontal gyrus (IFG; Brodmann area 44), plus the adjacent portion of the premotor area, also contains a significant number of mirror neurons, namely, those motor neurons that are activated both when observing and performing a specific action. Crucially, some neurons in this area are also activated by observing and performing nonidentical actions that are related to the same goal. This process allows the attribution of the semantic value of the observed action. In other words, the activation of this region during the observation of the action mediates the mapping of the visuomotor pattern into the imitator's semantic vocabulary of purposeful actions and the goals that are accomplished with them (Kohler, Keysers, Umiltà, Fogassi, Gallese, & Rizzolatti, 2002; Koski, Wohschlager, Bekkering, Woods, Dubeau, Mazziotta, *et al.*, 2002; Rumiati, Weiss, Tessari, Assmus,

Zilles, Herzog, *et al.*, 2005; Iacoboni & Dapretto, 2006). The final step in the neural pathways involves sending efferent copies of motor plans from the IFG back to the STS, so that the visual description of the observed action is compared to the predicted sensory consequences of the planned imitative action (Iacoboni, Koski, Brass, Bekkering, Woods, Dubeau, *et al.*, 2001; Carr, Iacoboni, Dubeau, Mazziotta, & Lenzi, 2003; Iacoboni, 2005), an evaluative step in the process that allows one to determine if the goal was reached.

Two aspects of the neuropsychological model described above stand out: 1) both the visual and the motor system are involved in the action understanding process. Rather than relying on low-level visuospatial properties of the action to derive a motor representation, we exploit our motor system to represent, or map, what we see via our action repertoire (Grezes & Decety, 2001; Rumiati *et al.*, 2005; Iacoboni, 2008); and 2) seeing an action elicits the motor program for implementing the same goal—that is, the specific conditions of the setting and the observer then determine how the action is imitated (e.g., whether or not the observer has the same effectors available to perform the action, or whether or not the same goal can be achieved with a more familiar or efficient motor program).

This ability to encode goals, in addition to the kinematics of the demonstrator's action, is what makes imitation flexible and selective in typical development. Such a “semantic” coding, as opposed to a “visuospatial” coding, results in a decreased demand on information processing resources, and more efficient imitative performance (Gattis, Bekkering, & Wohlschlagler, 2002; Tessari & Rumiati, 2004).

However, when the demonstration's action does not have a goal or a predefined meaning, the imitator cannot “translate” the action into a motor schema using his “semantic vocabulary.” The action, rather than being encoded on the basis of its goal, has to be processed in terms of its visuomotor properties via a non-semantic, “sub-lexical” route. Tessari and Rumiati (2004; see also Rumiati *et al.*, 2005; Tessari *et al.*, 2007) documented that the neurocognitive basis of processing “meaningless” actions, which must be mapped via the visual-spatial and kinematic pathways, overlaps only in part with neural network implementing the encoding of goal-directed actions. In particular, during the encoding of meaningless actions, less activation of the inferior frontal gyrus and more activation of the right occipital-parietal junction is observed (Rumiati *et al.*, 2005). These neuroimaging data indicate that when we cannot exploit the semantics of the action (a process mediated by the inferior frontal gyrus), we need to rely on a more pictorial description of the action. In this case the action, rather than being encoded as a unit, has to be broken down into a series of chunks that are each maintained “online” in working memory. Crucially, nothing in the kinematics of the action indicates when the action starts and when it ends. The imitator needs to rely on the demonstrator's ostensive cues to “isolate” the action to be imitated in the stream of the demonstrator's behavior.

These different routes are activated by the properties of the action stimulus. When an action is recognized as familiar and meaningful, the semantic coding is automatically activated; when the action is meaningless and it has no correspondence in the imitator's semantic vocabulary, the "sub-lexical" (more pictorial) route is selected (Press, Bird, Walsh, & Heyes, 2008). For the semantic coding process to take place, the imitator needs to have expertise with the action observed; the action observed needs to be present in his semantic vocabulary. This has important implications for autism, as children with autism, by definition, have a more limited range of activities in their repertoire (American Psychiatric Association, 2000) and less social expertise (Klin, Jones, Schultz, & Volkmar, 2003) than age-mates.

4. New research directions in imitation in autism: the role of action encoding

Research on imitation in autism has mainly focused on motor execution of imitation, or, what kinds of difficulties might impact children's ability to reproduce others' actions. Results of these studies are inconclusive (Vivanti, 2007). The first stage that enables imitation (i.e., the encoding of the action to be imitated) has been much less investigated. Investigating the encoding phase of imitation involves understanding how the imitator forms, retains, and operates on that specific representation (Whiten, 2002). We cannot read the mind of the imitator to see how he or she represents an action; however, we can access this process by 1) observing how the imitator will imitate the same action under different conditions (does the imitator process an action differently if we manipulate variables such as the demonstrator's gaze direction, length of exposure, or the context of the action?), 2) analyzing the imitator's visual attention pattern during the demonstration (what elements of the demonstration is the imitator considering?), and 3) determining what parts of the brain are active during the demonstration (what functional circuitries are implementing the encoding process?). Using these techniques, scientists are starting to uncover information on how actions are encoded in the imitation process by typically developing individuals. The most relevant of these notions, in relation to autism, is that when we encode an action, we encode more than the action itself.

For an efficient imitative learning process to take place, the imitator, given all the potential information available in the demonstrator's behavior, needs to take in some stimuli and ignore other stimuli (Carpenter, *et al.*, 1995; Bekkering, Wohlschlagel, & Gattis, 2000; Behne, Carpenter, & Tomasello, 2005; Tomasello, & Carpenter, 2005; Brass, Schmitt, Spengler, & Gergely, 2007; Carpenter & Call, 2007). The demonstrator's goal, and the context in which the action takes place, appear to be particularly relevant in

the imitator's representation of the demonstrator's action (Bekkering *et al.*, 2000; Gergely Bekkering, & Kiraly, 2002; Iacoboni, 2005). Consider the following example: The demonstrator is sitting at a table with a bottle (close to him) and a teacup (on the other side of the table). He moves his arm toward the teacup and grasps it. In doing so, he touches the bottle with his elbow, causing the bottle to move. If, while doing this action, the demonstrator looks at the bottle, the imitator might conclude that his goal was to deliberately move the bottle and then grasp the cup; if, instead, the demonstrator is looking at the teacup the whole time, the imitator might conclude that he is reaching for the teacup and, while doing so, accidentally touched the bottle. If asked to observe and then imitate the model, the imitator will, in the first situation, imitate both actions, and in the second situation, imitate only the action of grasping the teacup (Carpenter & Call, 2007; Southgate, Johnson, & Csibra, 2008). Therefore, the demonstrator's behaviors toward the object that he or she is acting upon crucially influences the way the action is encoded, and, ultimately, reproduced.

The imitator's encoding and reproduction of the action is also influenced by contextual aspects, such as objects and physical constraints in the environment. If the demonstrator is moving aside the bottle with his elbow while holding a large box in his hands, the imitator is very likely to move the bottle aside using his hand rather than the elbow (Gergely, Bekkering, & Kiraly, 2002). However, if the demonstrator's hands are empty, the imitator is more likely to move the bottle with his elbow. This pattern has been found in very young children as well as adults (Carpenter, Akhtar, & Tomasello, 1998; Southgate *et al.*, 2008; Kiraly, 2009). The interpretation of this imitative behavior is that the imitator evaluates the actions of the demonstrator in terms of goals, and means and assumes that another person will generally use the most efficient action available to accomplish a goal. In the example above, the observer assumes that the only reason the person holding the box is using his elbow is because his hands are otherwise occupied, and not because it is important to the task, and so the imitator uses the most rational and common action in order to achieve the same goal. However, if his hands are free, then the observer assumes there is a specific reason to use the elbow, and thus uses it as well.

This tendency of children to interpret an action as goal-directed appears to be a general bias of humans and develops very early. Behavioral data show that encoding an action as goal-directed represents the "default" output of the action understanding process from infancy on (Csibra & Gergely, 2007; Csibra, 2008). However, there are some motor acts that appear to be non-goal-directed. What happens when an observer sees an individual performing actions that are not directed toward any recognizable goal? Behavioral data indicate that children consider the demonstration's actions as goal-directed even when the action itself does not lead to an end-state. When the demonstrator is doing an apparently meaningless action or ges-

ture and he is providing some kind of ostensive cue, then the imitator encodes the action as a deliberate action to be attended to and imitated (in this case, observer interprets the ostensive cue to signal the demonstrator's goal to have the imitator attend and imitate his actions).

Indeed, imitation typically occurs in the framework of a social exchange in which the demonstrator provides communicative cues that help the imitator to understand what and how to imitate (Frith, 2008; Kiraly, 2009). In this framework, the demonstrator adopts a pedagogical stance by deliberately guiding the imitator through gesture, facial expressions, gaze, posture, and or vocalizations; the imitator, in turn, is socially motivated and cognitively able to participate in the exchange, and the imitation process takes place in a sort of mutually reinforcing choreography (Stern, 1985; Fonagy *et al.*, 2007; Gergely, Egyed, & Kiraly, 2007;). These kinds of exchanges are mediated by shared communicative meanings. The ostensive direct gaze is a particularly important communicative signal that precedes actions to which the demonstrator wants the imitator to pay attention (Sperber & Wilson, 1995). Children show special sensitivity to the direct gaze of another person, and appear to ascribe more salience to the actions that follow such a gaze, shown in their increased attention and exact imitation (Senju & Csibra, 2008; Kiraly, 2009). Therefore, the demonstrator's behavior toward the imitator crucially influences the way the action is encoded.

In these examples, the imitator observes the same exact motor action (touching a bottle with his elbow); however, he "sees" and imitates four different actions under specific circumstances. The same input is encoded so as to lead to four different outputs. The reverse phenomenon is also observed in human imitation: different inputs lead to the same output, apparently for the same reason: the underlying interpretation of the goal-directedness of the action. Noy, Rumiati and Flash (2008) documented that variations in features such as the orientation of the action do not change the way the action is imitated. In summary, children go beyond the "literal" information (Bruner, 1957). They do not "echo" an action via imitation, but rather frame the actions they see in a broader context that assumes a logical relation among the demonstrator's action, his intentions, and his communication.

However, another step is necessary for determining how actions will be processed: the properties of the action stimulus, rather than being a datum, depend on the imitator's selective attention to the relevant properties of the action. Encoding of a critical aspect of the demonstrator's action (i.e., where is he looking, what is he doing?) occurs only when attention is directed toward that feature (Klin, 2008). Children are exposed to a myriad of movements in daily life situations – how do they know what are the relevant aspects to be attended and imitated? Empirical data suggest that from infancy, children show very powerful preferential looking behaviors; they are strongly biased to selectively attend to specific features, namely faces, eyes (Morton & Johnson, 1991; Turati, Macchi Cassia, Simion, & Leo, 2006),

and hands (particularly when hands are manipulating objects; Amano, Kezuka, & Yamamoto, 2004). These features are those that are crucially involved in determining how the input is encoded and imitated (see above). This suggests that the mechanism gating perceptual input to the mirror-system-mediated action-understanding process is based on the imitator's preferential orientation toward specific features of the action. In other words, children are "programmed to learn" (Del Giudice, Manera, & Keysers, 2009), and possess a topology of salience (see Klin *et al.*, 2003) that biases them to select those features of the demonstration that lead to the semantic encoding of the action. This encoding process allows the child to combine information from past experiences (the semantic store) with information contained in the current experience, allowing the child to "go beyond the information given" to understand the current situation, flexibly learning within a social/pedagogical framework. Do children with autism also go "beyond the information given" when observing and imitating?

5. Preliminary evidence of action encoding abnormalities in autism and their relationship with imitative learning

The process of analysis and interpretation of the demonstrator's action described above, in which information in addition to the action itself is recruited, is mediated by a series of specific abilities, including efficient gaze processing, integration of different sources of information (Vivanti *et al.*, 2008), joint attention (Carpenter *et al.*, 1995; Hobson & Hobson, 2007), and understanding of emotion, intentions, and communicative cues conveyed by the demonstrator's face and body (Carpenter & Call, 2007; Southgate *et al.*, 2008). All of these abilities, which appear to be crucially involved in encoding and understanding, and ultimately imitating, others' actions, appear to be deficient in individuals with autism (Mundy & Neal, 2001; Mundy & Burnette, 2005; Schultz, Chawarska, & Volkmar, 2006; Dawson & Bernier, 2007; Pennington, 2009). Therefore, there are reasons to hypothesize that abnormalities in the way children with autism encode and understand the demonstrator's action might crucially contribute to their imitation deficit.

First of all, do children with autism pay attention to the demonstration? It is very common to hear parents of children with autism saying, "I try to teach him how to do that, but he doesn't pay attention to me!" Is that what really happens? Do they fail to imitate because they do not look at the demonstration? A basic grasp of the demonstrator's actions by individuals with autism is supported by studies using recognition tests (Smith & Bryson, 1998; Bennetto, 1999). In these studies, participants with autism, like comparison participants, were able to recognize the actions they had imitated from an array of actions represented in pictures. Although partici-

pants' observations of the demonstrator's action was adequate to permit later recognition, these studies leave open the question of differences in the focus and relative amount of visual attention during the demonstration.

Recently, Vivanti, Nadig, Ozonoff and Rogers (2008) empirically tested this hypothesis. They employed eye-tracking technology to examine what children with autism and typically developing children look at when actions to be imitated are being demonstrated to them. Their findings indicated that well-matched groups of children with autism and typically developing children look at to-be-imitated actions for similar durations; however, typically developing children, as a group, looked to the demonstrator's neutral face twice as long as the group of children with autism did. In the experiment, children were observing two different types of to-be-imitated actions: meaningful and non-meaningful actions. In the first case, the actions themselves (e.g., drawing a line, striking a xylophone) provided all of the elements necessary for the imitator's interpretation: the actions were "self-explaining," that is, no additional information was needed for the imitator to make sense of them. In the second case, the actions (e.g., flexing the arm at the elbow, moving the arm across the forehead) were ambiguous and did not have an obvious end-state or goal. When observing these latter actions, the group of typically developing children greatly increased their attention to the face of the demonstrator, as if searching for additional information to explain the action.

Interestingly, the group with autism also demonstrated increased looks to the face when the action to be imitated was not goal-directed. What strongly differentiated the two groups was the decreased quantity of visual attention to the demonstrator's face in the group with autism in both conditions.

These eye-tracking data indicate that children with autism, as a group, are actually looking at the demonstration, but they fail to look at the demonstrator as much as typically developing children do. Similar findings in an imitation task were obtained by Hobson and Hobson (2007) using a behavioral paradigm. They found that children with autism, compared to children with other developmental disabilities, were less inclined to look at the demonstrator during both the observation and the execution of an imitative task. Moreover, they found visual attention to the demonstrator's face to be related to better imitative performance. The tendency to look at the demonstrator's face has been documented in infancy as well as childhood in both typically developing children and those with intellectual deficits (Carpenter *et al.*, 1995; Hobson & Hobson, 2007). These data are consistent with the abundant research literature demonstrating that children with autism have reduced attention to social stimuli (Dawson, Munson, Estes, Osterling, McPartland, Toth *et al.*, 2002; Grelotti, Gauthier, & Schultz, 2002; Pelphrey, Sasson, Reznick, Paul, Goldman, & Piven., 2002; Dalton, Nacewicz, Johnstone, Schaefer, Gernsbacher, Goldsmith *et al.*,

2005), difficulties in face processing (Ashwin, Baron-Cohen, Wheelwright, O’Riordan, & Bullmore, 2007; Scherf, Behrmann, Minshew, & Luna, 2008), and abnormal visual scanning patterns (Klin *et al.*, 2003; Anderson, Colombo, & Shaddy, 2006; Speer, Cook, McMahon, & Clark, 2007). Converging evidence is provided by a study by Castiello (2003), which demonstrated that the observation of a person performing a goal-directed movement facilitated imitation only if the observer could see the actor’s gaze, though children with autism have not shown this same type of facilitation (Pierno, Becchio, Turella, Tubaldi, & Castiello, 2008). Thus, the current data suggest that, when a child with autism and a typically developing child are observing someone’s action, they are both observing the action, but they are not encoding the same breadth of social information (see also Rogers Young, Cook, Giolzetti, & Ozonoff, 2010). Differences in how children with autism imitate others appear to begin in the very first step of the process, with selective attention guiding the perceptual input to the rest of the system.

Imitation in autism might rely mainly on the encoding and reproduction of the motor information (i.e., the action itself), while typically developing children select and integrate extra-motor information to support a semantic coding of the action. Failure to detect cues provided by the demonstrator’s face might result in difficulties in processing more complex goal-directed actions, in which information provided by the demonstrator’s face is necessary to interpret the goal of the action. Imitation of simple goal-directed actions, in which the action itself is “self-explaining” and no extra-motor information is necessary to understand the demonstrator’s goal, might not be affected by this difference in visual attention, thus resulting in the often-replicated finding that children with autism show less deficit in imitating simple actions on objects than other types of imitations.

This interpretation is supported by findings from a recent study (Vivanti *et al.*, 2011) that tested the ability of children with autism to predict the outcome of an action in two conditions: 1) when the end-state of the action could be inferred on the basis of the objects involved in the action; and 2) when the demonstrator’s gaze direction was crucial for determining the course of the action. The group with autism performed as well as the group with typical development in the first condition, but were significantly impaired in the second condition. Gaze-pattern analyses revealed that children with autism showed significantly reduced attention to the direction of the demonstrator’s gaze compared to the contrast group. Correlation analyses suggested that failure to interpret this social cue to the demonstrator’s goal led to their poor performance.

It is tempting to speculate that failure to capture this type of social information results in persons with autism processing the action to be modelled via the “sublexical” route (see above) more frequently than others, and using the “semantic” route less frequently. This interpretation seems to be supported by studies documenting that, in contrast to typically develop-

ing children, children with ASD tend to imitate “accidental” actions performed by the demonstrator, thus reproducing the exact motor pattern observed, without appreciating the difference between “intentional” and “accidental” acts of the demonstrator (D’Entremont & Yazbek, 2007), though see contradictory evidence from Rogers *et al.*, 2010). Moreover, children with autism, unlike those with other developmental disabilities, are more likely to imitate the action itself (the motor pattern) but not the affective style of the demonstrator (e.g., knocking on a door gently versus harshly; Hobson, 1986, 1995; Hobson & Lee, 1999).

However, we also found that children with autism are able to predict the outcome of an action on the basis of the actor’s emotions (Vivanti *et al.*, 2011). This dissociation between the ability to understand the goals of an action on the basis of emotional expressions and gaze direction suggests that children with autism, rather than having a general inability to select and appreciate information conveyed from the face, are less sensitive to some specific social cues, in particular referential cues (e.g., gaze direction) that are particularly relevant to understand an action’s goals.

6. Autism and imitative learning: conclusions and future directions

The imitative learning deficit in autism cannot be characterized as a unitary phenomenon and is very likely to be the end result of a complex cognitive pathway. Different imitative behaviors and different aspects of the imitative process are based on different neurocognitive processes, and are likely impaired for different reasons in different individuals and different diagnostic groups. We build this concept from two elements: the complementarity of inferential and non-inferential processes in imitation, and the perspective of system inefficiency and vulnerability in autism and other neurological and neurodevelopmental disorders. Inferential and non-inferential processes may both be involved in different types of imitative behaviors and in the same imitative act. It might be the case that simpler forms of mirroring-based imitation occur earlier in development than simpler forms of inferential understanding. Simpler forms of inferential understanding likely precede more complex forms of imitative learning (Hurley, 2008). At the process level, an earlier mirror-based response to the demonstrator’s action might be re-scripted in more flexible formats as greater awareness of the attentional and intentional stance of the demonstrator develops, to permit more flexible and selective imitation. In other words, a top-down re-description of the demonstrator’s action might be built upon a base grounded in bottom-up perception-action encoding. The nature of the stimulus, the nature of the context, and the learning history of the observer all will influence the nature of the information processes that are involved in any par-

ticular imitative act. This perspective suggests that there is not convincing evidence for either a “bottom-up” or “top-down” account of the imitation deficit in autism; furthermore, framing the problem in such terms may not be the most productive, given our growing understanding of the imitation problem.

The second point we wish to highlight is that imitation and imitative learning competence involves a complex system of neurocognitive processes, including visual attention, social motivation, understanding of communicative cues, integration of multiple sources of information, working memory, transfer of visual input into the body schema (for novel movements and actions) as well as linked observation-action responses for familiar movements and actions, motor planning, executive processes, and inhibitory processes. All will be influenced by development and previous experiences. Imitation must involve much more than the mirror neuron system. Complex information processing systems can be disrupted in many ways, and research in autism has identified many differences in the performance of persons with ASD compared to others. It might be the case that this heterogeneous vulnerability in the components of the system causes the system to be inefficient, thus affecting many, but not all, imitative behaviors, in many, but not all, individuals with autism. The research into neurocognitive componential aspects of imitation in autism is steadily yielding more detailed information about imitative behavior and underlying brain activity. However, there is another question underlying the theories: To what extent does the imitation problem affect symptom expression and development in persons with autism? This question requires a different research approach, particularly from two study designs: longitudinal studies of infants who develop ASD, and treatment studies that allow imitation to be experimentally manipulated. Both types of studies are currently being conducted.

The longitudinal studies of infant siblings of children with autism have the potential to reveal much about the interaction of imitative abilities, developmental trajectories, and symptoms of autism. Zwaigenbaum *et al.* (Zwaigenbaum, Bryson, Rogers, Roberts, Brian, & Szatmari, 2005) have demonstrated that imitation impairments are present by the age of 12 months in children who will later develop autism, though Young *et al.* (Young, Rogers, Hutman, Ozonoff, Rozga, & Sigman, in review) did not find specific imitation deficits until 18 months in a similar sample. However, few longitudinal studies have thus far examined the relation between imitation abilities in the preschool period and social development or autism symptomatology at the level of individual differences, and this type of study is necessary for testing the theory that the imitation problems in autism contribute to the developing autism phenotype. Such studies are badly needed and should begin to emerge from the infant-sibling studies.

The second type of study needed involves treatment. Can one affect outcomes in ASD by teaching imitation early? Does teaching imitation confer

a specific benefit that is not conferred by teaching speech, joint attention, or pretend play? There is only indirect evidence for this at present. The interventions that have demonstrated the most powerful effects of intensive early intervention in ASD focus very heavily on imitation training at the start of the intervention, though it is taught in different ways (Lovaas, 1987; Smith, Groen, & Wynn, 2000; Rogers, & Dawson, 2010). Additionally, Ingersoll and Schreibman (2006) have described secondary advances in joint attention and other core skill areas resulting from imitation training. However, this question needs a design like that provided by Kasari, Paparella, Freeman, & Jahromi (2008), in which two different interventions are delivered to randomized groups with long-term follow-up to examine relative effects.

Both study designs – the longitudinal follow-along and the longitudinal comparative treatment interventions – are expensive and complex to carry out, but these designs are necessary to determine the specific role that imitation skills play in outcomes of young children with ASD. Determining the essential ingredients of early intervention programs is necessary if we are to eventually develop more targeted, individualized, and powerful intervention approaches for specific children, but given both the economic challenges of early intervention for autism and the poor outcomes that still result for so many, we must continue to isolate and examine the nature and the role of the imitation and learning deficit in ASD.

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