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Research report

Action simulation and mirroring in children with autism spectrum disorders

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ABSTRACT

Mental imitation, perhaps a precursor to motor imitation, involves visual perspective-taking and motor imagery. Research on mental imitation in autism spectrum disorders (ASD) has been rather limited compared to that on motor imitation. The main objective of this fMRI study is to determine the differences in brain responses underlying mirroring and mentalizing networks during mental imitation in children and adolescents with ASD. Thirteen high-functioning children and adolescents with ASD and 15 age-and- IQ-matched typically developing (TD) control participants took part in this fMRI study. In the MRI scanner, participants were shown cartoon pictures of people performing everyday actions (*Transitive actions*: e.g., ironing clothes but with the hand missing; and *Intransitive actions*: e.g., clapping hands with the palms missing) and were asked to identify which hand or palm orientation would best fit the gap. The main findings are: 1) both groups performed equally while processing transitive and intransitive actions; 2) both tasks yielded activation in the bilateral inferior frontal gyrus (IFG) and inferior parietal lobule (IPL) in ASD and TD groups; 3) Increased activation was seen in ASD children, relative to TD, in left ventral premotor and right middle temporal gyrus during intransitive actions; and 4) ASD symptom severity positively correlated with activation in left parietal, right middle temporal, and right premotor regions across all subjects. Overall, our findings suggest that regions mediating mirroring may be recruiting more brain resources in ASD and may have implications for understanding social movement through modeling.

1. Introduction

Imitation plays a crucial role in development, and has important implications for social development through modeling and the understanding of social movement [1]. Imitation is a necessary precursor to symbolic functioning [2] and provides a child with information about the actions and intentions of the social world, and a foundation for social development. People with autism spectrum disorders (ASD) have been found to struggle in imitating actions, gestures, and action sequences. Behaviorally, it has been shown that not all forms of imitation are equally impaired in ASD, but specific subsets of individuals may be more affected as opposed to the entire spectrum [3]. Rogers et al. [4] found improved performance in meaningful imitation compared to meaningless imitation in adolescents with ASD. Similarly, Hamilton et al. [5] found intact goal-state imitation and motor planning in children with ASD. Lower rates of spontaneous imitative behavior of actions on objects and gestures in children with ASD have been reported widely [6–8]. Neuroimaging studies have also provided evidence of altered recruitment of regions underlying imitation in children and adults with ASD [9]. For example, in a meta-analysis of 13 neuroimaging studies of action observation and action imitation in individuals with ASD, Yang and Hofmann [10] reported altered recruitment of several regions associated with imitation, such as the dorsolateral prefrontal cortex, anterior cingulate, and insula in individuals with ASD. However, it should be noted that several other studies have also provided contrary evidence as to intact brain response and imitation skills in individuals with ASD [11–13]. The inconsistency in the nature of imitation investigated and the differences in findings across studies underscore the need for further investigating imitation at behavioral and at neural levels in ASD.

The Mirror Neuron System (MNS) has been suggested to play an instrumental role in action simulation and action execution [14]. Core regions of the MNS include the inferior frontal gyrus (IFG)/ventral premotor cortex (PMv) and the inferior parietal lobe (IPL). These regions communicate closely with the superior temporal sulcus (STS) to produce action understanding and action simulation [15]. Successful imitation likely relies not only on these MNS regions, but also on their communication with other neural networks [16] including interactions

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with limbic regions [17,18] and with regions associated with processing theory-of-mind (ToM) [15]. It has been previously suggested that individuals with ASD who have deficits in imitation may also have an unusual MNS response [9,19]. However, other studies have revealed intact activity and even increased activity in ASD participants in the MNS during tasks of imitation compared to typically developing (TD) children [11,12,20].

Most studies in ASD have examined imitation from a motor perspective [11] or a combination of motor and something else such as goal-directed actions [12,20]. This could represent a problem because imitation difficulties may arise from problems related to motor planning or execution. In a study that examined different component processes of imitation in ASD (Bennetto, 1999 unpublished dissertation), individuals with ASD performed poorly in the motor functioning and action planning aspects of imitation, but not on the spatiotemporal representation, body schema, and memory compared to TD individuals. Altered brain activity and connectivity that may lead to impaired imitation abilities in ASD may arise from aberrant action planning through motor simulation, but not actual imitation deficits [21,22].

The current functional MRI study examines the role of action simulation and the neurobiological mechanisms underlying action simulation in imitation, independent of actual motor production in children with ASD. This action simulation or "mental imitation' paradigm has been defined as visual perceptive-taking and motor imagery [23,24]. The importance of examining mental imitation is emphasized by the simulation theory, which proposes that we gain insight into the mental workings of others by covertly or mentally simulating the actions ourselves without actually performing them [25]. Another important aspect of examining mental imitation is embodied cognition, which helps explain whether conceptual features that are engaged during fMRI imitation studies may actually apply to the real world when these same features are directly experienced [26]. In addition, two recent studies of embodied cognition in ASD examined mental simulation. In Conson et al. [27], mental simulation of one's own body motion was examined in order to take another person's perspective. They found that individuals with ASD solved the tasks of simulation by relying on a non-embodied strategy compared to TD controls who adopted an embodied strategy. In Conson et al. [28], the impact of bodily information on simulation skills of adolescents with ASD was tested. They found that while both ASD and TD groups were successful in mentally simulating actions, that ability was constrained by body posture more in ASD than in TD participants. These findings are of particular interest in the context of the embodied cognition framework which connects cognition with the world via sensory and motor processes [29], which shows impairment in individuals with ASD [30]. Thus, action simulation may play an important role in better understanding imitation and in assessing social functioning and embodied cognition in ASD. More specifically, the current study plans to isolate imitation independent of actual motor production to better assess behavioral and neural correlates of simulation.

Thus, the aim of this study is to determine the activation patterns observed in children with ASD when presented with a mental imitation task involving transitive actions (actions involving an object) and intransitive actions (actions not involving an object and more communicative in nature). Studying transitive and intransitive actions allows for the investigation of the communicative (intransitive) and non-communicative (transitive) aspects of imitation, which serves a specific purpose when studying individuals with ASD given their socio-communicative deficits. Given that healthy individuals perform better in intransitive than transitive actions [31], we predicted the same outcome in the TD group; however, the ASD group will have worse performance than the TD group in both actions. This is based on previous findings of impaired action planning, a skill mediated primarily by the frontal component of the MNS – the PMv, in children with ASD. We also predicted that individuals with ASD will show decreased levels of activation in MNS areas and frontal areas, but similar levels of activation in the parietal regions (e.g., IPL) during intransitive actions, but not during transitive actions. This hypothesis is based on previous results from a meta-analysis of action observation and imitation in ASD, where frontal areas showed decreased activation in the ASD group compared to TD, but no differences were found in parietal areas [10]. Symptom severity and social communication will be predictors of brain activation for both actions. The findings of this study will provide important insights into resolving imitation-derived activation and the difference in activation in children and adolescents with ASD during non-motor mental imitation. The findings will also add to the non-canonical MNS studies in ASD as the paradigm we used examines a combination of both imitation and communicative aspects of action understanding.

2. Material & methods

2.1. Participants

Thirteen high-functioning children and adolescents with ASD and 15 age-and-IQ-matched TD control participants took part in this fMRI study (age range: 8 to 17 years; minimum Full Scale and Non-Verbal IQ: 75, measured using the Wechsler Abbreviated Scales of Intelligence [WASI]; See Table 1). All participants with ASD were diagnosed using the autism diagnostic observation schedule (ADOS) and autism diagnostic interview (ADI), and were recruited from the autism center at our university and from local clinics and special schools. Current and past ASD symptoms were also assessed using the Autism-Spectrum Quotient (AQ) [32] and the Social Communication Scale (SCQ) [33]. The parents/guardians completed all questionnaires. TD participants were recruited using flyers and advertisements posted at our university campus, and in local community centers (e.g., libraries, YMCAs). Participants were not included in the study if they indicated having worked with metal or having metal implanted in their bodies (either surgically or accidentally) or if they had a history of psychiatric disorders. No participants indicated having a cognitive disorder, anxiety disorder, schizophrenia, or obsessive compulsive disorder. Before participating in the study, study procedures were explained to all participants and informed consent was obtained. The study protocol and consent form were approved by the ethics committee of the UAB Institutional Review Board for human subjects research.

2.2. Stimuli and experimental paradigm

The fMRI experiment consisted of an action simulation task designed in an event-related format. This experiment was aimed at measuring mental imitation ability, requiring subjects to perform all the necessary components of imitation except for the *motor execution* aspect. In other words, this task involved imagining the imitative act, which is usually a precursor to the motor action. This part also

Table 1
Demographic information.

	TD (n = 15; 4F)			ASD (n = 13; 2F)			*p-value*
	Mean	*S.D.*	*Range*	*Mean*	*S.D.*	*Range*	
Age	12	1.63	9–15	12	2.99	8–17	0.69
FSIQ	102	16.19	83–130	109	17.27	80–126	0.32
VIQ	98	17.6	84–134	109	18.2	74–128	0.22
PIQ	99	9.57	84–119	108	15.82	74–124	0.15
AQ	35	27.29	5–80	72	34.36	32–135	0.01
SCQ	4	3.73	0–10	18	8.32	1–31	< 0.001
RMSD	0.26	0.11	0.11–0.45	0.26	0.15	0.05–0.50	0.98

Values are presented as mean, standard deviation and range. The *p* value is independent-*t* tests for differences between groups. TD, typically developing; ASD, autism spectrum disorder, F female, FSIQ, Full-scale IQ; VIQ, Verbal IQ; PIQ, performance IQ; AQ, autism quotient; SCQ, social communication questionnaire; and RMSD, root mean square deviation.