Travaux du 19ème CIL | 19th ICL papers
Congrès International des Linguistes, Genève 20-27 Juillet 2013
International Congress of Linguists, Geneva 20-27 July 2013

19 ICL
19th International Congress of Linguists
July 21-27 2013
Geneva - Switzerland

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oral presentation in workshop: 112 Language and Mind in Autism (Stephanie DURRLEMAN, Hélène DELAGE, Laurice TULLER, Philippe PRÉVOST & Ira NOVECK)

Published and distributed by: Département de Linguistique de l'Université de Genève, Rue de Candolle 2, CH-1205 Genève, Switzerland
Editor: Département de Linguistique de l'Université de Genève, Switzerland
ISBN:978-2-8399-1580-9

Low to high: Simple functions and complex sociocommunicative difficulties in ASD

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Abstract

The autism spectrum disorders are a set of serious neurodevelopmental disorders characterized by impairments in two interrelated domains: social interactions, and language and communication. Our understanding of the origin of language deficits in ASD has long focused on social deficits; many researchers have attributed language delays primarily to the lack of social interest. Research from our lab and others has complicated this picture. We have demonstrated that language impairments in ASD are at least partially driven by deficits in very low-level (core) cognitive, non-social, processes, which appear to cascade upwards and lead to more comprehensive deficits in both communicative and social processes. These low-level or core cognitive processes include atypical *strengths* in auditory discrimination as well as deficits in the temporal coordination of motor movements. These motor movements are discussed in terms of models of embodied cognition, with the suggestion that motor movements are less effectively incorporated into language processing in ASD. We discuss how such models may help us to better understand ASD. The identification of core cognitive deficits may provide clues to the mechanisms underlying the symptom presentation in ASD.

Autism spectrum disorder (ASD) is characterized by impairments in social interactions, language and communication, and the presence of repetitive interests and behaviors. The bulk of empirical research in the past decade has emphasized the social nature of language deficits, a logical focus given the centrality of social interaction to the role of language. In contrast, the current paper presents detailed evidence that low-level, non-social cognitive processes place significant constraints on language acquisition and processing in ASD.

The DSM diagnostic system has undergone substantial changes in 2013, with regard to the diagnostic criteria for ASD. Specifically, the DSM-4 (American Psychiatric Association, 2000) specified that for autism spectrum disorder, there were three primary domains of impairment, including 1) difficulties in social relatedness and reciprocity, 2) difficulties in language and communication, and 3) the presence of repetitive behaviors and stereotyped interests. The DSM-5, published in 2013 (American Psychiatric Association, 2013), specified major changes to the ASD diagnosis. First, the distinct diagnoses of *Autistic Disorder*, *Pervasive Developmental Disorder NOS*, *Asperger's Disorder*, *Rett's Disorder*, and *Childhood Disintegrative Disorder* changed; the DSM-5 specifies just two: *Autism Spectrum Disorder* and *Social (Pragmatic) Communication Disorder* (with the latter falling under the "Communication Disorders" grouping).

In the new ASD diagnostic system, there are just two domains of impairment in ASD: 1) difficulties in social communication and interaction (including impairments in social-emotional reciprocity, in nonverbal communicative behaviors used for social interaction, and in in developing and maintaining relationships); and 2) the presence of restricted, repetitive behaviors, interests, and activities (including stereotyped/ repetitive speech, motor movements, or use of objects; adherence to routines, ritualized patterns, and resistance to change; highly restricted, fixated interests that are abnormal in intensity or focus; and hyper- or hypo-reactivity to sensory input and unusual interest in sensory input).

As such, the current diagnostic system removes "language and communication" as a primary domain of impairment in ASD. Why did this change get made? One important consideration was that communication deficits are intimately related to social deficits; in fact, the DSM authors suggest that they are manifestations of a "single set of symptoms" that can be present in different contexts. Of course, it is true that "language" has a strongly social component; however, from the perspective of a psycholinguist, there are many, many other non-social (or less-social) processes that are highly relevant to language acquisition, comprehension, and production: statistical learning, phonological categorization, working memory, motor control, semantic organization, visuospatial processing, inhibition, cognitive control, syntactic priming, etc.; the list is long. This DSM change also tends to reduce the potential relevance of examining syntactic structures in language deficits. From this perspective, the determination to exclude language and communication as a primary symptom domain of ASD is dissatisfying, as it will likely decrease research efforts aimed at examining non-social aspects of language. There are other important ramifications: From a clinical perspective, speech intervention and other language supports may come to be seen as ancillary or less critical for children with ASD.

It should be noted that there is an alternative to the strict focus on diagnostic criteria of disorders: NIMH Research Domain Criteria (R-DOC), which conceptualizes mental disorders as *biological* disorders involving brain circuits that implicate specific domains of cognition, emotion, or behavior (Insel, 2013). Some researchers may focus on syntactic, morphological, semantic, and phonological aspects of language acquisition and use in ASD, relating them to other cognitive processes (and in turn, tying those processes to underlying brain functions and to other symptoms of ASD).

In the spirit of this enterprise, the focus of the current paper is to review several non-social and low-level processes that impact language abilities in people with ASD. The processes in question are a) pitch discrimination, b) co-speech gestures, and c) embodied approach/avoidance processing. Each of these processes is described independently elsewhere. Before discussing these empirical studies, we provide a brief overview of language abilities in individuals with ASD (see also Eigsti, de Marchena, Schuh, & Kelley, 2011 for a more detailed review).

Language in ASD

While individuals with high-functioning ASD (typically defined as those with full-scale IQ scores > 78 or in the typical range, or > 78) eventually achieve fluent language skills, some 25-30% of affected individuals remain functionally nonverbal throughout the lifespan (Anderson, Lord, & Risi, 2007). Of those who do acquire functional language, most exhibit significant delays in acquisition (Mitchell et al., 2006; Tager-Flusberg, Paul, & Lord, 2005), with many children producing first words at age 24 months (a full 12 months after the standard time), and first phrases at 48 months (where the typical time is 18-24 months; see also Grandgeorge et al., 2009). There is relatively limited research on phonological development in ASD; this is an active area of research in our lab. Findings to date generally suggest that in sound categorization and production, individuals with ASD show no deficits (Boucher, 1976, 2003). Similarly, although there have been well-documented findings that individuals with ASD may produce more neologisms than children with other developmental delays (Eigsti, Bennetto, & Dadlani, 2007), and that they may show differences in some aspects of word-learning such as the shape bias (Tek, Jaffery, Fein, & Naigles, 2008) and semantic priming (Kamio, Robins, Kelley, Swainson, & Fein, 2007), many aspects of word learning and semantic organization more generally may be unimpaired (de Marchena, Eigsti, Worek, Ono, & Snedeker, 2011).

As for the more combinatorial language domains of morphology and syntax, the literature is mixed. Some have claimed that there are clear subgroups in ASD, distinguished by the presence or absence of morphosyntactic impairments (Kjelgaard & Tager-Flusberg, 2001; Rapin, 1996); it is likely this kind of finding that motivated, in part, the DSM-5 diagnostic criteria changes. However, a number of studies indicate that young children with ASD show not just delays but rather very different patterns of morphosyntactic development (Bartolucci, 1982; Eigsti et al., 2007; Rapin & Dunn, 2003), and that these findings extend into early adolescence (Eigsti & Bennetto, 2009). These differences are likely to be less apparent when probed using untimed, highly-structured standardized measures, and are more apparent in spontaneous language assessments (Brynskov, Eigsti, Jørgensen, Lemcke, & Krøjgaard, under review) and on tasks when there is an additional load that requires cognitive resources (Schuh, Mirman, & Eigsti, in review).

As for the domain of language pragmatics, findings universally demonstrate significant impairments for individuals with ASD of all ages and at all functional levels (Paul, 2007). There are deficits in conversational skills such as turn-taking (Capps, Kehres, & Sigman, 1998), prosody(Eigsti, Schuh, Mencl, Schultz, & Paul, 2012; Paul, Augustyn, Klin, & Volkmar, 2005), comprehension of indirect requests and other such indirect language (Paul & Cohen, 1985; Rajendran, Mitchell, & Rickards, 2005; Uchiyama et al., 2006), and the integration of gestures with speech (de Marchena & Eigsti, 2010; Garcia-Perez, Lee, & Hobson, 2007).

Given this profile of mixed empirical findings for more “structural” aspects of language, and very clear findings of pragmatic impairments, some have concluded that it is the *social* aspects of language acquisition and processing in ASD that are impaired (again, it is likely this conclusion that underlies the diagnostic changes in the DSM-5). To support an alternative approach, in which language impairments are seen as central to the ASD diagnosis and in which structural language processes in ASD are targets of investigation, we present three lines of work.

Optimal outcomes/Tone discrimination (Eigsti & Fein, 2013)

The first study concerns a unique group of children that was diagnosed with ASD early in development (prior to age five years) but which now shows no symptoms of the diagnosis – that is, children in this group have "lost" their ASD diagnosis. This group is described as having "optimal outcomes" (OO) (Fein et al., 2013). A number of papers have detailed language (Irvine, Eigsti, & Fein, in review; Kelley, Paul, Fein, & Naigles, 2006a; Suh et al., 2014b; Tyson et al., 2014) and academic skills in OO(Troyb, Orinstein, et al., 2013), along with executive functions (Troyb, Rosenthal, et al., 2013), restrictive and repetitive behaviors (Troyb et al., in press), gestalt and detail processing (Fitch, Fein, & Eigsti, in press), interventions (Orinstein et al., 2014) and medical-developmental histories (Barton et al., under review).

A detailed investigation of standardized language abilities in individuals with OO ages 8 – 21 years reported that the OO group scored in the average range or above on all measures and showed few differences from a typically developing (TD) comparison group (Tyson et al., 2014). As for pragmatic language deficits, they too are generally are completely resolved, though a small set of pragmatic difficulties persists. A study of OO children ages 5-9 years found that the OO group gave fewer causal explanations and character motivations and were more likely to misinterpret story events during narrative production (Kelley, Paul, Fein, & Naigles, 2006b); including most of the same children, a study of OO children at ages 8 – 13 years showed *no* pragmatic deficits on standardized language measures (Kelley, Naigles, & Fein, 2010). Moreover, a study of spontaneous narrative production found that OO and TD groups did not differ in ambiguous pronoun production, and produced fewer ambiguous pronouns than peers with ASD, thought they used more idiosyncratic language (Suh et al., 2014a).

The focus of the "pitch" study examined an interesting phenomenon in ASD: *the presence of superior auditory perceptual skills*. In addition to replicating previous findings of heightened pitch discrimination in a group of youth with ASD, the study goal was to probe pitch discrimination skills in OO, and the correlation among these skills, ASD symptomatology and language milestones.

Participants in the OO group all received an ASD diagnosis prior to age five years from a specialist in the field of autism, focusing directly on the ASD diagnosis, and verified in a written report. Participants in the OO group did not exhibit current ASD symptomatology according to the Autism Diagnostic Observation Schedule (ADOS; Lord, Rutter, DiLavore, & Risi, 2002) or clinical judgment. In addition to IQ scores in or above the average range, OO participants had age-appropriate social and communication skills, according to the Vineland Adaptive Behavior Scales (Vineland-II; Sparrow, Cicchetti, & Balla, 2005) and were enrolled in regular education classes.

Participants in the ASD group met current diagnostic criteria for ASD according to the ADOS and expert clinical judgment. Participants in the TD group had no ASD symptoms according to the ADOS, the Social Communication Questionnaire (Rutter, Bailey, & Lord, 2003), and clinical judgment, and had no first-degree relatives with an ASD diagnosis. In order to avoid a hyper-normative group, TD children were not excluded for learning disorders or other psychiatric conditions.

Tone discrimination task. To assess pitch discrimination, participants listened to 120 pairs of tones on headphones and made a two-alternative forced-choice same/different judgment. Steady-state pure tones were 100 ms in length, with a 1000 ms inter-stimulus interval. The inter-trial interval was controlled by the subject's response without upper limit;

subsequent trials were presented 500 ms following a response. Forty tone pairs were presented at each of three difficulty levels, where different pairs differed by 3% (easy), 2% (medium), or 1% (hard) of total frequency; pitch stimuli were modeled on prior research on pitch discrimination in adults with ASD (Bonnel et al., 2003) and were designed to be challenging for nonmusicians to avoid ceiling effects. Furthermore, to assess pitch discrimination generally, rather than as a language-specific capacity, the range was distinct from that typically observed in voiced human speech (80-250 Hz). Responses were analyzed for reaction time (RT) and the *d′* statistic, which describes accuracy without an influence of response bias and was computed as a function of hits and false alarms.

Results of the pitch discrimination task were intriguing. There was a significant group difference in *d′* (discrimination), F (2, 65) = 3.25, p = .04, η^2_p = .09, with a main effect of difficulty, F (2, 130) = 22.90, p < .001, η^2_p = .252, and no group X condition interaction, F (4, 130) = 1.22, p = .31, η^2_p = .04. Across difficulty levels, the TD group scores were significantly lower scores than the ASD group scores, F (1,38)= 1.38, p = .02. In contrast, scores did not differ for OO versus ASD, F (1, 45) = .08, p = .77, or OO versus TD, F (1, 44) = .003, p = .99. The ASD group showed the *best* pitch discrimination, followed by the OO group, followed by the TD group. There was no group difference in RT as a function of tone-condition, indicating that group differences in accuracy did not reflect a speed-accuracy tradeoff, F (2,67) = 1.97, p = .15, η^2_p = .04.

Symptom severity accounted for unique and significant variance in individual differences in pitch perception abilities (averaged across three difficulty levels), controlling for age and IQ, in a linear regression analysis; model R^2 = .173, F (3, 69) = 4.40, p = .007. Each predictor contributed significant independent variance to pitch discrimination, and *better* discrimination was associated with *greater* symptom severity.

We also looked at the relationship between pitch discrimination and language milestones. Parents of participants in the ASD (N=16) and OO (N=20) groups reported the age at which children produced single words and multi-word phrases, a process used effectively in prior research (Eigsti & Bennetto, 2009); parents who were not able to recall these data or reference baby books were excluded from the analysis. The OO group showed a tendency to produce first words later, on average, than the ASD group, F (1,45) = 3.32, p = .08, at 27.2 (11.6) months versus 21.0 (11.6) months, respectively, though first phrases were produced at a similar time, at 35.2 (11.5) months versus 35.4 (10.1) months, F (1,45) = 0.004, p = .95. As such, ASD and OO participants were split into "typical" (n = 25) and "delayed" (no words at age 24 months; n = 25) language milestone groups; pitch discrimination as a function of language milestone was examined in a repeated-measures MANCOVA, controlling for age and FSIQ. The main effects of language milestone, F (1,46) = .11, p = .75, η^2_p = .002, and pitch condition, F (2,92) = 0.36, p = .70, η^2_p = 0.01, were not significant, but there was a significant interaction of milestone and pitch condition, F (2,92) = 4.92, p = .009, η^2_p = .10. Specifically, children with delayed first words *differed more* in performance per condition, with significant differences for each condition (3%, 2%, 1%) relative to the others; performance in the on-time group was similar for the 3% and 2% conditions. Group differences for the 3% pitch conditions just missed significance, with the delayed group tending towards *better* performance, F (1, 46) = 3.79, p = .06, η^2_p = .08. This pattern of findings confirms the relevance of heightened pitch discrimination in language delays.

Unlike *early* language milestones, there was no association between pitch discrimination abilities and *current* language skills (receptive vocabulary via PPVT scores, and structural language knowledge via CELF scores), all p's > .20.

This study reported a relationship among low-level perceptual differences – specifically, pitch discrimination; language delays; and ASD symptom severity. Unlike most studies of neurodevelopmental disorders, this study found better performance (on pitch discrimination) for the clinical group of ASD. That is, individuals with specific language impairment, dyslexia or other language impairments typically present with significantly poorer frequency discrimination abilities (Loui, Kroog, Zuk, Winner, & Schlaug, 2011; McArthur & Bishop, 2004). These data are distinguished by a novel characteristic in comparison to other disorders, in that *enhanced rather than impaired* pitch discrimination was linked to language delays and current symptomatology.

Furthermore, the sample of youth with OO showed no enhancement in pitch discrimination – their performance did not differ from the TD group (nor did it differ from the ASD group's performance). Results were consistent with both significant *early* ASD symptomatology (including delays in language milestones) and intact *current* abilities in this OO group. Consistent with the group effect, symptom severity accounted for unique and significant variance in individual differences in pitch perception abilities.

In addition to symptom severity, these findings documented a correlation between an *early language milestone* (first words), and auditory perceptual abilities assessed a decade later. Intriguingly, delays in first words were associated with better pitch perception. We proposed that this link is consistent with a causal mechanism: exceptionally strong pitch discrimination skills may be harmful, rather than helpful, for language acquisition during the first two years of life, possibly by impairing the formation of phonological categories.

The pitch discrimination study described here suggests that a non-social, low-level perceptual process may have significant social, high-level consequences. The second section of the paper describes a related study of nonverbal (co-speech) gestures in ASD.

Gestures (de Marchena & Eigsti, 2010)

Gestures – the spontaneous manual movements that accompany speech – are an important form of nonverbal communication that facilitates early language learning and knowledge acquisition (David McNeill, 1992). Gestures help speakers to better represent information that they are communicating in speech (Kita, 2000), and otherwise support language production (Krauss, 1998). However, both communicative gestures, and the high-level cognitive processes with which gesture is most centrally involved, show significant individual variability in ASD.

Abnormalities in nonverbal communication have been consistently reported since the earliest descriptions of ASD (Kanner, 1943). For example, the original reports of what came to be called Asperger syndrome described conversational gestures as “large,” “clumsy,” and “inappropriate,” and gesture comprehension as absent (Asperger 1944, from Wing, 1981). These early clinicians described the atypical composition of gestures, their poor integration with speech, and a general decrease in quantities of gestures. Today, the diagnostic description of ASD specifies a “delay in, or total lack of, the development of spoken language (*not accompanied by an attempt to compensate through alternative modes of communication such as gesture or mime*)” and a “marked impairment in the use of multiple *nonverbal behaviors* such as eye gaze, facial expression, body postures, and *gestures* to regulate social interaction” (American Psychiatric Association, 2000, p.75, emphasis added). The quality and quantity of gesture, and its integration with speech, are central to fully one-third of items on the primary diagnostic instrument for autism, the Autism Diagnostic Observation Schedule (ADOS, Lord et al., 2002). Thus, the presence of communicative gesture deficits in individuals with ASD is well established in the clinical literature.

The empirical data on conversational gestures in ASD, in contrast, are limited. In McNeill’s (1992) widely-used taxonomy, there are four categories of gesture, based on motion parameters and semantic qualities: 1) *Iconic* gestures, which visually depict what they mean by showing events or objects in physical space (e.g., after watching a cartoon in which Tweetybird's owner chases Sylvester the Cat, holding a furled umbrella, a speaker might say, “*she chases him out again*” while the speaker’s hand, gripping an imaginary object, swings from left to right, (as cited in D. McNeill, 1985, p. 353); 2) *Metaphoric* gestures, which also depict an object or event in space, but convey an abstract concept. For example, *justice* might be represented by moving the hands, palm up, like two sides of a scale; 3) *Deictic* gestures, which are points to a location in order to direct a listener's attention or to indicate abstract referents in speech by establishing and referring to a location that is associated with that referent (D. McNeill & Levy, 1993); and 4) *Beat* gestures, the rhythmic hand movements that convey emphasis, and are closely timed with the prosody of speech.

Most gesture research in ASD has examined deictic gestures. Pointing in ASD is found to be significantly reduced in declarative (i.e., attention sharing) as compared to imperative (i.e., requesting) contexts (Bono, Daley, & Sigman, 2004; Camaioni, Perucchini, Muratori, & Milone, 1997; Loveland & Landry, 1986; Mundy, Sigman, & Kasari, 1990; Mundy, Sigman, Ungerer, & Sherman, 1986), a finding which highlights that the *social* aspects of these gestures likely contribute to their delayed production (Baron-Cohen, 1989; Klin, Jones, Schultz, Volkmar, & Cohen, 2002). The literature on non-pointing gestures in ASD is sparser and less conclusive. It may be that children with ASD simply *appear* to gesture less due to overall reductions in communicative acts. For example, although early studies found reduced rates of gesture in children with ASD (Bartak, Rutter, & Cox, 1975), others have failed to find group differences after controlling for overall amount of speech (Attwood, Frith, & Hermelin, 1988; Capps et al., 1998). In fact, some have found iconic gestures to be a relative communicative strength for children with ASD, perhaps because enacting experiences is more accessible than verbalizing them (Capps et al., 1998), and consistent with gesture use in other speech-disordered populations (described above). Children with ASD also show a reduced variety of gestures (Colgan et al., 2006; Wetherby & Prutting, 1984), which may strengthen the impression of fewer gestures.

Participants in the gesture study included 20 adolescents with ASD and 16 adolescents with TD matched on chronological age, gender, and full scale IQ. Participants viewed six (8.5 by 7 inch) cards containing black-and-white line drawings depicting the story of two monkeys. After examining the cards, they were asked to stand up and tell the story. Participants who put their hands in their pockets were asked to remove them. No further instructions were given, and participants were never explicitly instructed to gesture. Story narrations were recorded on digital video for transcription, gesture coding, and synchrony analyses.

All gestures produced during narrations were identified and categorized according to McNeill's (1992) taxonomy. Gesture-speech synchrony was coded for all iconic gestures, and then we analyzed the start and endpoints of the speech and gesture pairs (e.g., "the monkey **threw** a coconut at him" with accompanying "throw" gesture for the bolded portion). Finally, a group of ten undergraduate students rated all stories along two dimensions of "story quality": (1) *How well were you able to follow this story?* and (2) *How engaged were you during this story?* To determine the relative contributions of verbal and nonverbal communication to story ratings, raters were instructed to listen to half of the stories without the accompanying video (*radio* condition) and watch the other half with both audio and video (*TV* condition).

Results indicated that the number of iconic gestures produced during narratives was similar across groups, t (25) = -1.46, p = .16, Cohen's d = .58, and that there were no group differences in the length of gestures or the co-occurring speech, F (2,23) = 0.64, p = .54, η^2_p = .05, indicating that gestures produced by youth with ASD and TD did not differ in sheer *quantity* or overall *duration.* However, stories produced by the ASD group were rated across conditions as significantly harder to follow, F (1,28) = 12.71, p = .001, η^2_p = 0.31, and less engaging, F (1,28) = 5.02, p = .03, η^2_p = 0.15. Furthermore, adolescents with ASD produced gestures that were strikingly less synchronized with speech, compared to TD adolescents, t

(23) = -2.72, *p* = .01, Cohen's *d* = -1.13.

In this narrative task as well as other studies (de Marchena & Eigsti, under review), we have found that adolescents with ASD and TD spontaneously produced the same number of gestures, and that the gestures map onto similar cognitive processes. The findings provide evidence that the integration of verbal and nonverbal communication is impaired in ASD, even given comparable baseline rates of communication. Gesture-speech coordination requires the efficient mobilization and ordering of distinct behaviors. There is a growing literature demonstrating impairments in behavioral timing in ASD. For example, electrophysiological studies have shown delayed responses to social stimuli by children with ASD, compared to TD peers ((McPartland, Dawson, Webb, Panagiotides, & Carver, 2004; Webb, Dawson, Bernier, & Panagiotides, 2006). A recent study of facial mimicry that measured facial muscle activity (via electromyography) showed that children with ASD differed from TD peers only their latency to mimic (Oberman, Winkielman, & Ramachandran, 2009) . Although the amount and appropriateness of mimicry was comparable, children with ASD took longer to mimic, suggesting that deficits in interpersonal synchrony were driven primarily by inefficient timing of behaviors, rather than by the execution of the behaviors themselves. Timing impairments are also present in non-social cognitive processes (Sears & Steinmetz, 2000). This result could reflect differences in motor processes, a possibility that led to our research on perception-action coordination and its impact on representation in ASD – a study of embodied cognition.

Embodiment (Eigsti, 2013; Eigsti, Rosset, Col Cozzari, Da Fonseca, & Deruelle, in press)

Movement shapes cognitive development. For example, impairments in the control of arm movements lead to impaired development of the sense of peripersonal space; this leads in turn to deficits in the primitive sense of quantity and the number line, and thereby to a high prevalence of math-specific learning disorders (Johnson & Wade, 2009). A variety of studies has shown motor coordination problems: in fine motor control (Szatmari, Tuff, Finlayson, & Bartolucci, 1990); grip planning (Hughes, 1996); anticipatory movement preparation (Rinehart, Bradshaw, Brereton, & Tonge, 2001); gait and posture (Ghazziudin, Tsai, & Ghaziuddin, 1992); balance and coordination (Mari, Castiello, Marks, Marraffa, & Prior, 2003); and imitation and pantomime (DeMyer et al., 1972; Stone, 1997). While planned actions may ultimately be "accurate" (e.g., reach a target), they are more temporally and spatially variable (Glazebrook, Gonzalez, Hansen, & Elliott, 2009). Interestingly, motor impairments are generally subtle (Dowell, Mahone, & Mostofsky, 2009) and present in both the production and perception of motion. For example, research using point light displays (in which dots are superimposed onto the joints of people in motion) has shown that people with ASD can extract complex meaning from such displays, but are less sensitive to higher-order emotional information (Parron et al., 2008), including difficulty comprehending point-light displays (unpublished data, reported in Klin et al., 2003).

Embodied cognition refers to the notion that bodily experiences play an integral role in human cognition; that is, our ability to represent objects and events is subserved by sensorimotor systems that govern acting on and in objects and events (Barsalou, 1999). In contrast to traditional approaches to cognition, in which sensory, motor, and emotional experiences are encoded in the form of abstract symbols, stripped of their perceptual and experiential bases, embodied models of cognition suggest that these experiences are stored in a manner that maps onto the original neural systems (visual, olfactory, motor, and auditory) that encoded them in the first place.

In one classic study of embodiment, individuals were asked to hold a pencil in their mouths while watching cartoons (Strack, Martin, & Stepper, 1988). Some participants were directed to orient the pencil laterally, projecting away from the face; in a second group, the pencil was oriented parallel to the mouth. These distinct facial positions were chosen because they activate, respectively, the musculature involve in frowning or smiling. The dependent measure in the study was participant judgments of cartoon humor; consistent with an embodied model of cognition, the "smile-activating" group rated the cartoons as significantly funnier. When subjects activated their smile musculature, as they watched a cartoon, they found the cartoon to be more humorous; the muscle activation influenced their representation of the cartoon. Effects were entirely implicit; although the relevant musculature was active, participants were not instructed to smile *per se*.

There are a number of similar findings: when participants shake versus nod their heads (under the guise of judging the quality of headphones), while listening to a persuasive message, the listeners in the nodding condition are more likely to agree with the message in subsequent evaluation (Wells & Petty, 1980). Again, attitudes toward a stimulus are influenced by a physical (bodily) posture enacted when the individual encountered the stimulus; note that there is no *a priori* reason why smiling while seeing something should make one find that stimulus more humorous or pleasant, unless one is encoding the smile posture as part of the stimulus representation. The opposite is also true: when individuals' motor movements are inhibited, there is *interference* in the experience of emotion and processing of emotional information (Niedenthal, Barsalou, Ric, & Krauth-Gruber, 2005).

The notion of embodiment – that our sensorimotor input gives us access to the actions, emotions, and sensations, of other people (Gallese, 2006) – seems intuitively relevant to ASD, because individuals with ASD struggle to understand others, and to be as automatically and implicitly engaged with other people. If the neural state that obtains when a stimulus is first encountered impacts subsequent processing of that stimulus, motor impairments could impact the quality of neural sensorimotor representation, resulting in weaker embodiment effects, especially in the context of reduced functional connectivity for relevant sensorimotor processing regions. This was the possibility tested in the current study by drawing on the well-established "approach/avoidance" phenomenon. Researchers since Darwin (1872) have suggested that the approach/avoidance “system,” encoded in evolutionarily ancient limbic brain systems, is a fundamental response pathway for potentially dangerous or useful triggers. In the present experiment, participants held a physical "approach" posture (associated with pleasing stimuli) or an "avoid" posture (associated with aversive stimuli) and were presented with novel stimuli. Prior research using this method has indicated that approach stimuli are evaluated *more positively* than avoid stimuli when participants see them on a subsequent occasion, a result interpreted as an embodiment effect (Cacioppo, Priester, & Berntson, 1993; Forster, 1998).

Participants were 20 high-functioning males with ASD ages 11-29 years, matched on chronological age and gender with 20 TD males. There were two phases in the task. In the *Encoding Phase*, participants were seated at a table and adopted an *approach* or an *avoidance* postures (posture order was counterbalanced across groups). In the *approach* (flexion) posture, participants pressed upwards on the underside of the table with palms facing up. In the *avoidance* (extension) posture, they pushed downwards on the tabletop, palms down. These postures do not look, on the surface, like approach (e.g., hugging) or avoidance (e.g., repulsion) movements, but nevertheless activate relevant muscle groups (Cacioppo et al., 1993). While participants held a posture, they saw a series of Japanese ideographs (kanji; twelve per posture), presented on a 15-inch laptop screen; after a one-minute break, they were instructed to assume the other posture, and saw twelve new kanji. During this encoding phase, participants made a verbal like/don't like judgment about each kanji.

The second *Evaluation Phase* probed whether participants had differentially encoded the 24 kanji as a function of the approach/avoid posture in which the stimuli were first encountered. Participants sat in a relaxed posture in front of the laptop and were presented with 36 randomly ordered kanji: 12 familiar *approach* kanji, 12 familiar *avoid* kanji, and 12 control kanji. Participants judged which of two images was most likely to depict the kanji's meaning; because they had no prior experience with Japanese writing, they were told to "make your best guess." Kanji were presented in the upper third of the screen at center; after 1000 ms, two color photo images appeared below the kanji. Images presented during the Evaluation Phase were drawn from the International Affective Picture System (IAPS, Lang, Bradley, & Cuthbert, 2008), which provides normative ratings for *valence* (1 = unpleasant, 9 = pleasant) and *arousal* (1 = calm, 9 = excited). The 36 image pairs were designed to include one strongly positive image and one neutral image.

Analyses examined summed valence values for image choices as a function of posture (approach, avoid, control). These results indicated a main effect of condition, F (2, 76) = 4.66, $p = 0.01$, $\eta^2_p = .109$. Across groups, ratings for Approach kanji tended to be higher than for Avoid kanji, and were significantly higher than for Control kanji. There was no effect of group, F (1, 38) = 1.35, $p = 0.25$. However, there was a significant condition X group interaction, F (2, 76) = 3.86, $p = 0.03$, such that participants in the TD group had higher Approach valences relative to both Avoid and Control valences. In contrast, in the ASD group, there were no valence differences for any condition contrasts. Furthermore, the degree to which participants in the ASD group failed to choose positive images in the Approach condition was significantly associated with ADOS social symptoms, r (15) = -.551, $p = .02$. Thus, greater symptom severity was associated with reduced embodiment effects.

Following James (1884), experimental data has long indicated that, in typically developing individuals, activation of the flexor muscles is related to positive emotions and the extensors to negative emotions (Cacioppo et al., 1993). This is thought to reflect a lifetime of experience of contingencies between the acquisition or consumption of desired objects and arm flexion, on the one hand, or noxious or aversive stimuli and arm extension, on the other hand. The pairing of body actions and evaluative contingencies are thought to form the basis of a general association between motor postures and evaluative (affective) attitudes, an adaptive response that enhances the efficiency with which we process important cues. For the current task to elicit measurable effects requires that the specific combination of actions and stimuli presented in the experiment call this approach/avoidance "system" into action.

In the TD group, results indicated that motor action during an encounter with a novel visual stimulus influenced subsequent evaluations of that stimulus after a delay. *In contrast, participants with ASD showed no embodiment effects*. Although both groups "liked" similar numbers of kanji overall, suggesting that they found the stimuli equally pleasing, the ASD group showed no initial differentiation between Approach and Avoid kanji, unlike the TD group, suggesting that the lack of embodiment effects may have reflected differences in the encoding stage. Further, there was a significant relationship between autism symptomatology severity and postural effects; those with more social impairments were less likely to choose a strongly positive (as opposed to a neutral) image for the Approach kanji. This relationship suggests symptom severity in the ASD group was related to the strength of embodiment effects and may be a sensitive index of implicit processing (e.g., Hubert, Wicker, Monfardini, & Deruelle, 2009).

While preliminary, there is good empirical support for the possibility that motor actions and sensory cues are co-activated and bound together in subsequent re-activations. For example, studies of object localization in rodents indicate that motor pathways (e.g., of the whisker vibrissae) are intrinsically involved in the representation of external objects with a hierarchical set of feedback loops (Yu, Derdikman, Haidarliu, & Ahissar, 2006). In humans, studies have shown overlapping representations of visually-presented objects in regions (left premotor cortex and left intraparietal sulcus) involved in motor action and action planning (Yee, Drucker, & Thompson-Schill, 2010).

The lack of embodiment demonstrated by the ASD group could reflect (at least) three distinct mechanisms. **First**, the association between these physical postures and affective valence could be present in ASD, but weakened by group differences in the experience of specific images. While the norms for the images used in this study include a large, representative population, there are no data from individuals with ASD; the images could have distinct valence values in this population. Arguing against this possibility, results indicated no evidence of a reduced preference in general for the positive images. **Second**, participants with ASD may not have assumed the physical postures in the same manner as participants with TD, as there was no physiological verification that the same sets of flexion and extensor muscle groups were active, to the same degree. In fact, experimenters observed that participants with ASD often held the postures with greater enthusiasm and effort; effects of such muscle "hyperactivation" for embodiment are unclear. This hypothesis is consistent with the possibility that motor control differences (Dziuk et al., 2007; Jansiewicz et al., 2006; Macneil & Mostofsky, 2012) meaningfully contribute to affective processing. If so, embodiment differences would be limited to associations between motor and other representations, and would likely be specifically correlated with degree of motor impairments. Certainly, this possibility merits further attention. **Third**, if body postures may have had a reduced influence on stimulus encoding, aside from affective considerations, because of reduced connections between sensory and motor inputs to higher-level association regions (e.g., Mostofsky & Ewen, 2011). Inefficiencies in mapping stimuli from distinct modalities onto a single representation could lead to the lack of embodiment effects seen in the ASD participants as a group. The current results, including the finding of a significant relationship between ASD severity and sensorimotor effects, raise the possibility that differences in sensorimotor mapping may be central to the social and communicative difficulties in ASD. Because of the salience of these low-level but ubiquitous processes for social interaction and communication, the current results also suggest that impairments in embodied processes could play an important role in the etiology of ASD.

In this paper, we have described three processes that each show the influence of focal deficits in low-level cognitive processes on high-level and more social domains. These low-level processes included pitch discrimination, motor coordination with speech, and the integration of body posture into complex stimulus representations. We propose that the identification of such low-level deficits may help to illuminate core mechanisms of ASD. Furthermore, we suggest that rather than the manifestation of a simple set of symptoms present in differing contexts, deficits in language and social reciprocity may reflect the operation of distinct mechanism. Rather than relying entirely on the DSM-5 criteria, researchers wishing to probe language and communication deficits in ASD may prefer to refer to the RDOC framework as a guide to research on mental and developmental disorders. In the longer term, the diagnostic criteria for ASD may once again come to specifically incorporate impairments in language and communication as a specific domain of impairment, a change which would help to highlight the importance of non-social processes for development.

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