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Atypical preference for infant-directed speech as an early marker of autism spectrum disorders? A literature review and directions for further research

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### Abstract

Autism spectrum disorders (ASD) refer to a complex group of neurodevelopmental disorders causing difficulties with communication and interpersonal relationships, as well as restricted and repetitive behaviors and interests. As early identification, diagnosis, and intervention provide better long-term outcomes, early markers of ASD have gained increased research attention. This review examines evidence that auditory processing enhanced by social interest, in particular auditory preference of speech directed towards infants and young children (i.e., infant-directed speech – IDS), may be an early marker of risk for ASD. Although this review provides evidence for IDS preference as, indeed, a potential early marker of ASD, the explanation for differences in IDS processing among children with ASD versus other children remains unclear, as are the implications of these impairments for later social-communicative development. Therefore, it is crucial to explore atypicalities in IDS processing early on development and to understand whether preferential listening to specific types of speech sounds in the first years of life may help to predict the impairments in social and language development.

*Keywords:* Autism Spectrum Disorders, Early markers, Infant-Directed Speech,  
Review

## INTRODUCTION

Autism spectrum disorders (ASD) refer to a heterogeneous and complex group of neurodevelopmental conditions causing difficulties with communication and interpersonal relationships, as well as restricted and repetitive behaviors and interests (American Psychiatric Association, 2013). As the prevalence of this condition is increasing (global median of prevalence estimates of ASD is 62/10 000; Elsabbagh et al., 2012), understanding ASD early characteristics is a social, economic, and health issue. Early identification could provide better long-term outcomes and decrease the cost of care of these individuals over their lifetime (Chasson, Harris, & Neely, 2007; Dawson, 2008; Dawson et al., 2012).

Very young children have biases that orient their attention to relevant signals present in the environment. Typically developing infants pay more attention to socially relevant stimuli than nonsocial stimuli (Butterfield & Siperstein, 1970; Valenza, Simion, Cassia, & Umiltà, 1996; Vouloumanos & Werker, 2007), and crucially to the speech addressed to them, i.e., “infant-directed speech” (IDS; Cooper & Aslin, 1990; Dunst, Gorman, & Hamby, 2012; Fernald, 1985; McRoberts, McDonough, & Lakusta, 2009; Schachner & Hannon, 2011; Werker, Pegg, & Mcleod, 1994). Indeed, research suggests that IDS effectively orients and holds infants’ attention, and promotes their social and language development (Cristia, 2013; Floccia et al., 2016; Kubicek et al. 2014; Kuhl, 2007; Weisleder & Fernald 2013;). In contrast, individuals with ASD have known deficits in the realm of social communication, and there is reason to hypothesize that this typical preference for social relevant stimuli is altered in this population. Previous work found atypicalities in the orientation to relevant auditory stimuli (for review: O’Connor, 2012). For instance, comparing the percentage of head-turns in the direction of the samples of IDS versus non-speech analogs between typically developing children and children with ASD, the ASD group demonstrated a strong listening preference for non-speech analog signals, unlike the typical developing group

(Kuhl, Coffey-Corina, Padden, & Dawson, 2005).

To explain these atypical biases that orient the attention of individuals with ASD to certain signals in the environment, several theoretical frameworks have been proposed. Some theories are mainly focused on differences in low-level processing (for review: Happé & Frith, 2006; Mottron et al., 2006). In this context, the Theory of Weak Central Coherence (Frith, 1989) postulates that individuals with ASD have a tendency to focus on individual elements rather than the whole, combined with an inability to integrate information into context. As an alternative to the previous model, the Enhanced Perceptual Functioning (Mottron et al., 2006) suggests that individuals with ASD have improved perception of low-level perceptual information in comparison to higher-order operations. This makes perceptual processes more difficult to control and more disruptive to the development of other behaviors and abilities. A related framework to the Enhanced Perceptual Functioning theory, which has specifically been used to describe auditory processing in ASD, is the Neural Complexity Hypothesis (Bertone, Mottron, Jelenic, & Faubert, 2005; Samson et al., 2006). This framework suggests enhanced perception of simple, low-level auditory stimuli in individuals with ASD together with impaired perception of more complex auditory information. Specifically, the authors proposed that individuals with ASD, in comparison to typically developing individuals, show superior performance for simple tones processed in the primary auditory cortex, but reduced performance for complex tones processed in the associative auditory cortex. According to this point of view, this enhanced perception of low-level auditory features may be prejudicial to high-level processing, affecting the response to the categorical patterns that characterize IDS.

Other theories have focused on social-cognitive aspects of processing, such as the Theory of Mind (Baron-Cohen, Leslie, & Frith, 1985), the Theory of Executive Dysfunction (Hughes & Russel, 1993), and the Social Motivation Theory (Chevallier et al., 2012),

hypothesizing that individuals with ASD have diminished attention to certain stimuli because of its social-cognitive aspects. In this approach, the Theory of Mind framework is useful to explain high-order abnormalities in the process that enable most of us to understand that others have beliefs, desires, thoughts, hopes, and emotions that may differ from our own (Baron-Cohen et al., 1985). The Theory of Executive Functioning suggests that symptoms of ASD are a result of a primary problem in the executive control of action (Hughes & Russell, 1993; Ozonoff, Rogers, Farnham, & Pennington, 1994; Pennington et al., 1997). This theory identifies difficulties in planning, initiation, and inhibition skills as a core deficit that underlines this disorder (Rajendran & Mitchell, 2007). Indeed, the distinction made within this theory between two interrelated constructs, one emotional (hot) and one cognitive (cool) (Zimmerman et al., 2016), could also help us understand these atypicalities. It is suggested that some social skills, namely the ability to recognize emotions and make social inferences, are supported by working memory as well as by response initiation and suppression processes. Finally, the Social Motivation Theory purports that mechanisms related to social motivation may represent the primary deficit in ASD, manifested by diminished social orientation, social reward, and social maintaining. This theory highlights the fact that individuals with ASD react to social scenes in an atypical manner, for instance, paying greater attention to objects compared to people than typically developing children. These atypical developmental processes ultimately deprive them of adequate social learning opportunities. According to this point of view, individuals with ASD have diminished attention to IDS because of its social-cognitive aspects.

In the present paper, we provide a comprehensive review of evidence related to auditory processing enhanced by social interest, namely the processing of IDS, particularly focusing on the auditory preferences in younger siblings of children with ASD (infants at high-risk for ASD), as around 20% of these children have been found to meet the criteria for

ASD by their third year of life (Ozonoff et al., 2011; Szatmari et al., 2016). Studies using this prospective research design are useful to better understand the nature of several atypicalities in ASD. They allow the comparison between the developmental trajectories of infants who later do or do not meet ASD diagnostic criteria, and provide a unique opportunity to characterize ASD development. Our goal is to better understand the atypical biases in IDS preference and processing that may underlie the atypical social-communicative development in ASD, and explore potential implications for early identification and early intervention. This highlights previous suggestions in that auditory preference and processing of IDS may be a potentially early marker of ASD, providing important theoretical and clinical implications. This review was conducted using the PsycINFO database. Articles were selected through the combination of the keywords ‘Autism’ and ‘Auditory Processing’ together or in conjunction with the keywords ‘Infant-Directed Speech’, ‘Child-Directed Speech’, ‘Motherese’, and/or ‘Maternal Speech’. Based upon title and abstract screening, a total of 41 references were identified through the search process and were selected for full text review. The final sample of articles was divided into three categories: general auditory processing in ASD, auditory processing of IDS in ASD, and auditory preference of IDS in infants at high-risk for ASD. The design characteristics and the main findings of the reviewed studies related to auditory processing of IDS in ASD and auditory preference of IDS in infants at high-risk for ASD are presented in Table 1.

#### **GENERAL AUDITORY PROCESSING IN ASD**

Research on general auditory processing in ASD investigated both basic stimuli (particularly, the dimensions of pitch and loudness), as well as more complex processing (e.g., prosody). Regarding basic auditory processing in ASD, special attention has been given to the perception of pitch. Initial work comes from case studies in autistic savants, which

found absolute pitch processing despite other deficits on language and cognitive skills (e.g., Kanner, 1943; Mottron, Peretz, Belleville, & Rouleau, 1999; Young & Nettelbeck, 1995). Further work examined this absolute pitch processing, and the results showed that participants with ASD were more accurate at identifying and recalling pure tones than IQ-matched typically developing peers (Heaton, Hermelin, & Pring, 1998). Similar results were found in later work: individuals with ASD exhibited superior pitch memory and identification of familiar tones from musical chords than IQ-matched typically developing children (Heaton, 2003). Several subsequent studies found that individuals with ASD were more proficient at the discrimination and categorization of pitch differences between lexical tones, pure tones, words pairs, nonwords, and non-speech stimuli relative to controls (Bonnell et al., 2003; Heaton, 2005; Heaton, Hudry, Ludlow, & Hill, 2008; Järvinen-Pasley & Heaton, 2007; Järvinen-Pasley et al., 2008a; Järvinen-Pasley, Pasley, & Heaton, 2008b; O’Riordan & Passetti, 2006). Less research has been conducted regarding the perception and processing of loudness, but studies of these variables reported hypersensitivity to loud sounds concurrent with typical performance on discrimination tasks (Bonnell et al., 2010; Jones et al., 2009).

Regarding complex auditory processing, children with ASD have shown a number of processing patterns similar to those of typically developing children, e.g., recalling stressed words better than unstressed ones (Fine, Bartolucci, Ginsberg, & Szatmari, 1991), discriminating word pairs differing in first- vs. last-syllable stress patterns (Grossman, Bemis, Plesa-Skwerer, & Tager-Flusberg, 2010), and distinguishing sentence types such as statements vs. questions (Paul, Augustyn, Klin, & Volkmark, 2005; Peppé et al., 2007; Peppé et al., 2011). However, impairments in complex auditory processing have also been found. For instance, significant deficits in the perception of contrastive stress were reported (e.g., Paul et al., 2005), as well as delays or impairments such the tendency to perceive pairs of the same auditory stimuli as prosodically different (Peppé et al., 2007). Other studies also



showed prosody as a deficit at the communicative level in children with ASD. For instance, ASD children tend to judge questions as statements and produce questioning intonation when a statement was required, and tend to show problems with affective tasks and with the interpretation and production of contrastive stress (Peppé et al., 2007). In sum, individuals with ASD often reveal impaired performance in tasks with more complex stimuli such as speech (Dawson et al., 1998; Dawson et al., 2004; Fujikawa-Brooks et al., 2010; Gervais et al., 2004; Källstrand et al., 2010; Kuhl et al., 2005; Lepistö et al., 2009; Teder-Salejarvi, Pierce, Courchesne, & Hillyard, 2005; Whitehouse & Bishop, 2008).

In addition to more accurate pitch perception together with impairments in complex auditory processing, reduced preference for linguistic/social information was also found. In fact, more specific deficits have been found for social stimuli versus non-social stimuli (Dawson et al., 1998; Dawson et al., 2004; Kuhl et al., 2005; O'Connor, 2012, for a review). Thus, researchers have investigated listening preferences of individuals with ASD. Klin (1991) compared preferences of children with ASD compared to children with intellectual deficits and typically developing children. A preferential listening task was presented to the three groups, with each child hearing his or her own mother's voice and a sound of superimposed voices. The results showed that the children with intellectual deficits and the typically developing children preferred to listen to their mothers' speech. However, children with ASD either preferred the superimposed voices or showed no preference. Several other studies found atypical processing of social stimuli (both for auditory and visual modalities; Dawson et al., 1998; Dawson et al., 2004; Dawson, Webb, & McPartland, 2005; Rutherford, Baron-Cohen, & Wheelwright, 2002). Moreover, brain-imaging studies confirmed that children with ASD show atypical neural activation as a reaction to speech but not to non-speech sounds (Gervais et al., 2004), as well as abnormal cortical auditory processing (Boddaert et al., 2004).

### AUDITORY PROCESSING OF INFANT-DIRECTED SPEECH (IDS) IN ASD

As IDS is a socially relevant linguistic stimulus, attenuated preferences for this kind of speech in individuals with ASD have captured increasing research attention. Infant-directed speech is an important speech style used by adults when speaking to infants (e.g., Snow & Ferguson, 1977), and it is generally characterized as having a variety of linguistic modifications in the syntax, lexicon, and prosody. For example, compared to adult-directed speech, (a) sentences in IDS tend to be shorter and often grammatically more simplified (Newport, Gleitman, & Gleitman, 1977); (b) the set of prosodic contours is less variable (Fernald & Simon, 1984); (c) frequently, focused words are placed at the end of sentences and marked with exaggerated pitch peaks (Fernald & Mazzie, 1991); and (d) higher pitch, larger pitch range, slower tempo, and enhanced rhythmic features tend to be used (Fernald, 1992; for a recent review, see Cristia, 2013).

IDS may serve to (a) obtain and/or maintain attention (Fernald, 1992), (b) to communicate affective and contextual information (Fernald, 1992), and (c) to enhance language learning (Morgan & Demuth, 1996; Song, Demuth, & Morgan, 2010; Kuhl, 2007) in a number of different domains such as word segmentation (e.g., Thiessen, Hill, & Saffran, 2005; Floccia et al., 2016), word learning (e.g., Saffran, Aslin, & Newport, 1996; Weisleder & Fernald, 2013), and audio–visual associative learning (Kaplan, Bachorowski, Smoski, & Hudenko, 2002; Kaplan, Jung, Ryther, & Zarlengo-Strouse, 1996; Kubicek et al., 2014).

From birth, typically developing infants prefer to listen to IDS versus other speech or auditory stimuli (Cooper & Aslin, 1990; Fernald, 1985; McRoberts et al., 2009; Werker et al., 1994), and this preference continues through preschool (Klin, 1991; Kuhl et al., 2005; Paul et al., 2007). This has been shown both by studies using behavioral methods and studies using electrophysiological (e.g., Zangl & Mills, 2007) and neuroimaging techniques (e.g.,

Vouloumanos, Kiehl, Werker, & Liddle, 2001). Furthermore, research found that 5-month-old infants had a preference for individuals who previously used IDS (Schachner & Hannon, 2011). Indeed, the social and communicative aspects of IDS are highly attractive among typically developing infants.

It seems that although typically developing children prefer listening to IDS, children with ASD as a group do not demonstrate a similar preference. For instance, researchers examined whether children with ASD demonstrated a preference for IDS, compared to three other groups: children with other developmental disabilities matched for language age, typically developing children matched for chronological age, and typically developing children matched for language age. In the experiment, the children heard IDS and "rotated" samples of the same speech (i.e., manipulated original speech sounds that had some of the same acoustic properties, but did not sound like speech). Results showed that the children with ASD in the second and third year of life demonstrated the least preference for IDS, whereas the typically developing chronological age-matched group presented the most marked preference for IDS. Children with ASD demonstrated significantly less preference for IDS than their age-matched peers, but were not significantly different from either of the two other groups (Paul et al., 2007). However, it has been suggested that the way that IDS stimuli are presented may influence preference patterns (Watson et al., 2012). That is, children with ASD and their language age-matched peers with typical development spent similar amount of time looking at videotaped IDS, but when IDS was presented live, the language age-matched typically developing children showed increased looking time to the IDS speaker, and significantly exceeded the amount of looking time for children with ASD in the live condition. This is not surprising given the findings that social interaction plays a significant role in early language learning, as demonstrated by studies with typically developing infants that compared live exposure to language to video or audio-only presentation (Kuhl, Tsao, &

Liu, 2003; Kuhl, 2007; Kuhl & Rivera-Gaxiola, 2008).

Research also examined auditory preferences in preschool children with ASD compared to typically developing children matched for mental age using a head-turn paradigm that paired IDS samples and non-speech analog signals of the IDS samples (Kuhl et al., 2005). On average, the children with ASD showed a preference for the non-speech analog signals over IDS, whereas their typically developing peers did not demonstrate a preference. This study then analyzed the discrimination of an English phonemic contrast (/wa/ as the standard and /ba/ as the deviant) through mismatch negativity (MMN), using a control group of typically developing children matched to the ASD sample based on chronological age. The children with ASD were separated into subgroups based on their listening preference (i.e., for the nonspeech analog,  $N = 20$ , or for IDS,  $N = 7$ ), and the researchers found different neural patterns for the two ASD subgroups. The children with ASD who preferred IDS had a similar amplitude of MMN response to that of the typically developing children, whereas the children with ASD who preferred non-speech analogs with similar acoustic features did not show a clear MMN response to the deviant speech syllable (Kuhl et al., 2005).

Moreover, an interesting relationship has been found between IDS processing and typical language development, with specific features of IDS (e.g., higher pitch and exaggerated prosody) apparently assisting socio-communicative learning (e.g., Kuhl et al., 2005; Paul et al., 2007; Thiessen et al., 2005; Tsao, Liu, & Kuhl, 2004). For example, results showed that 7-month-olds use transitional probabilities between syllables to distinguish nonsense words (versus “partial words”) within nonsense sentences when the sentences were presented using the prosody typical of IDS, but did not show evidence of discriminating between words and partial words when sentences were presented with the prosody of adult-directed speech (Thiessen et al., 2005). This study intentionally limited the IDS properties of their stimuli to pitch-based cues (higher pitch and exaggerated pitch contours). However,

other properties might also be involved in the link between IDS processing and socio-communicative learning. For example, research found that the recognition of words by 19-month-olds might be affected by other properties of natural IDS, specifically slow speaking rate and vowel hyper-articulation (Song et al., 2010).

Different processing patterns among infants known to be at risk for ASD or young children diagnosed with ASD may also predict later language outcomes and aid in identifying early intervention targets or strategies. For example, children with ASD who prefer listening to non-speech over IDS are more likely to exhibit deficits in expressive language abilities (Kuhl et al., 2005). For the specific case of ASD, research also found that behavioral measures and physiological responses to IDS are significantly correlated to later communication skills of children with this diagnosis (Watson et al., 2010). Furthermore, the child's responsiveness to IDS may have a crucial impact on the quantity of IDS used by caregivers, and this may restrict optimal language learning conditions for the children (e.g., Wan et al., 2013). These findings suggest that IDS might play a crucial role in language learning among children with ASD. The knowledge about the importance of IDS preference as a potential early marker of risk for ASD, as well as a predictor of language outcomes, has developed and become more promising in recent years because research groups have addressed these questions from different points of view. Studies with infants at high-risk for ASD have been especially valuable.

#### **AUDITORY PREFERENCE OF INFANT-DIRECTED SPEECH IN INFANTS AT HIGH-RISK FOR ASD**

An important issue regarding the potential value of atypical IDS preference as a marker of risk for ASD or predictor of language outcomes is to identify when individuals with ASD begin to orient less to IDS. That is, a key diagnostic assumption is that ASD involves an early disruption of neurodevelopment (for review: Jones et al., 2014). Therefore, many studies in

the past decades have focused on early signs and indicators. Retrospective research using parent reports as well as home videos has shown impairments in a range of abilities in the first years of life of children later diagnosed with ASD (for review: Barbaro & Dissanayake, 2009; Costanzo et al., 2015; Szatmari et al. 2016; Yirmiya & Charman, 2010). More recently, as around 20% of siblings of children with ASD meet criteria for this disorder by their third year of age (Ozonoff et al., 2011), prospective studies of infant siblings have frequently been used as a methodological approach to studying early markers of ASD. These studies follow younger siblings of children with ASD from early infancy until 2-3 years of age (when the diagnosis can be achieved). They allow the comparison between different developmental trajectories of infants who later do or do not meet ASD diagnostic criteria. Because of the opportunity to directly observe behaviors under controlled conditions (difficult to achieve in retrospective videoanalysis studies), and to avoid recall biases (which are a concern when using retrospective parent report methods), these prospective studies of infant siblings are more reliable than retrospective studies (Costanzo et al., 2015). In addition to permitting the observation of behavior in a standardized way, prospective studies of infant siblings offer opportunities to collect behavioral, neurophysiological, and/or electrophysiological data.

Using these methods, researchers have found patterns in behavioral development by around the end of the first year of life that may be seen as early risk markers for ASD, such as less responsiveness when the infant's name is called, reduced joint attention, repetitive behaviors involving body movements and/or atypical use of objects, and atypical emotional regulation (e.g., Elssabagh et al., 2012b; Lazenby et al., 2016; Osterling, Dawson, & Munson, 2002; Ozonoff et al., 2010; Szatmari et al., 2016). Although the use of prospective design with infants at high-risk for ASD to study ASD characteristics is a relatively new methodology, results suggest that differences in brain function that later cause the behavioral characteristics of ASD may be detectable early in the first year of life, such as less selective

neural responses to social stimuli (auditory and visual) than low-risk controls (Lloyd-Fox et al., 2013; Elsabbagh et al., 2012b). Given that a preference for IDS is observed among typically developing infants in the early months of life, and that evidence was found that this preference is not seen among many children with ASD, examining speech preference among infants at risk for ASD at a very young age is important. In one study comparing high-risk infant siblings to low-risk infant siblings at 6, 8, 12, and 18 months, it was found that neither group looked reliably longer at stimuli during IDS than adult-directed speech samples until the age of 18 months, at which timepoint each group looked longer at IDS stimuli, with no significant difference between the two groups (Droucker, Curtin, & Vouloumanos, 2013). However, the low-risk siblings showed a trend to look longer at IDS than adult-directed speech at 8 months that was not apparent at this age in the high-risk siblings. The low-risk group also showed higher expressive language scores at 18 months than the high-risk group, and this result correlated with preferences for IDS at 12 months. Because this study compared high-risk infants to low-risk infants without consideration of ASD symptoms or clinical outcomes in the high-risk infants, however, the question of whether early atypical preference patterns for IDS versus other auditory stimuli predicts later ASD was not answered. More directly relevant to this specific issue, is a study that addressed the question of whether atypical preferences for speech at 12 months are associated with ASD symptoms at 18 months (Curtin & Vouloumanos, 2013). At 12 months, high-risk infants were compared to low-risk infants on their preference for speech stimuli versus complex non-speech analogs of the speech stimuli. The infants in both groups looked longer at a visual stimulus (checkerboard) presented concurrently with speech than when the visual stimulus was presented concurrently with nonspeech; however, the difference in looking time was significant only for the low-risk infants, and the high-risk infants were significantly more variable than low-risk infants in their looking time. A difference score was computed by

subtracting looking during nonspeech versus looking during speech as a speech preference index. Addressing the primary question of the study, the researchers found that the speech preference index at 12 months had a moderately strong correlation with ASD markers (measured with the Autism Observation Scale for Infants; Bryson et al., 2008) at 18 months for the high-risk infants, but a near zero correlation for the low-risk infants. The high-risk group did not listen reliably longer to speech and this group's atypical preference for speech was associated with autistic behaviors at 18 months. Findings from these two studies of infant siblings of children with ASD suggest that the atypical preferences related to IDS stimuli seen among children with ASD may arise in early development; however, because neither study considered definitive diagnostic outcomes for the children, the findings fall short of providing conclusive evidence regarding early atypical preferences related to IDS as a marker for later ASD diagnosis. Nevertheless, the two studies provide strong evidence that atypical preferences for other stimuli versus IDS predict deficits in later language development and social communication.

## DISCUSSION

Research shows that individuals with ASD are often more skilled than typically developing peers at low-level processing of auditory stimuli (i.e., pitch; Bonnel et al., 2010; Bonnel et al., 2003; Heaton et al., 2008; Heaton, Williams, Cummins, & Happé, 2008; Jones et al., 2009; O'Riordan & Passetti, 2006). By contrast, they often reveal impaired performance in tasks with more complex auditory stimuli such as speech, and/or in more difficult tasks involving processing of auditory stimuli (Dawson et al., 1998; Dawson et al., 2004; Fujikawa-Brooks et al., 2010; Gervais et al., 2004; Källstrand et al., 2010; Kuhl et al., 2003; Lepistö et al., 2009; Teder-Salejarvi et al., 2005; Whitehouse & Bishop, 2008). Some studies also have found that individuals with ASD have an atypical preference for sounds; in



particular, they do not show the expected preferences for IDS stimuli over other auditory stimuli (e.g., Kuhl, Tsao, & Liu, 2003; Paul et al., 2007). Furthermore, abnormalities in IDS processing were also characteristic of preschool children with ASD. Research related to the implications of these atypical IDS-related preferences for social-communicative development and ASD symptomatology has been growing in recent years, but it is still scarce.

Research about predictors of ASD has become promising. Retrospective studies that focused on parental reports and home videos were an important early method to gain insights into the early development of individuals with ASD, and to identify possible pre-clinical signs, indicators, or markers. More recently, these kind of studies have been complemented with prospective studies. Prospective studies represent an approach of great potential because they allow the study of different variables and the control of experimental design. This information can improve the detection of early signs and the distinction of ASD from other developmental disorders early on development. Thus, prospective studies of infants at high-risk for ASD offer the opportunity to examine whether atypical preferences related to IDS aid in the prediction of clinical outcomes and underlie the challenges in the development of language and communication experienced by many high-risk infants.

This review provided some evidence of preference patterns involving IDS as a potential early marker of ASD and of language outcomes in preschool children and in infants at high-risk for this disorder. However, although group-level associations between IDS processing and later development are observed over time, outcomes for individual children vary widely. Existing research is inconsistent in findings related to the nature or extent of differences between low- and high-risk infants, and has not clarified whether high-risk infants who go on to be diagnosed with ASD are different from other infants in their preferences for speech stimuli from early infancy, or whether these differences emerge gradually over the first years of life. Indeed, our overall understanding of the role of IDS as a predictive marker

of risk for ASD is limited. Although the prospective studies with high-risk infant sibling samples have several advantages, recent research has also highlighted implications for the comparability of children with ASD ascertained from prospective high-risk samples versus other children with ASD. The high-risk group may display less severe ASD symptoms and better adaptive skills than children identified from the community, including those with no family history (Sacrey et al., 2017). Therefore, caution should be taken in generalizing findings from high-risk samples versus other methods. In further research these potential differences should be explored.

As it has been mentioned in the introduction, several theories have been proposed to explain differences between individuals with ASD when compared to typically developing peers. The implications of these theories for the understanding of why individuals with ASD orient less to speech compared to individuals without ASD could be explored in future research. According to the theories of perceptual functioning, the enhanced perception of low-level auditory features may be prejudicial to high-level processing, affecting the response to the categorical patterns that characterize IDS. However, the preference for IDS is independent of low level acoustics, because, for instance, Kuhl and colleagues (2005) tested auditory preference to IDS and non-speech analogs with the same pitch and amplitudes, and found that children with autism who preferred IDS were similar to typically developing peers in their linguistics processing of speech. Thus, it would be reasonable to suggest that the social-cognitive aspects of IDS account for atypical speech preferences in children with ASD, and children at-risk for ASD. Future research should evaluate alternative predictions that different general theories would make related to patterns of preference for speech or IDS among infants at high-risk for ASD. In other words, understanding the relationship between IDS preference patterns and ASD could provide insights into the nature and etiology of this disorder, as well as contribute to the early diagnosis of ASD.

Beyond understanding whether theories of ASD can explain group differences in speech preferences between children with ASD and those with other disabilities or typical development, there is increasing interest in the theoretical and clinical importance of understanding the factors behind the heterogeneity in outcomes among children with ASD. Although findings to date suggest that IDS might play a crucial role in social-communicative learning, it is crucial to understand whether preferential listening to specific speech sounds in the first years of life may help to explain the impairments in social and language development. As highlighted by Costanzo and colleagues (2015), the longitudinal structure of prospective studies of high-risk infants not only contributes to our understanding of the onset of the disorder, but also of its developmental trajectory over time. Such evidence may inform the development of intervention programs for at-risk infants, designed to change atypical IDS preference patterns as a potential mediator of later (and better) language and social-communication outcomes.

Furthermore, as IDS could play a vital role in the way listeners react to speech, thus affecting language and communication development, knowing more about differences between clinical populations could help early and differential diagnosis with welcome clinical implications. This review suggests that, potentially, preference for IDS should be included in behavioral assessment and in screening questionnaires that assess behaviors in early development that suggest risk for ASD or other neurodevelopmental disorders (e.g., First Year Inventory, Baranek, Watson, Crais, & Reznick, 2003; Symbolic Behavior Scales-Infant Toddler Checklist, Wetherby & Prizant, 2002).

Still, the explanation for differences in IDS processing among children with ASD versus other children remains unclear, as are the implications of these impairments for later social-communicative development. Future research can inform the field about the extent to which early preference patterns related to IDS stimuli account for variability in social-

communication outcomes among those infants who go on to be diagnosed with ASD, extending the work of Kuhl and colleagues, (2005) by addressing within-group variability. More research is needed to address several limitations identified in the literature that constrain the generalization power of the findings reported so far: (1) lack of accurate description of sample characteristics (e.g., age, sex, neurodevelopmental characteristics, and adaptive behavior); (2) small sample sizes; (3) no standard diagnostic instruments for diagnostic confirmation; and (4) lack of longitudinal and follow-up analyses. The impact of future research can be enhanced by considering alternative theories related to key questions that remain unanswered: What is the explanation for reduced orientation/attention to IDS in children with ASD compared to other children? What are the implications of these impairments for social and language development?

**DECLARATION OF INTEREST**

The authors report no declarations of interest.

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Table 1. Description of included studies related to auditory processing of infant-directed speech (IDS) in ASD and in infants at high-risk for ASD

| Source - Author (year)                   | Sample  | Design   | Main Findings  |
|--|---|--|--|
| <i>Auditory Processing of IDS in ASD</i> |   |  |  |
| Kuhl et al. (2005)                       | <ul style="list-style-type: none"> <li>• <math>N = 73</math> (ASD <math>n = 29</math>; Typically Developing mental age match <math>n = 29</math>; Typically Developing chronological age match <math>n = 15</math>).</li> <li>• CA = participants age range between 32 and 70 months.</li> </ul>              | <ul style="list-style-type: none"> <li>• Auditory preference test to extract a social measure, using Head Turn: <ul style="list-style-type: none"> <li>○ Children heard eight IDS samples against non-speech analogs of the same signals.</li> <li>○ Speech samples were between 4.8 and 5.3 seconds in duration.</li> </ul> </li> <li>• Phonetic discrimination assessed with mismatch negativity (MMN), an event-related potential (ERP), to extract a linguistic measure: <ul style="list-style-type: none"> <li>○ Children heard speech stimuli: consonant–vowel syllables /ba/ and /wa/, computer synthesized to be identical except for the duration of the initial formant</li> <li>○ Stimuli were 80 ms long.</li> </ul> </li> </ul> | <ul style="list-style-type: none"> <li>• Children with ASD differed from controls and demonstrated a preference for the nonspeech analogs, as well as failed to show a significant MMN in response to a syllable change.</li> <li>• When ASD children were divided into subgroups based on auditory preferences (speech vs. nonspeech), ASD children who preferred non-speech still failed to show an MMN in response to a syllable change, whereas ASD children who preferred IDS did not differ from the controls.</li> </ul>        |
| Paul et al. (2007)                       | <ul style="list-style-type: none"> <li>• <math>N = 158</math> (ASD <math>n = 52</math>; Developmentally Delayed = 32; Typical Developing age match <math>n = 44</math>; Typically Developing language match <math>n = 30</math>).</li> <li>• CA = participants age range between 14 and 36 months.</li> </ul> | <ul style="list-style-type: none"> <li>• Auditory preference protocol.</li> <li>• Children heard IDS and "rotated" samples of the same speech (i.e., manipulated original speech sounds that had some of the same acoustic properties, but did not sound like speech).</li> <li>• 2 sessions each lasting 5-10 min.</li> </ul>   | <ul style="list-style-type: none"> <li>• Children with ASD in the second and third year of life demonstrated the least preference for IDS, whereas the typically developing chronological age-matched group presented the most marked preference for IDS.</li> <li>• Children with ASD demonstrated significantly less preference for IDS than their age-matched peers, but were not significantly different from either of the two other groups.</li> </ul>   |
| Watson et al. (2010)                     | <ul style="list-style-type: none"> <li>• <math>N = 22</math> (with ASD).</li> <li>• CA = participants age at entry ranged between 28 and 42 months (<math>N = 19</math> participated in the longitudinal follow-up at 40 to 55 months).</li> </ul>  | <ul style="list-style-type: none"> <li>• Communication skills (at entry and readministered 12 months later): <ul style="list-style-type: none"> <li>○ Receptive language.</li> <li>○ Expressive language.</li> <li>○ Social-communicative adaptive skills.</li> </ul> </li> <li>• Looking measures - sustained looking at the target stimuli (at entry): <ul style="list-style-type: none"> <li>○ The nonsocial stimulus condition consisted of a music video comprised of digitized classical music accompanied by nonsocial</li> </ul> </li> </ul>   | <ul style="list-style-type: none"> <li>• Looking during IDS was strongly correlated with all entry and follow-up communication skills.</li> <li>• Respiratory sinus arrhythmia (i.e., vagal activity) during IDS was moderately to strongly correlated with entry receptive language, follow-up expressive language, and social-communicative adaptive skills.</li> <li>• After controlling for entry communication skills, vagal activity during IDS accounted for significant variance in follow-up communication skills.</li> </ul> |

|   |  |   |  |
|---|--|---|--|
|   |  | <p>visual images (moving toys, visual patterns).<br/>The length of the nonsocial stimulus condition was two minutes.</p> <ul style="list-style-type: none"> <li>○ The IDS condition included three different vignettes: (a) a video story, (b) a live puppet show, and (c) a video toy. The length for each of these IDS vignettes was one minute.</li> </ul> <ul style="list-style-type: none"> <li>● Physiological measures (at entry): <ul style="list-style-type: none"> <li>○ Respiratory sinus arrhythmia (i.e., vagal activity).</li> </ul> </li> </ul>  |  |
| Watson et al. (2012)  | <ul style="list-style-type: none"> <li>● <math>N = 51</math> (ASD <math>n = 22</math>; Typical Developing language age match <math>n = 15</math>; Typically Developing chronological age match <math>n = 14</math>).</li> <li>● CA = participants age range between 29 and 42 months.</li> </ul> | <ul style="list-style-type: none"> <li>● Looking measures - sustained looking at the target stimuli: <ul style="list-style-type: none"> <li>○ The nonsocial stimulus condition consisted of a music video comprised of digitized classical music accompanied by nonsocial visual images (moving toys, visual patterns). The length of the nonsocial stimulus condition was two minutes.</li> <li>○ The IDS condition included three different vignettes: (a) a video story, (b) a live puppet show, and (c) a video toy. The length for each of these IDS vignettes was one minute.</li> </ul> </li> <li>● Physiological measures: <ul style="list-style-type: none"> <li>○ Heart activity.</li> <li>○ Respiratory sinus arrhythmia.</li> </ul> </li> </ul> | <ul style="list-style-type: none"> <li>● Children with ASD demonstrated diminished attention to IDS compared to typically developing peers at the same chronological age.</li> <li>● Children with ASD showed no differences in looking at nonsocial stimuli.</li> <li>● Children with ASD and language age-matched peers differed in patterns of looking at live versus videotaped IDS stimuli.</li> <li>● Children with ASD demonstrated faster heart rates than chronological age-matched peers, but did not differ significantly on respiratory sinus arrhythmia.</li> </ul>   |
| <p><i>Auditory Preference of IDS in Infants at High-Risk for ASD</i></p> <p>Curtin &amp; Vouloumanos (2013)</p> | <ul style="list-style-type: none"> <li>● <math>N = 62</math> (High-risk <math>n = 31</math>; Low-risk <math>n = 31</math>).</li> <li>● CA = participants tested at ages 12 and 18 months.</li> </ul>   | <ul style="list-style-type: none"> <li>● Sequential looking preference procedure. <ul style="list-style-type: none"> <li>○ Infants heard two types of auditory stimuli: a speech set composed of nonsense words and a non-speech set composed of complex non-speech analogues (each one with a duration of 40s).</li> </ul> </li> <li>● General functioning assessed at 12 months (using Mullen Scales of Early Learning).</li> <li>● Autistic-like behavior assessed at 18 months (using Autism Observation Scales Infancy).</li> </ul>  | <ul style="list-style-type: none"> <li>● At 12 months, the infants in both groups looked longer at a visual stimulus (checkerboard) presented concurrently with speech than when the visual stimulus was presented concurrently with non-speech; however, the difference in looking time was significant only for the low-risk infants, and the high-risk infants were significantly more variable than low-risk infants in their looking time.</li> <li>● The high-risk group did not listen reliably longer to speech and this group's atypical preference was associated with autistic behaviors at 18 months.</li> </ul> |

Droucker et al. (2013)

- $N = 36$  (High-risk  $n = 14$ ; Low-risk  $n = 22$ ).
- CA = participants tested at ages 6, 8, 12, and 18 months.
- Sequential looking preference procedure
  - Infants heard 2 IDS and 2 adult-directed speech passages (each one with a duration of 40s) paired with a checkerboard or a face.
- Expressive language assessed at 12 and 18 months (using MacArthur-Bates Communicative Development Inventories: Words and Gestures).
- General functioning assessed at 12 months (using Mullen Scales of Early Learning).
- The low-risk group showed a trend to look longer at IDS than adult-directed speech at 8 months that was not apparent at this age in the high-risk siblings.
- The low-risk group also showed higher expressive language scores at 18 months than the high-risk group, and this result correlated with preferences for IDS at 12 months.

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*Note.*  $N$  = number of participants; CA = chronological age