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36 Multisensory Processing in Autism Spectrum Disorders: Intersensory Processing Disturbance as a Basis for Atypical Development

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Autism spectrum disorder (ASD) is a neurodevelopmental disorder with symptom onset prior to age 3. Although there is great variability in symptom severity and intellectual functioning, ASD is defined by a triad of symptoms, including impairments in social functioning and interaction, impairments in communication, and restricted, repetitive, and stereotyped behaviors, interests, and activities (DSM-IV-TR: American Psychiatric Association, 2000). In this chapter we develop the view that typical social and communicative functioning rests on a foundation of intersensory/multisensory processing skills that develop and emerge across the first 6 months of life and are further refined across development (see also Bahrick, 2010). Intersensory processing entails perception of unified and coordinated information across the senses, including visual, auditory, tactile, and proprioceptive stimulation. Critical skills, such as social orienting and joint attention, which are found to be impaired in autism, also rely on a foundation of intersensory functioning (see also Mundy & Burnette, 2005). Attention, perception, learning, and interacting with the social world of people, language, and meaningful action depend on integrating dynamic, rapidly changing auditory, visual, tactile, and proprioceptive information from social and nonsocial events. Below we briefly describe the typical development of these skills across infancy and their links to social and communicative functioning. We then examine evidence of intersensory skills and impairments in individuals with ASD. Finally, we evaluate intersensory processing disturbance as a potential basis for explaining fundamental impairments in autism, including social and communicative functioning as well as stereotyped, repetitive behaviors.

By 3 years of age, children with ASD show a variety of impairments in social and communicative functioning, including reduced eye contact and attention to social partners, poor joint attention skills, little imitation, poor facial recognition, and altered emotional responsiveness (e.g., Dawson et al., 2004; Mundy, 1995; Mundy & Burnette, 2005; Volkmar, Paul, Klin, & Cohen, 2005). Children with ASD also show atypical patterns of attention and sensory processing. Compared to typically developing (TD) children, children with ASD are said to show *sticky attention* or *overselectivity*, including impairments in disengaging attention from competing stimulation to orient to new events (Landry & Bryson, 2004; Rincover & Ducharme, 1987), particularly to social events (Dawson, Meltzoff, Osterling, Rinaldi, & Brown, 1998; Dawson et al., 2004; Swettenham et al., 1998). They also show heightened attention to detail relative to global information (see Brock, Brown, Boucher, & Rippon, 2002; Frith & Happé, 1994; Happé, 1999; Happé & Frith, 2006), enhanced visual search, and certain enhancements in visual and auditory processing, including discrimination of surface properties such as pattern and feature information (Mottron, Dawson, Soulières, Hubert, & Burack, 2006; O'Riordan, Plaisted, Driver, & Baron-Cohen, 2001). However, this heightened or enhanced processing is thought to reflect low-level perceptual processing of simple objects and events, and sensory impairments are evident as the complexity of the stimuli grows (Bertone, Mottron, Jelenic, & Faubert, 2005; Minshew & Hobson, 2008). For example, the processing of faces is impaired (Dawson, Webb, & McPartland, 2005; see Schultz, 2005, for a review). How and when do these impairments in attention, sensory processing, and social and communicative functioning develop, and how are they interrelated? Characterizing early behavioral markers and the nature of developmental cascades that lead to increasing symptom severity in ASD is currently a significant

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challenge facing scientists and practitioners. It is crucial for early detection of children at risk for developing ASD, and early detection, in turn, is critical for developing more effective interventions.

Accomplishing these goals relies on a clear and detailed understanding of the typical development of attention and social and communicative functioning. A better understanding of what guides and constrains typical development will provide a basis for identifying atypical developmental trajectories and generating testable hypotheses about their origins. Small differences in developmental timing can have large effects on developmental outcomes, as effects of early experience are amplified across developmental cascades (Bahrick, 2010; Knudsen, Heckman, Cameron, & Shonkoff, 2006; Mundy & Burnette, 2005; Smith & Thelen, 2003; Turkewitz & Devenny, 1993). New skills are built on the foundation of prior input and skills, which in turn are developed and regulated in bidirectional interaction with feedback from the social and physical environment. Understanding which skills and input are most fundamental for regulating this delicate balance across development is critical to understanding atypical development (Karmiloff-Smith, 1998; Karmiloff-Smith & Thomas, 2003).

Consistent with this systems perspective, investigators of autism generally agree that identifying precursors or areas of impairment that are *primary* and have the potential to affect a wide range of later-developing symptoms is critical to early diagnosis and intervention (e.g., Landa, 2007; Sigman, Dijamco, Gratier, & Rozga, 2004; Zwaigenbaum et al., 2005). The symptoms of autism emerge and worsen across development, affecting an increasingly wide variety of areas, including social, communicative, and cognitive functioning, and associated neural development (Mundy & Burnette, 2005; Sigman et al., 2004; Volkmar, Lord, Bailey, Schultz, & Klin, 2004). Unfortunately, diagnosis is not typically made until 18–24 months or later, when significant delays in social and communicative functioning are already well established (Akshoomoff, Pierce, & Courchesne, 2002; Dawson et al., 2002; Sigman et al., 2004; Stone et al., 1999; Webb & Jones, 2009). Thus, identifying fundamental early-developing skills that provide a foundation for social and communicative functioning and establishing the extent to which they are impaired or intact in young children with autism are central to this effort. Accordingly, much research effort has focused on disturbances in early attentional processes such as social orienting (Dawson et al., 1998, 2004) and joint attention (Leekam & Moore, 2001; Mundy, 1995; Mundy & Burnette, 2005; Mundy, Sullivan, & Mastergeorge, 2009), both of which are seen as hallmarks of autism spectrum disorders. We propose that intersensory processing, an even earlier-developing system, may constitute another fundamental area of disturbance in autism and in turn would cause impairments to these and other related skills critical to social and communicative functioning.

Recent findings provide evidence of increasingly early onset of symptoms in ASD. Siblings of children with autism, who have a greater risk for developing ASD, show symptoms of the *broad phenotype* (symptoms that fall along the spectrum of behaviors associated with autism) in the first year of life (Cassel et al., 2007; Dawson et al., 2002; Merin, Young, Ozonoff, & Rogers, 2007), and findings of neurodevelopmental anomalies occur even in prenatal development (see Akshoomoff et al., 2002, for a review). It has thus become increasingly clear that research efforts should focus on identifying impairments in fundamental skills that emerge and develop early, at least within the first year of life (Cassel et al., 2007; Ibanez, Messinger, Newell, Lambert, & Sheskin, 2008; Rogers, 2009; Young, Merin, Rogers, & Ozonoff, 2009). Moreover, applying a developmental perspective is critical to understanding developmental disorders. This focus can reveal critical links between impairments in social and communicative functioning and development of prior skills on which these capabilities rest.

INTERSENSORY PERCEPTION IN TYPICAL DEVELOPMENT

The world of objects and events provides a continuous flux of changing stimulation to all our senses concurrently. It provides far more stimulation than can be attended or perceived at any given time. Adults are adept at selectively attending to unitary multimodal events that are relevant to their needs and goals (such as the face and voice of a person speaking) and ignoring information that is irrelevant. This presents a fundamental challenge for infants. How do naive perceivers determine which sights and sounds constitute unitary events and which are unrelated? How and when do they develop economical and efficient patterns of selective attention to maximize detection of relevant information and ignore the vast amount of irrelevant sensory variation? An understanding of the nature and trajectory of the typical development of attention and intersensory processing of social and nonsocial events is key to understanding the nature, basis, and timing of atypical development of attention and intersensory processing in children with autism.

Research demonstrates that these skills emerge rapidly across the first 6 months of life (see Bahrick,

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2010; Bahrick & Lickliter, 2002; Gibson, 1969; Gibson & Pick, 2000; Kellman & Arterberry, 1998; Rochat, 1999). Infants establish increasingly efficient patterns of selectively attending to people, faces, voices, and the movements of objects. Across the first 6 months of life, they learn to follow gaze, detect contingencies, engage in dyadic social interactions, and categorize objects and events in a manner consistent with adults (Flavell & Miller, 1998; Flom, Lee, & Muir, 2007; Harrist & Waugh, 2002; Moore, 2006; Mundy & Burnette, 2005; Rakison & Oakes, 2003). What guides these remarkable developmental achievements? Research has demonstrated that one fundamental basis for organizing and guiding selective attention and perceptual development is the detection of intersensory redundancy and amodal properties of stimulation (see Bahrick, 2010; Bahrick & Lickliter, 2002; Lewkowicz, 2000).

Amodal information is information that is not specific to a particular sense modality but can be redundantly specified across more than one sense (auditory, visual, tactile, proprioceptive). Amodal information (e.g., synchrony, rhythm, tempo, intensity) includes changes along three basic dimensions of stimulation: time, space, and intensity (see Bahrick, 2009; Bahrick & Lickliter, 2002). Because all events occupy a particular spatial location, occur across time, and have a characteristic intensity pattern, virtually all events provide amodal information. For example, across the visual and tactile modalities, shape, size, and texture are amodal and can be specified in either modality. Similarly, across auditory and visual stimulation, synchrony, rhythm, duration, tempo, intensity, and changing location can be also be specified by multimodal stimulation. Changes in these parameters of stimulation can also convey emotion (happy vs. sad vs. angry) as well as specify communicative intent (e.g., prosodic cues in speech for approval vs. prohibition).

By detecting amodal information, perceivers attend to unified, multimodal events rather than unrelated streams of auditory, visual, and tactile stimulation. For example, if one detects the temporal synchrony, rhythm, and tempo common to a speaker's face and voice, a unified event—the person speaking—is selectively attended and perceived. Evidence indicates that amodal information, particularly temporal synchrony, provides the "glue" that binds information across the senses and organizes early perceptual development (Bahrick, 2010; Bahrick & Lickliter, 2002; Lewkowicz, 2000). The ventriloquism effect (Alais & Burr, 2004; Radeau & Bertelson, 1977) takes advantage of this principle. By moving the dummy's mouth in synchrony with his speech sounds, the ventriloquist creates a common amodal pattern, giving the impression that the dummy is speaking. In this illusion, temporal synchrony overrides spatial incongruity, illustrating the powerful role of temporal synchrony in "unifying" attention to audiovisual events. Sensitivity to amodal information can also act as a buffer against learning inappropriate associations across the senses. When attending to a pattern of stimulation, such as the sounds of speech, concurrent but unrelated patterns, such as movements of nearby objects or people, are not attended because they typically do not share the same temporal structure as the speech.

Typically developing infants are adept at detecting amodal information even in the first months of life (Bahrick & Pickens, 1994; Lewkowicz, 2000; Walker-Andrews, 1997; see also Lewkowicz & Lickliter, 1994). They can perceive common temporal relations between sights and sounds in both social and nonsocial events. By 2 months, infants detect face-voice synchrony during speech (Dodd, 1979; Lewkowicz, 2010; Lewkowicz, Leo, & Simion, 2010; Morrongiello, Fenwick, & Chance, 1998). A few months later they detect the spectral information common to the shape of the mouth and certain speech sounds (Kuhl & Meltzoff, 1982; Kuhl, Williams, & Meltzoff, 1991) and perceive emotion common to faces and voices (Flom & Bahrick, 2007; Walker-Andrews, 1997). Infants are highly sensitive to infant-directed speech and prefer it over adult-directed speech (Cooper & Aslin, 1990; Fernald, 1985; see Soderstrom, 2007, for a review). This provides exaggerated temporal patterning and intensity and pitch changes across the face and voice, magnifying amodal information. Infants also engage in dyadic synchrony with a social partner, timing their movements and vocalizations in a turn-taking pattern with an adult partner (Jaffe, Beebe, Feldstein, Crown, & Jasnow, 2001; Tronick, 1989; see Harrist & Waugh, 2002, for a review). This highly intercoordinated mutual exchange of sounds, touch, and movement is a foundation for communication and social development (Bahrick, 2010; Jaffe et al., 2001; Rochat, 1999; Tronick, 2007). Infant sensitivity to amodal information in nonsocial events is equally impressive. Infants can relate moving objects with their impact sounds on the basis of temporal synchrony (Bahrick, 1983, 1987, 1988; Lewkowicz, 1992, 1996), their common tempo of action (Bahrick, Flom, & Lickliter, 2002; Spelke, 1979), rhythm (Bahrick & Lickliter, 2000; Mendelson & Ferland, 1982), and collocation (Fenwick & Morrongiello, 1998). They can also detect more fine-grained temporal information such as the temporal microstructure specifying the substance and composition of moving objects (Bahrick, 1983, 1987, 1988, 1992). Thus, intersensory processing skills develop rapidly across infancy, and by 6 months, infants detect and attend to amodal

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information across a wide range of social and nonsocial events.

Research has demonstrated that infants detect amodal information developmentally prior to other (modality-specific) properties of events and that perceptual processing proceeds in order of increasing specificity, from global to increasingly more specific information (Bahrick, 2001; Gibson, 1969). For example, temporal synchrony is detected prior to more specific information about a particular object or event such as its color, shape, or pitch of the sound it makes (Bahrick, 1992, 1994, 2001). This pattern of increasing specificity is a cornerstone of perceptual development (Gibson, 1969). Early detection of amodal information such as temporal synchrony effectively functions as the gatekeeper to further perceptual processing, allowing general information from unitary multimodal events to provide a coherent framework for incorporating more specific detail. This orderly progression, where amodal information leads and modality-specific information is detected somewhat later, promotes perceptual coherence and prevents piecemeal processing where details are perceived before the development of a general event structure (Bahrick, 2010). Intriguingly, deficits in this area are considered to be primary impairments in autism. Individuals with autism are described as having a perceptual-cognitive style characterized by piecemeal processing and "weak central coherence," enhanced detection of detail at the expense of a general context or global framework (Brock et al., 2002; Frith & Happé, 1994; Happé & Frith, 2006; Mottron et al., 2006; Plaisted, 2001).

The development of a surprising variety of skills rests on detection of amodal information, including detection of a speaker in a crowd, perception of emotional expressions, and communicative intent in audiovisual speech, all areas of impairment in ASD. Amodal information, particularly audiovisual synchrony, is also critical for learning the arbitrary relation between words and the objects to which they refer, a cornerstone of language development (Gogate & Bahrick, 1998; Gogate, Walker-Andrews, & Bahrick, 2001; Hollich, Newman, & Jusczyk, 2005). For example, by 7 months, infants learn to pair a speech sound with an object when the object is moved in synchrony with the sound but not if the object is still or moved asynchronously (Gogate & Bahrick, 1998). Infants also learn to distinguish self from other on the basis of amodal visual-proprioceptive information. By 3 to 5 months infants can detect the congruence between the proprioceptive feedback from their own movements and the visual experience of that movement and prefer to look at the movements of other infants over the self (Bahrick & Watson, 1985; Rochat & Morgan, 1995; Schmuckler, 1996). These critical skills emerge from a foundation of detecting amodal information made available by redundancy across the senses.

When the same amodal information (e.g., rhythm, tempo, intensity) is concurrently and synchronously available to multiple senses, this is termed *intersensory redundancy* (Bahrick & Lickliter, 2000, 2002). Intersensory redundancy has been found to be highly salient to humans and animals alike, and this salience appears grounded in fundamental neural principles (see Calvert, Spence, & Stein, 2004, for a review). Most importantly, intersensory redundancy promotes heightened neural responsiveness as compared with the same information presented to each modality alone (Stein & Meredith, 1993). The intersensory redundancy hypothesis (IRH) (Bahrick & Lickliter, 2000, 2002), a model of early selective attention, provides a framework for understanding how and under what conditions attention is allocated to different properties of stimulation (amodal vs. modality specific), how salience hierarchies are created, and how this guides perceptual development.

According to the IRH, highly salient intersensory redundancy recruits selective attention to multimodal events and their redundantly specified properties at the expense of other properties of stimulation. Thus, selective attention to amodal properties (rhythm, tempo, intensity) is enhanced in multimodal stimulation as compared with these same properties experienced in unimodal stimulation. This is termed *intersensory facilitation*. Redundancy across the senses makes amodal properties stand out from the background of other properties of stimulation. In contrast, when the same events are experienced unimodally, such as hearing speech or watching a person's actions, modality-specific properties (such as color and pattern of the face and clothes or pitch and timbre of the voice) become more salient, in part because intersensory redundancy is not available to compete for and capture attention.

Predictions of the IRH have been supported across a wide range of infant studies. For example, research has found that younger infants detect the rhythm and tempo of a toy hammer tapping in bimodal redundant stimulation (synchronous sights and sounds of impact) but not in unimodal, nonredundant stimulation (when they can see or hear the hammer tapping alone, or when the sights and sounds of the hammer are asynchronously presented) (Bahrick, Flom, et al., 2002; Bahrick & Lickliter, 2000, 2004). A few months later in development they can detect the rhythm and tempo in both redundant bimodal and nonredundant unimodal stimulation (Bahrick & Lickliter, 2004). In contrast, in unimodal visual stimulation, when redundancy is not competing for attention, infants detect visual properties including the orientation of the hammer's motion (upward vs. downward) but not until later in development do they detect its orientation in bimodal synchronous stimulation where intersensory redundancy focuses attention on the amodal properties of rhythm and tempo (Bahrick, Lickliter, & Flom, 2006; Flom & Bahrick, 2010). Similar results have been found for infant detection of amodal properties in social events. For example, emotion and prosody (based on amodal redundant information) are detected at the expense of information supporting face and voice identification (based on unimodal nonredundant information) in multimodal stimulation in very early development (Castellanos & Bahrick, 2008; Flom & Bahrick, 2007; Shuman & Bahrick, 2007; Vaillant-Molina & Bahrick, in press). This attentional trade-off between detection of amodal and modality-specific properties as a function of type of stimulation guides perceptual development in an orderly progression.

Thus, infant sensitivity to intersensory redundancy in multimodal stimulation promotes the development of an attentional salience hierarchy where amodal properties recruit attention prior to other properties of events. Attention to properties of objects and events proceeds in order of attentional salience with the most salient properties processed first and other properties processed later in exploratory time (Bahrick, 2010; Bahrick, Gogate, & Ruiz, 2002; Bahrick & Newell, 2008; Craik, 2005; Craik & Byrd, 1982; Craik & Lockhart, 1972). With age and experience with events, infants' processing skills become more efficient, and they progress though attentional salience hierarchies more rapidly. Given that most events are multimodal, on balance, this hierarchy also creates a processing priority for amodal properties over modality-specific properties of stimulation across development. This salience hierarchy is important for organizing and regulating perceptual development by ensuring that meaningful, coordinated patterns of sensory stimulation "pop out" amid the vast amount of concurrent stimulation and by allowing general event contexts and global structure to provide a framework for perception of specific details (see Bahrick, 2010; Bahrick & Lickliter, 2002). In effect, this salience hierarchy bootstraps the development of coordinated, coherent perceptual processing, preventing piecemeal processing and weak central coherence that characterize perceptual processing in ASD. Thus, the fundamental processes that promote coherent perceptual processing develop in early infancy.

Moreover, salience hierarchies exert the greatest influence when attentional resources are most limited, such as in early development, under conditions of competing stimulation, or when tasks are difficult in relation to the skills of a perceiver (see Bahrick, 2010; Bahrick & Lickliter, in press; Bahrick, Lickliter, Castellanos, & Vaillant-Molina, 2009). Thus, although these attentional biases are most evident in early development, they are likely to be evident across the life span, particularly under conditions of high cognitive load, task difficulty, and attentional demands.

Because children with autism show a "social orienting impairment" (Dawson et al., 1998, 2004; Mundy & Neal, 2001), it seems critical to understand how and when typical *social orienting* emerges and develops. Although there are a variety of hypotheses for its basis, it is generally agreed that social stimuli hold a special status for young infants and that even very young infants show a preference for social over nonsocial events (e.g., Farah, Wilson, Drain, & Tanaka, 1998; Gauthier & Nelson, 2001; Legerstee, 1992; Morton & Johnson, 1991; Valenza, Simion, Cassia, & Umiltà, 1996). Despite this widely held belief, little is known about how and when this preference emerges and develops and what conditions promote its development.

We have proposed that the salience of intersensory redundancy plays a fundamental role in this developmental process (Bahrick, 2010; Bahrick, Todd, et al., 2009). Compared to nonsocial events, social events provide extraordinary amounts of intersensory redundancy that likely recruit and maintain attention to faces, voices, gesture, and audiovisual speech. According to this view, attention to social events is a result of experience interacting with the social world, abstracting increasingly finer levels of intersensory redundancy, and is thus refined and shaped across development. Accordingly, infants should demonstrate a gradual emergence of attention to social events across the first weeks and months of life, with heightened interest in social events that provide the greatest amount of intersensory redundancy. Surprisingly, little research has systematically investigated the emergence of attention to social vs. nonsocial events across infancy.

As a first step in this direction we assessed the nature and development of infant preferences for social versus nonsocial events as a function of whether or not they provided intersensory redundancy across the ages of 2 to 8 months. Data from more than 700 infants tested in infant control habituation procedures in our lab over the past decade were recoded and analyzed (Bahrick, Todd, et al., 2009). Infants had received either social (i.e., women speaking using infant-directed speech) or nonsocial events (i.e., objects striking a surface) under conditions of either redundant audiovisual stimulation (with natural synchronous sounds) or nonredundant unimodal visual stimulation (silent). Findings indicated that younger infants showed longer looks, more

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processing time and less disengagement than older infants and that, overall, infants showed greater attention to events that provided intersensory redundancy than those that did not. Moreover, significant differences between attention to social and nonsocial events emerged across development, including longer looks, more processing time, and less disengagement from social events. Attention to social events providing intersensory redundancy was maintained across 2 to 8 months of age, whereas attention to nonsocial events and events providing no redundancy declined.

These findings indicate a gradual emergence of enhanced attention to social, audiovisual speech events over both nonsocial object events and unimodal visual social events between 2 and 8 months of age. They are consistent with the view that social orienting emerges gradually across infancy as a function of intersensory redundancy. Further studies are currently under way to assess the contributions of overall amount of stimulation and intersensory redundancy to social orienting. Together, these findings are consistent with the view that intersensory processing and the salience of amodal properties of stimulation provide a fundamental basis for the emergence and development of attention to social events across infancy.

INTERSENSORY PERCEPTION IN ATYPICAL DEVELOPMENT

Because of the critical role of intersensory processing in the typical emergence of social orienting and the deficits in social orienting and related skills seen in children with autism, we explore here intersensory processing disturbance as one important basis for the fundamental impairments in social and communicative functioning in autism. Social events provide an extraordinary amount of intersensory redundancy and are typically more variable and complex than nonsocial events (Adolphs, 2001; Dawson et al., 2004); therefore, an impairment in intersensory processing skills would typically impact social attention to a greater extent than attention to nonsocial events. Decreased intersensory processing efficiency could reduce the salience and processing priority given to social events. Even a small difference in intersensory processing skill could amplify across development, resulting in substantial differences in overall attention to social events as well as producing cognitive differences in later development (also see Bahrick, 2010; Mundy & Burnette, 2005).

How might impaired or imprecise detection of intersensory redundancy affect perception of multimodal events and, in turn, alter developmental trajectories? Because sensitivity to amodal information is both the glue that binds information across the senses and a buffer against learning inappropriate associations across the senses, these processes would be compromised and become more effortful than in typical development. First, even small impairments in detecting synchrony and other amodal properties in infancy and beyond would compromise selective attention to unitary multimodal events.

This would impair audiovisual localization (e.g., the face of a speaker “pops out” in a crowd due to audiovisual synchrony), and localizing events in the context of competing stimulation would be more difficult, requiring more time or alternative strategies. Imprecise synchrony detection would also cause multimodal events to seem more disjoint and characterized by more loosely connected streams of auditory, visual, tactile, and proprioceptive stimulation. Moreover, stimulation from concurrent but unrelated events (e.g., a fan blade turning; a meaningless action) may be more easily confused or mistakenly blended with focal events (e.g., voice of a person), requiring more time and effort to sort out. These tendencies would promote processing of events consistent with reports of piecemeal processing and weak central coherence (Happé & Frith, 2006).

Second, in typical development, *unitization* (similar to binding) of synchronous auditory and visual stimulation effectively simplifies and reduces the overall amount of experienced stimulation (see Spear & McKinzie, 1994). Thus, typically developing perceivers detect invariant patterns across synchronous streams of auditory and visual stimulation such as audiovisual speech or music. These patterns are normally perceived as unitary rhythmic patterns rather than patterns in separate modalities. In contrast, altered synchrony detection could impair *unitization*, resulting not only in reduced coherence and integration across modalities but also in the experience of a greater overall amount of perceived stimulation and complexity. In the case of complex multimodal stimulation, such as social interaction, for individuals with imprecise intersensory skills, the sheer amount of dynamically changing multimodal stimulation could be experienced as confusing, aversive, and well beyond the optimal range of sensory stimulation. This could discourage perceptual processing and social engagement, promoting social orienting impairments typically seen in ASD.

Third, imprecise detection of intersensory redundancy could alter the typical salience hierarchy where amodal information is detected prior to modality-specific information, both across development and within an episode of exploration. This typical sequence, which effectively simplifies sensory stimulation and helps to organize perception of detail within the context of a

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general event or object structure, would be disrupted. Alteration of this salience hierarchy would also promote piecemeal processing, where modality-specific detail may be attended prior to perceiving a unitary event, again leading to an abundance of loosely connected, poorly integrated information as the focus of attention.

Fourth, impaired detection of intersensory redundancy would also lead to enhanced unimodal visual and/or auditory processing in some domains. Decreased unitization and altered salience hierarchies would enhance attention to modality-specific detail and promote processing of local over global information, consistent with observations of weak central coherence and enhanced perceptual functioning (Happé & Frith, 2006; Mottron et al., 2006). For example, detail such as the appearance of the clothing, jewelry, or the pitch or pattern of a voice may be attended without the general social/communicative context of the event. At the same time, an altered unisensory profile in which the modality-specific properties of events were selectively attended and processed at the expense of amodal properties, could lead to further atypical intersensory processing, in a mutually reinforcing cycle.

In sum, it is apparent how alterations in intersensory processing, a cornerstone of social orienting and interaction, could significantly contribute to impairments in social orienting and interaction in ASD. Multimodal stimulation would likely be experienced as more complex, less unitized and cohesive, and overstimulating, shifting processing resources toward unisensory information and modality-specific detail. These alterations of attention would decrease infant responsiveness to typical social stimulation (i.e., social orienting impairments), in turn eliciting altered social and communicative input from adult caretakers. Thus, further social, emotional, and communicative development, which all rely on social interaction, affective exchange, and joint attention, would be compromised and in turn would impair subsequent language, social, and cognitive development (see Bahrick, 2010; Mundy & Burnette, 2005). Because development is a self-organizing, interactive system, where skills in one stage promote the input and provide the basis for interaction in subsequent stages, small differences in intersensory functioning can amplify and continue to feed back across development, creating a widening gap between typical and atypical developmental trajectories.

Evaluating Evidence for Intersensory Processing Disturbance in Autism

To what extent and under what conditions do individuals with ASD show atypical processing of multimodal events compared with TD and/or non-ASD developmentally delayed (DD) children? Although a growing research effort on this topic (see Iarocci & McDonald, 2006, for a review) now reveals a variety of intersensory impairments in autism, there is little understanding of the nature, basis, and extent of these impairments, nor is there agreement regarding the conditions that promote altered intersensory processing in autism. To evaluate evidence for an intersensory processing disturbance in ASD, we review findings of audiovisual processing of social and nonsocial events from four areas of focus, each characterized by different methods and addressing somewhat different research questions: (1) intersensory matching of auditory and visual stimulation from speech, affective events, and nonsocial events, (2) intersensory integration in audiovisual speech perception as measured by tasks such as the McGurk and speech in noise tasks, (3) the intersensory temporal integration window, and (4) intersensory perception and attentional disengagement. Because of space constraints we have focused our review on audiovisual intersensory functioning, the area of greatest research focus. However, studies investigating other modalities, including proprioceptive-visual functioning (Gergely, 2001) and mirror neuron system functioning (a multisensory neural network that responds to both observed and performed actions) (see Gallese, Rochat, Cossu, & Sinigaglia, 2009; Oberman & Ramachandran, 2007; Williams, Whiten, & Singh, 2004), also provide evidence for intersensory impairments.

In our review we emphasize a number of factors that impact conclusions drawn from intersensory research, including task complexity (simple vs. complex) and stimulus type (social vs. nonsocial). We explore whether intersensory processing disturbances are more pronounced in social than nonsocial events. Because social events are typically more complex and variable than nonsocial events and provide exaggerated intersensory redundancy, a general intersensory processing disturbance would be expected to lead to greater impairments in processing social events than nonsocial events. Compared with typically developing controls, individuals with ASD may show comparable processing of simpler, *low-level stimuli* (including those in a variety of nonsocial events) but impaired processing of more complex stimuli, including social events (Bertone et al., 2005; Minshew & Hobson, 2008). In addition, where possible, we evaluate evidence of intersensory processing disturbances in light of changes in unisensory auditory and visual function. We ask if there is evidence of compromised unisensory processing and, if so, are multisensory processing deficits found once these unisensory processing deficits have been controlled? Given the

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tight link between the two, evidence that intersensory processing disturbances are a fundamental impairment rather than solely the result of unisensory impairments is important for understanding underlying mechanisms of development.

Intermodal Matching in ASD

A popular method for studying intersensory perception in early development is the intermodal preference procedure (Bahrick, 1983, 1987; Spelke, 1976). In this method, two side-by-side visual events are presented with an accompanying soundtrack that matches one of the events (e.g., is synchronous or shares the same tempo or rhythm) and is incongruent with the other event (e.g., out of synchrony or displays a different tempo or rhythm). Evidence of auditory-visual intermodal matching is found in 3- to 4-month-old typically developing infants (Dodd, 1979; Spelke, 1976) and is indicated by a proportion of total looking time to the sound synchronous display that is significantly greater than chance (50%). The intermodal preference procedure requires no verbal skills and places low cognitive demands on the child, making it ideal for testing intersensory integration in nonverbal participants. This task, however, does not easily lend itself to tests of unimodal functioning, and thus, unisensory measures are typically not included.

Several studies have demonstrated intersensory matching in individuals with ASD. Children and adolescents with ASD showed preferential looking to the visual display of a nonsocial event that matched a soundtrack (Loveland et al., 1995; Walker-Andrews, Haviland, Huffman, & Toci, 1994) as well as to faces and voices that were matched for affective expressions (Haviland, Walker-Andrews, Huffman, & Toci, 1996; Loveland et al., 1995). Klin, Lin, Gorrindo, Ramsay, and Jones (2009) found reduced preferences for point displays of human actions, suggesting decreased interest in social events, but looking was positively correlated with degree of audiovisual synchrony. In contrast, TD children preferred socially relevant stimuli regardless of degree of synchrony. Together, these findings suggest that individuals with autism show sensitivity to audiovisual synchrony and increased attention to higher levels of synchrony.

Intersensory impairments have also been documented. Using measures of event-related potentials, Magnée, de Gelder, van Engeland, and Kemner (2008a) found evidence of intact early perceptual processing of facial expressions but impaired audiovisual processing of fearful faces and voices in ASD as compared with TD adults. In intermodal matching behavioral studies, Loveland et al. (1995) found that children with ASD were impaired in detecting face-voice affective correspondence (with synchrony controlled) compared to DD controls (matched for verbal and mental age), and both groups showed improved performance when temporal synchrony was available. In contrast, the two groups showed no difference in detecting intermodal correspondence between inanimate objects and their sounds. This study thus suggests some sensitivity to face-voice synchrony and greater intersensory processing deficits for social as opposed to nonsocial events in ASD. It should be noted, however, that it is difficult to draw conclusions about the basis of these differences, as social and nonsocial events typically differ in terms of stimulus complexity, predictability, amount of stimulation, and, in the above study, synchrony. Although many differences are inherent in comparisons of social versus nonsocial events, some studies have made an effort to equate or assess task complexity and predictability.

For example, Bebko, Weiss, Demark, and Gomez (2006) attempted to address this issue by presenting both simple and complex social events along with nonsocial events. They assessed whether children with ASD showed evidence of integrating audio and visual information on the basis of temporal synchrony compared to TD and DD controls matched on adaptive functioning. Two identical side-by-side films of a nonsocial event (e.g., Mousetrap game), a simple social event (woman counting), or a complex social event (woman telling a story) were presented with their accompanying soundtracks that were temporally synchronous with one of the films. All groups showed significantly greater than chance looking to the sound-synchronized displays of the nonsocial event. In contrast, only DD and TD children looked significantly more to the sound-synchronized social events (both simple and complex linguistic), whereas children with ASD showed chance responding. Further, a significant negative relationship between time spent looking away from the complex linguistic social events and linguistic abilities in children with ASD emerged. Children with ASD thus showed impaired audiovisual matching on the basis of temporal synchrony for social but not nonsocial events.

These findings are consistent with an intersensory processing impairment in ASD, primarily affecting social events. No measures of unimodal processing (audio or visual only) were taken, leaving open the question of whether the impaired multisensory processing could be linked to impaired unisensory processing abilities. Further, Bebko et al. (2006) reported no differences in time spent looking away from social versus nonsocial events. Future studies should also assess time

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spent looking to the social versus nonsocial stimuli to determine the extent to which differences in matching could be associated with differences in looking time to social versus nonsocial events.

Intersensory Integration in Speech in ASD

Research on intersensory integration in speech has typically assessed the extent to which visual speech influences the perception of auditory speech in individuals with ASD as compared with typical development, and the conditions under which evidence for impairments versus integration are most apparent. At least two procedures for assessing audiovisual integration of speech events have been used: the McGurk effect and "speech-in-noise" tasks. Both tasks can also be used to measure unimodal visual processing when the auditory stimulation is silent (lipreading), or unimodal auditory processing in the absence of a dynamic visual display.

In the McGurk task (MacDonald & McGurk, 1978; McGurk & MacDonald, 1976), evidence of audiovisual integration is inferred from the perception of an illusory percept (the McGurk effect). For example, when the visual display of a speech sound (e.g., seeing /ga/) is mismatched with a temporally synchronous soundtrack (e.g., hearing /ba/), the resulting illusion represents a synthesis of the visual and audio information (e.g., perceiving /da/). Such a synthesis is considered to reflect the underlying integration of the visual and auditory cues. Even young infants show the McGurk effect (Burnham & Dodd, 2004; Desjardins & Werker, 2004; Rosenblum, Schmuckler, & Johnson, 1997). Overall, children and adolescents with ASD report perceiving audiovisual illusions in the McGurk task, but they perceive significantly fewer illusions (e.g., approximately 40% less) than controls (de Gelder, Vroomen, & Van der Heide, 1991; Mongillo et al., 2008; Williams, Massaro, Peel, Bosseler, & Suddendorf, 2004), suggesting impaired intersensory integration. However, Williams, Massaro, et al. (2004) found that impaired integration was attributable to impaired unimodal visual processing and that intersensory performance improved following training in lipreading. This demonstrated successful transfer of unimodal visual skills to facilitate intersensory processing in ASD (see also Massaro & Bosseler, 2003). In contrast, de Gelder et al. (1991) found no differences in lipreading between ASD and control groups and demonstrated impaired audiovisual integration and impaired face processing in ASD. Magnée, de Gelder, van Engeland, and Kemner (2008b) found no impairments in early, low-level integration but significant impairments in late, phonological audiovisual integration according to measures of event-related potentials. Further, although few studies have compared intersensory functioning for speech versus nonsocial stimuli, one study (Mongillo et al., 2008) found intersensory impairments for social tasks (McGurk and audiovisual gender matching) but no impairments for nonsocial tasks (audiovisual matching of ball size and composition). Despite inconsistencies across studies, in summary these findings demonstrate that children with ASD show evidence of intersensory processing of audiovisual speech (e.g., McGurk illusions; unimodal-bimodal transfer effects) but that these intersensory abilities as well as unimodal processing may be impaired when compared with TD controls (typically matched for verbal ability and/or mental age). These findings also indicate a close connection between unisensory and intersensory abilities, with deficits in unisensory processing having clear effects on intersensory integration, but also that the demonstrated intersensory deficits may extend beyond those predicted on the basis of unisensory function.

Speech-in-noise tasks assess integration of audiovisual speech by presenting the visual image of a speaker synchronized with auditory speech embedded in background noise. The level of background noise relative to the speech signal can be manipulated and signal-to-noise ratios (SNRs) and individual thresholds determined. Typically developing individuals show enhanced identification of the speech signal (detection at lower SNRs) when the visual stimulus is present, indicating audiovisual integration. Smith and Bennetto (2007) assessed intersensory and unimodal speech processing in adolescents with ASD versus TD controls. They found that individuals with ASD required larger SNRs (louder speech signals compared to background noise) than TD controls, suggesting less benefit from the visual stimulus (impaired integration). Unimodal visual (lipreading) impairments were also found. However, once these unisensory effects were controlled, the deficits in audiovisual speech processing were still evident and were thus attributed to a unique intersensory deficit, above and beyond the unisensory deficits.

It is clear from all the above findings that individuals with autism show evidence of audiovisual integration in speech as well as evidence of impairments in audiovisual integration. However, the basis for intersensory impairments is still unclear. The extent to which intersensory impairments arise from differences in unimodal processing (lipreading, attention to the face, auditory speech detection), intersensory processing, or both is not yet known. As described above, several studies have shown clear differences in intersensory processing above and beyond those of unimodal processing differences (de Gelder et al., 1991; Magnée et al., 2008b; Q

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Smith & Bennetto, 2007). Others find unimodal differences and/or multisensory differences but have not assessed their relative contributions, and one study found multisensory differences directly attributable to unimodal differences (Williams, Massaro, et al., 2004). In addition, given that social orienting impairments (Dawson et al., 1998, 2004) and impairments in face processing (Dawson et al., 2005; de Gelder et al., 1991; Schultz, 2005) characterize ASD, decreased attention to the facial stimuli in the McGurk and speech in noise studies by individuals with ASD could impair performance in both the visual and audiovisual conditions. Reduced attention to and processing of the face thus could be both a basis for unisensory impairments and an outcome of unisensory and multisensory impairments. Consistent with this view, intersensory speech processing improvements following training in lipreading were found (Massaro & Bosseler, 2003; Williams, Massaro, et al., 2004), possibly resulting from enhanced attention to the face, unimodal to multimodal transfer of learning, or both. Although studies attempt to ensure that subjects attend to face stimuli (Magnée et al., 2008a; Williams, Massaro, et al., 2004), little relevant data are generally reported. Given the close link between unisensory and multisensory functioning, it is important for future studies to quantify and directly compare visual attention measures across ASD and control groups. Further, studies of speech processing typically have not included nonsocial comparisons (but see Mongillo et al., 2008), and thus the extent to which impairments are enhanced for social stimuli as compared with nonsocial stimuli is not known. Thus, taken together, the findings of audiovisual speech perception research provide evidence for intersensory impairments in ASD, typically along with reduced sensitivity to visual speech information, and point out the close associations among intersensory impairments, unisensory impairments, and visual attention to faces.

Audiovisual Temporal Integration Window in ASD

Another multisensory illusion, the *flash-beep task*, can be considered to be a nonsocial analogue to the audiovisual speech tasks. It assesses the influence of auditory stimulation (beeps) on the perception of visual stimulation (flashes of light). In this procedure, when two beeps are presented along with a single flash, respondents typically report perceiving an illusion of two visual flashes (Shams, Kamitani, & Shimojo, 2000). Van der Smagt, van Engeland, and Kemner (2007) reported that individuals with ASD also perceived the illusion of a second flash and that the number of second flashes reported was not significantly different from TD controls, indicating intact intersensory processing. However, this illusion is dependent on the stimulus onset asynchrony (SOA) between the flash and the beeps; as these become more temporally disparate, the illusion weakens. Given the fundamental role of temporal processing and unitization of audiovisual stimuli for both social and nonsocial event perception in typical development, manipulating the temporal parameters of these stimuli is of particular significance.

Foss-Feig et al. (2010) presented the flash-beep stimuli at different SOAs to assess differences in the *temporal binding window*, the time frame across which auditory and visual stimuli are integrated, for 8- to 17-year-old children with ASD as compared with mental-age-matched TD controls. Children with ASD reported perceiving the flash-beep illusion at greater SOAs (±300 msec) than TD controls (±150 msec). Thus, children with ASD showed evidence of successful audiovisual integration, although across a much larger temporal processing window than TD children. This finding suggests that individuals with ASD may show more extensive but less temporally precise audiovisual integration.

This difference could have profound implications for perception. Less temporally precise and more extended temporal binding of visual and auditory stimulation would particularly impair audiovisual processing in *noisy environments*, those with multiple concurrent multimodal events, such as social contexts (also see related evidence of reduced distracter effects as a function of greater attentional load in TD [Lavie, 1995, 2005] and ASD [Remington, Swettenham, Campbell, & Coleman, 2009]). For example, it could impair audiovisual localization (of a speaker in a crowd), decreasing the "pop out" effect and reducing unitization, leading to mistaken blending of unrelated concurrent auditory and visual stimuli, and promoting more disjointed or piecemeal processing of auditory and visual stimulation. This could alter typical salience hierarchies (amodal prior to modality-specific processing). In naturalistic social environments there would be many instances of *accidental synchrony* between unrelated streams of auditory and visual stimulation. Thus, noisy environments would likely be confusing and/or aversive to individuals with a wider, less precise temporal binding window. In an effort to reduce uncertainty and overall perceived amount of stimulation, individuals with a wider temporal window may show increased attentional selectivity to simpler, more predictable patterns, including self-contingent stimulation or tightly coupled patterns of motor, auditory, and/or visual stimulation. In contrast, in an uncluttered, quiet environment with low levels of stimulation and single audiovisual events (with little chance of accidental synchrony from unrelated events), audiovisual integration and intermodal learning may be enhanced, facilitating unitization and effectively simplifying multimodal stimulation. In this case, more predictable, tightly coupled patterns of multimodal stimulation may be more attractive and of greater interest to individuals with a wider temporal binding window. Of great interest for future research would be uncovering the nature of changes in the temporal binding window across development in children with ASD. It is known that infants have a wider window than adults (Lewkowicz, 1996, 2010), and with experience the window becomes more precise and narrowed to conform to the typical parameters of auditory-visual onset asynchronies in social and nonsocial events. Thus, the wider window observed in ASD suggests the possibility of less experience-dependent narrowing in ASD than in typical development.

A wider, less precise intersensory processing window may also contribute to the repetitive and stereotyped behaviors observed in some individuals with ASD, such as arm waving, twirling, producing repetitive sound sequences, and spinning or banging objects (Lewis & Bodfish, 1998; Richler, Huerta, Bishop, & Lord, 2010; Turner, 1999). Repetitive behaviors could serve to hone and shape the temporal integration window across visual, auditory, proprioceptive, and tactile stimulation. Repeated experience with precise synchrony across different forms of stimulation facilitates coupling of multimodal systems and likely promotes experience-dependent narrowing of the temporal integration window. Such behaviors may include perception-action loops involving recurrent, predictable coupling of motor, auditory, visual, and/or tactile stimulation, similar to that described by Piaget's primary circular reactions (Piaget, 1952). Primary circular reactions appear similar in form to the repetitive behaviors and patterns of self-stimulation observed in some individuals with ASD. Such multimodal perception-action loops are considered a cornerstone of cognitive development (Piaget, 1952) and generate stable, predictable intersensory patterns that link perception and action across time and space. For example, each time the infant opens his hand or shakes a rattle, he can simultaneously feel, see, and/or hear the perfectly contingent and synchronous proprioceptive-visual/auditory stimulation. It is now appreciated that multimodal perception-action loops drive neural change and connectivity (see Ghazanfar & Schroeder, 2006; Sheya & Smith, 2010; Smith & Thelen, 2003) serving to integrate sensory and motor systems. Thus, individuals with ASD may be drawn to repetitive behaviors, in part, because they provide more predictable and well-integrated multisensory stimulation in an environment abounding with imprecisely and unpredictably coupled patterns of sensory stimulation. Participating in simple repetitive perception-action loops may help some children with ASD compensate for an atypically wide temporal binding window and a reduced focus on amodal and global pattern information by creating simple, salient, self-generated patterns. Attending to simple synchronized patterns may in turn gradually facilitate experience-dependent narrowing of the temporal binding window across development. However, this narrowing would likely occur at a much slower pace than in typical development.

Intersensory Perception and Attentional Disengagement

Impaired attention disengagement, sometimes referred to as sticky attention or overselectivity, is known to be a fundamental characteristic of autism (Landry & Bryson, 2004; Swettenham et al., 1998; Wainwright & Bryson, 1996). Although its basis is unclear, some propose that a domain general "disengagement deficit" underlies the development of ASD (Courchesne, Chisum, & Townsend, 1994; Landry & Bryson, 2004). It affects areas as basic to social interaction as orienting to one's own name (Dawson et al., 2004) and joint attention (Mundy & Burnette, 2005). However, experimental research on this topic has focused primarily on unimodal visual stimulation using primarily static images, assessing disengagement from a central visual target to a peripheral one using a modified spatial orienting task (see Johnson, Posner, & Rothbart, 1991). Although we have learned a great deal about visual attention using this approach, it is not known how such findings might translate to the natural environment of dynamic, multimodal events.

We propose that a disturbance in intersensory processing would reduce the attentional salience of intersensory redundancy and lead to significant impairments in orienting and disengagment of attention to unified multimodal events, particularly in complex environments. Impaired integration and/or a wider temporal binding window would likely impact social events to a greater extent than nonsocial events given their greater complexity and faster pace, making social stimulation more challenging and cognitively demanding for individuals with ASD.

We recently developed a paradigm to extend investigations of attention disengagement and orienting to more naturalistic, dynamic, multimodal events (Bahrick, Todd, Vaillant-Molina, Sorondo, & Ronacher, 2010; Newell, Bahrick, Vaillant-Molina, Shuman, & Castellanos, 2007). The Multisensory Attention Assessment

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Protocol (MAAP) presents videos of naturalistic social and nonsocial events in a procedure that blends features of the three-screen visual orienting tasks (Johnson et al., 1991; Landry & Bryson, 2004) and the intermodal preference method (Bahrick, 1983, 1987; Spelke, 1976) and is easily used with infants and children. In this paradigm, trials consisting of a silent, dynamically changing central visual event followed by two side-by-side events (along with a soundtrack synchronized with one peripheral event) are presented. In some trials, the central event is terminated just prior to the onset of the peripheral events (orienting trials), whereas in other trials, the central event stays on along with the peripheral events (disengagement trials). Intermodal matching and latency to orient and disengage to the audiovisual events are assessed. Separate blocks of trials present social versus nonsocial events.

Findings of our preliminary study demonstrate that relative to TD children, children with ASD showed impairments in disengaging and maintaining attention to social events when there was competing stimulation from the concurrent central event but were less impaired in disengaging and attending to nonsocial events. Also, in the absence of competing stimulation, attention switching (orienting) did not differ from that of controls (Newell et al., 2007). Further, children with ASD as compared with TD controls showed decreased attention (more looking away, shorter looks, and less looking time) to social, but not nonsocial, events (Bahrick, Todd, et al., 2009). They also showed impaired intermodal matching compared to TD controls, demonstrating no preference for the sound-synchronous over asynchronous social or nonsocial events (Bahrick et al., 2010). Further, attention to social events was found to be negatively related to symptom severity in autism, with less looking to social events correlated with more symptoms.

Together, these findings indicate greater attentional impairments for social events (which are more complex and amplify intersensory redundancy) than for nonsocial events, particularly in the context of competing stimulation. They suggest that impaired intersensory functioning is one likely basis for the development of disengagement deficits in ASD. This domain-general impairment would have its greatest impact on attention in “noisy” environments and for complex events such as social events, in which attentional resources are challenged.

SUMMARY AND CONCLUSIONS

Evidence across the diverse topics reviewed in this chapter, including intermodal matching, audiovisual speech perception, the temporal integration window, and attention disengagement, indicates that children and adolescents with ASD show a significantly altered intersensory processing profile when compared with TD children. Despite inconsistencies across methods and findings, a number of general conclusions have emerged, and these set the stage for future study.

First, individuals with ASD show relatively intact intersensory processing abilities across a number of domains, particularly for nonsocial and simple events. For example, they showed no impairments in intermodal matching of nonsocial events in several studies (Bebko et al., 2006; Loveland et al., 1995; Mongillo et al., 2008; Walker-Andrews et al., 1994), evidence of intact audiovisual speech integration for simple syllables in multimodal as compared to unimodal control conditions in two studies (Massaro & Bosseler, 2003; Williams, Massaro, et al., 2004), and no difference in attentional orienting to audiovisual events in the absence of competing stimulation (Newell et al., 2007). Second, individuals with ASD show impaired intersensory functioning for more complex events, particularly those with a social context. For example, they showed deficits in intermodal matching for simple and complex social events but no deficits for nonsocial events (Bebko et al., 2006), impaired audiovisual speech integration as indexed by a reduced McGurk effect (de Gelder et al., 1991; Mongillo et al., 2008), impaired audiovisual processing for speech but not nonsocial events (Mongillo et al., 2008; Smith & Bennetto, 2007), and greater disengagement deficits to look at social as compared with nonsocial events (Newell et al., 2007). We suggest that individuals with ASD typically show the greatest impairments in processing social events because social events are inherently more multimodal, unpredictable, and provide greater amounts of temporal variability and intersensory redundancy than nonsocial events (Bahrick, 2010). Third, children with ASD also show unisensory impairments that necessarily limit intersensory functioning. For example, reduced lipreading (Williams, Massaro, et al., 2004), face processing (Dawson et al., 2005; de Gelder et al., 1991; see Schultz, 2005), and detection of speech in noise (Smith & Bennetto, 2007) have all been found in ASD. Fourth, children and adolescents with ASD appear to have a larger temporal window for integrating audiovisual events (Foss-Feig et al., 2010), suggesting less precise and more temporally extended integration. This could lead to impaired binding of auditory, visual, and proprioceptive stimulation, impaired selective attention to sound-specified events in the context of accidental synchrony from competing stimulation, piecemeal processing of multisensory stimulation, and amplification of social

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orienting impairments across development. On the other hand, a larger window may promote attention to and participation in simple, repetitive perception-action loops that provide more easily detectable patterns of synchrony, enhancing links among auditory, visual, and motor stimulation. In sum, individuals with ASD appear to show atypical processing of multimodal stimulation, particularly for complex social events, and more typical processing of simple and nonsocial events, with the greatest impairments in the context of competing stimulation. This may both underlie and contribute to social orienting impairments in autism.

Based on the available evidence, however, the underlying mechanisms resulting in the autism phenotype(s) are difficult to distill. Given impairments in unisensory processes, including reduced attention to the face and speech, it is difficult to determine the extent to which intersensory impairments derive from unisensory deficits and the extent to which multisensory processes are uniquely affected. Sorting out the basis of impairment is a challenge for future research.

Regardless of the basis, impaired intersensory functioning would be expected to have a wide cascade of consequences across development. Intersensory redundancy is highly salient and organizes and constrains typical perceptual development. It is the glue that binds stimulation across the senses, functioning as the gatekeeper for further processing of unitary events, and promoting the development of salience hierarchies such that attention to general information precedes acquisition of more specific detail. Intersensory processing also biases attention to social events. Impaired intersensory functioning would affect all of these domains underlying social orienting impairments and cascade to other skills that rely on intersensory functioning, including joint attention, social interaction, and language learning, and in turn amplify disturbance in later social and communicative functioning (Bahrick, 2010; Mundy & Burnette, 2005). Moreover, we have also argued that impaired intersensory processing would lead to repetitive behaviors, serving to link sensory and motor patterns, similar to the role of primary circular reactions observed in early development (Piaget, 1952). We thus conclude that an intersensory processing disturbance could affect all three domains of impairment that define ASD: social, communication, and repetitive behaviors.

These findings have significant potential implications for intervention. Because individuals with ASD appear to have intact intersensory processing capabilities for simple events, these skills could serve as an anchor and basis for intervention. Training attention to achieve more precise multimodal synchrony detection could promote more typical intersensory processing and, in turn, generalize to more complex social events, cascading across a wide variety of related domains of impairment.

Developing a deeper understanding of the role of intersensory impairments in ASD poses multiple challenges for future research. Investigating developmental trajectories for intersensory processing impairments will be critical to enhancing our understanding of mechanisms, causal relations, and implications for intervention. Few studies have taken a developmental perspective. Teasing out the role of unisensory versus multisensory impairments within single research designs (including differential attention and processing of faces and speech) will also enhance our understanding of underlying mechanisms. Considering frequent confounds across studies, such as task difficulty and complexity for social and nonsocial events, would facilitate translation of findings across studies. Experimentally manipulated levels of intersensory redundancy would help to clarify the nature of relations between intersensory processing and attention deficits in autism. Assessing relations between intersensory impairments and symptom severity would provide insight into individual differences and the specificity of intersensory impairments to ASD. Finally, bringing together multiple levels of analysis, including genetic, neural, and physiological, to converge with findings of behavioral studies will also be critical to developing a deeper understanding of the interrelated system of influences underlying intersensory functioning and impairments.

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