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THE IMPACT OF SYNCHRONIZED TACTILE STIMULATION ON JOINT ATTENTION IN 11-MONTH-OLD INFANTS

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ABSTRACT

Infants explore the world through many combinations of sight, sound, smell, taste and touch. A recent theory known as the "intersensory redundancy hypothesis" posits that the temporal overlap of stimulation across different sense modalities drives selective attention in infancy. Social communication typically involves visual, auditory and tactile cues for infants. Although infrequently studied, rhythmic touch is thought to be inherently rewarding; if manipulated within a social context, it may be able to reinforce joint attention. Given that joint attention is fundamental to the development of social communication, this study investigated the convergent effects of visual, auditory and tactile cues on the expression of joint attention in 10 infants between 11 to 12 months of age. The addition of synchronized (but not asynchronous) tactile stimulation to natural communication cues was associated with higher performance on a joint attention measure (i.e. more frequent responses to parental requests). Implications for autism are discussed.

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Outside of the typical research setting, infants explore both physically and socially through many combinations of sight, sound, smell, taste and touch. A recent theory known as the "intersensory redundancy hypothesis" posits that the temporal overlap of stimulation across different sense modalities drives selective attention in infancy (Bahrick, 2010). Much of adult social communication involves intersensory redundancy across visual and auditory cues. In infancy, these cues are usually accompanied by touch as well (Moszkowski & Stack, 2007). Although touch is thought to be inherently rewarding, it remains one of the least studied sensory systems (Stack, 2010). Given that joint attention is fundamental to the development of social communication (Mundy & Jarrold, 2010), a crucial question remains: how do visual, auditory and tactile cues add up to influence joint attention?

The remainder of this chapter contains a critical review of recent literature regarding the impact of these three sensory cues on the development of social communication. Initial sections will provide an overview of the typical and atypical development of joint attention behaviours, as well as a discussion of past and current theories regarding the mechanisms and epistemology of joint attention. Contemporary research on touch will be presented next, followed by a detailed explanation of multimodal perception and the theoretical implications of the intersensory redundancy hypothesis. The review concludes with a discussion of the general purpose of this thesis and of its specific hypotheses.

Joint Attention

The construct of joint attention was originally characterized as a tendency for six month old infants to "follow the gaze" of their adult caregivers during dyadic social interactions (Scaife & Bruner, 1975). Since that time, additional observed behaviours have joined this early gaze-following phenomenon as markers of joint attention. A current working definition of joint attention is the degree to which one person coordinates their attention with that of a social partner, such as by looking at the same object or event, for the purpose of a shared experience of that object or event (Mundy, Gwaltney & Henderson, 2010).

The tendency to follow another person's gaze at six months of age remains the first behavioural manifestation of joint attention development. As infants approach the end of their first year of life, they become increasingly interested and able to expand their dyadic interactions to include external objects and events (Dunham & Moore, 2005). In this developmental "revolution" (Tomasello, Kruger & Ratner, 1993), infants start to understand others' behaviour as goal-directed (Woodward, 2003) and they begin to expect and evaluate such behaviour to be rational (Gergely, Nadasdy, Csibra & Biro, 1995). By 12 months of age, infants incorporate information about gaze direction and emotional expression to predict others' subsequent action (Phillips, Wellman & Spelke, 2002). Typical behavioural expressions of joint attention that appear between 9 and 15 months of age include reaching for objects or people, showing or giving objects to others, gaze alternation, and pointing (Dunham & Moore, 2005). The scope of shared attention continues to expand during the first three years of life, from objects and people to ultimately include the infinite symbolic realm of imagination and cultural meaning (Adamson, Bakeman & Deckner, 2004).

Joint attention appears fundamental to subsequent aspects of social and cognitive development. Individual differences in joint attention skills during infancy have been related to later cognitive and language development (e.g., Adamson, Bakeman & Deckner, 2004; Delgado et al., 2002; Morales, Mundy & Rojas, 1998; Smith & Ulvund, 2003), as well as to self regulation and social competence during childhood (e.g., Morales, Mundy, Crowson, Neal & Delgado, 2005; Vaughan Van Hecke et al., 2007). Difficulties in establishing joint attention have been associated with an increased risk for developmental disorders related to autism across three decades of research. Children with autism display fewer basic joint attention behaviours when compared to typically developing peers and to those with developmental disabilities such as Down syndrome (e.g. Adamson, Bakeman, Deckner & Romski, 2009). Infants at risk for autism often display fewer acts of all types of joint attention behaviour (i.e. eliciting joint attention and responding to attentional bids from others) as early as 15 to 18 months (e.g. Cassel et al., 2007). As development progresses, the deficits in spontaneously eliciting joint attention tend to remain more robust than do those in responding to the attentional bids of others (Jones, 2009); low levels of social interest are a core feature of autism (American Psychiatric Association, 2000). Fortunately, early interventions for increasing joint attention often have long term beneficial effects on subsequent social development in autism (e.g. Jones, Carr & Feeley, 2006).

Theories of Joint Attention. Scaife and Bruner (1975) interpreted the gaze following that they observed in their landmark study as a marker of social communicative processes distinct from (albeit required for) the development of language. This hypothesis remains supported by research demonstrating two distinct but interacting neurocognitive systems in adults, one unique to language and the other corresponding to communication processes beyond language (e.g. Willems et al., 2009).

Following the work of Scaife and Bruner, some early theories of joint attention predominantly focused on explaining the mechanisms underlying gaze following. Butterworth (1995) outlined a maturational origin of joint attention, specifically for gaze following behaviour. He demonstrated that six month old infants could reliably follow their caregivers' gaze; this "ecological mechanism" was explained as the infants' use of the caregiver's gaze as a signal to look in a general direction (e.g. right or left) combined with an overlap in the features of the environment that would naturally compel the attention of both caregiver and child. By the end of the first year of life, infants appeared to use a more precise "geometric localization" (theoretically in addition to the earlier mechanism) in order to calculate the position of an object of interest (relative to a caregiver's head or arm). These abilities were thought to enable the production and comprehension of later observed communicative pointing behaviour.

Another well known nativist theory of joint attention was Baron Cohen's (1995) evolutionary argument for an "eye direction detector" and a "shared attention mechanism". The case for an eye direction detector was supported by studies in which animals such as birds and snakes were shown to recognize the eye direction of potential threats (and of potential mates, in the case of primates). The shared attention mechanism was purported to use the eye direction information to produce early joint attention experiences and to subsequently provide the foundation for a developing theory of mind in humans. These mechanisms were described as modular, in that they were highly specialized in their input and output and thought to be separate from other basic perceptual and cognitive functions.

In contrast, other theorists (e.g. Seibert et al., 1982) have suggested that joint attention may be an expression of more general cognitive development, such that these general cognitive processes underlie both joint attention and later social and cognitive measures. Supporting this idea are the findings that joint attention has been correlated with visual processing ability and responses to novel stimuli in infancy (Mundy, Seibert, & Hogan, 1984), as well as with later childhood IQ (Smith & Ulvund, 2003). Seibert and colleagues (1982) further emphasized that behaviours beyond gaze following should be classified under the joint attention construct. Specifically, Seibert defined the Initiating Joint Attention (IJA) skill as the use of eye contact plus protodeclarative acts such as pointing or showing (Bates, 1976), in order to spontaneously initiate coordinated attention.

Seibert considered the IJA skill to be itself part of a larger constellation of social communicative functions, which he divided according to their apparently intended purposes. IJA implied direction of another's attention to some external object or event in order to share the experience of it. Initiating Behavior Regulation (IBR) was more instrumental; this category comprised behaviours aimed to direct the behaviour of one's interaction partner (e.g. to elicit help in obtaining some out of reach object). Initiating Social Interaction (ISI) encompassed behaviours meant to draw attention to oneself in order to be playful or to maintain a pleasant interaction. Each of these skills was theoretically paired with a response-based counterpart. For example, Responding to Joint Attention (RJA) consisted of an infant's responses (mostly gaze or point following) to their interaction partner's IJA behaviour. To systematically evaluate these joint attention and related social communicative behaviours and to establish age norms for performance on them, Seibert (1982) produced a semi-structured measure called the Early Social-Communication Scales. A current version of this measure will be discussed further in the methods section.

Tomasello's (1995) social cognitive model of joint attention also extended the construct of joint attention beyond gaze following, not because it was thought to be reflective of some overarching domain general process like IQ, but because he redefined the construct to require more evidence of infant intentionality than mere visual behaviour. He argued that "attention is intentional" by necessity, and that joint attention is not thought to be achievable until infants reach a critical stage of social cognitive development, in which the emergence of other social behaviours (e.g. gaze alternation, communicative gestures and imitation) are considered markers of truly shared experience. In this view, the knowledge that others have intentions largely comes about between the ages of 12 to 15 months (Tomasello, Carpenter, Call, Behne & Moll, 2005). This understanding is in turn thought to provide a basis for subsequent development in referential communication and language acquisition (Brooks & Meltzoff, 2005; Tomasello, Carpenter, Call, Behne & Moll, 2005). Symbolic thought, in particular, was described as a transformation of joint attention, such that symbols both lead to and depend upon the social coordination of attention to abstract representations.

The more widespread use of brain imaging technology and an increasing theoretical interest in executive functions fostered the advent of multiple process models in which several emotional or "hot" (Zelazo, Qu & Muller, 2005) executive processes are purported to influence the development of joint attention and subsequent social-cognitive skills. Joint attention was not considered to be simply subsumed under the executive function taxonomy. Instead, different combinations of executive processes may impact different aspects of the development of joint attention. The neural correlates of joint attention and its related social-communicative behaviours have largely supported this idea. For example, IJA (or protodeclarative) pointing, but not IBR (protoimperative) pointing in 18 month old infants was found to correlate with their frontal region EEG activity measured when they were 14 months old (Henderson, Yoder, Yale & McDuffie, 2002; Mundy, Card & Fox, 2000).

As technology advanced, a mutually beneficial exchange of ideas sprang up between developmental psychologists and those working in the fields of cognitive science and artificial intelligence. Artificial intelligence researchers known as connectionists had begun to model human cognitive abilities in the 1980s and 1990s, seeking to build intelligence up from the "bottom" level of non-intentional, non-feeling pieces of information arranged into artificial neural networks (e.g. Smolensky, 1988). They were met with resistance from those who had worked for years to describe the mind by breaking it down from the "top" level of propositional thought, who much preferred symbolic and syntactic models of abstract thinking (e.g. Fodor & Pylyshyn, 1988). This latter view, known as computationalism, was a more parsimonious explanation for the explicit learning of domain specific material (e.g. mathematical rules). Connectionism had the explanatory advantage in the domains of implicit learning and procedural knowledge. Eventually, many researchers came to accept that developing intelligence requires some sort of dynamic system, which would use both of the "bottom-up" and the "top-down" approaches to cognition in a complementary fashion (e.g. Lewis, 2000; Smith & Thelen, 2003).

The most recent model of joint attention comes from the dynamic system approach. Mundy and Jarrold (2010) proposed that joint attention involves incremental gains in the infants' ability to engage in simultaneous or "parallel processing" of information about their own attention and about the attention of other people. More specifically, the perception and processing of joint attention is described as a tripartite activity in which three sources of information are critical: 1) an object or event, 2) some other person's attention and behaviour related to that object or event, and 3) proprioceptive and interoceptive information about our own experience of the situation (e.g. Mundy & Newell, 2007).

Joint attention is thought to stem from the development of a distributed brain network involving the frontal and parietal cortical systems. Practice with joint attention feeds back into this brain system to further develop its structure. This model further posits that IJA and RJA behaviours stem from two complementary neural systems, previously described by Posner and his colleagues (e.g. Posner & Petersen, 1990) as the anterior and posterior cortical attention networks.

The posterior system of attention, associated with RJA behaviours, regulates the rapid, automatic and involuntary orienting of attention (Frieschen, Bayliss & Tipper, 2007). It begins to develop within the first three months of human life, and it prioritizes attention to biologically meaningful information (Posner & Rothbart, 2007). Something akin to Butterworth's "ecological mechanism" or Baron-Cohen's "eye direction detector" has been demonstrated within this system, which comprises neural networks of the parietal/precuneus and superior temporal cortices. These are activated when perceiving others' head and eye orientations as well as one's own relative spatial positioning in the environment. An fMRI study by Materna, Dicke and Thier (2008) suggested that the posterior part of the superior temporal sulcus and the precuneus are specifically involved in the extraction of directional information about the eyes of other people and the application of this information in order to shift one's own gaze and establish simultaneous looking behaviour.

IJA behaviour has been more closely tied with the anterior system of attention (Mundy & Jarrold, 2010), which is involved in more volitional (i.e. self-initiated, goal-directed and effortful) attention, and which includes parts of the anterior cingulate, the medial superior frontal cortex, the orbital frontal cortex and the anterior prefrontal cortex (Dosenbach et al., 2007). If IJA behaviours are afforded more volitional control, it follows that individual differences in IJA engagement would be associated with motivational differences regarding the reward value of social interaction (e.g. Dawson et al., 2004). Indeed, an adult fMRI study by Schilbach and colleagues (2010) recently demonstrated that the action of directing someone else's gaze to an object is associated with activity in the ventral striatum; this appears to underlie the reward-related aspects of joint attention.

Although these neural bases of attention contribute to a developmental dissociation of IJA and RJA behaviours (Mundy & Newell, 2007), they do not operate in complete independence. Self-referenced information is one of the three key sources of information required for joint attention, and it may be the first that infants can access reliably (Mundy & Jarrold, 2010). The integration of proprioceptive cues (such as vestibular feedback and ocular muscle cues) and interoceptive information (such as arousal related to the positive, negative or neutral emotional valence of an event) seems to be required for an infant to feel a specific way *about* an external object or event. The associated activity of the anterior insula (corresponding to interoceptive processing) and the anterior cingulate and parietal cortices (implicated in proprioceptive processing), appear primary in the integration of these two facets of self-referenced information (Craig, 2009; Balslev & Miall, 2008; Uddin & Menon, 2009). Comparative animal studies further suggest that interoception and its integration with proprioceptive information may be more advanced in humans (versus primates) by way of the Von Economo neurons of the anterior cingulate (Allman et al., 2005; Craig, 2003).

Another network for processing the spatial, behavioural, vocal and affect information of others appears to be mostly distinct from the self-referenced processing areas (Emery, 2000). Along with the primary sensory cortex, this network activates cortical neurons in the parietal, temporal and frontal lobes (Mundy, Gwaltney & Henderson, 2010). The existence of these two partially overlapping yet distinct systems for processing internally versus externally generated information may aid the initial differentiation of self from others (Decety & Sommerville, 2003; Northoff et al., 2006).

Joint attention is thought to developmentally progress in a continuous manner: the increasing consolidation of information yields a greater capacity for processing and vice versa

(Mundy & Jarrold, 2010). Frequent co-activation of the self-referenced and other-referenced systems of perception allows for some basic categorization of knowledge about self and others (Keysers & Perrett, 2006), and processing this knowledge becomes an increasingly efficient and automatic process (Mundy, Gwaltney & Henderson, 2010). These components of the parallel processing model for joint attention are illustrated in Figure 1. Similarly, the co-activation of the posterior (RJA) and anterior (IJA) systems allows infants to consolidate the joint processing of self-others attention, freeing up additional processing resources to dedicate to higher order social and symbolic relationships. These co-activated processes have not yet been exhaustively or exactly specified, but Mundy and Jarrold (2010) suggest that this Hebbian mapping drives the subsequent depth of information processing and memory as infants grow older. They also propose that joint attention eventually becomes internalized as the capacity to coordinate covert attention to internal representations (e.g., symbolic thought; self-awareness). This consolidation process (especially the initial co-activation of interoceptive and proprioceptive information) seems to be the crucial filter through which implicit, automatic or procedural information processing appears to be abstracted into intentional information and its associated attentional deployment, eventually yielding the abstract and propositional manipulation of knowledge that any scholastic instruction would depend on.

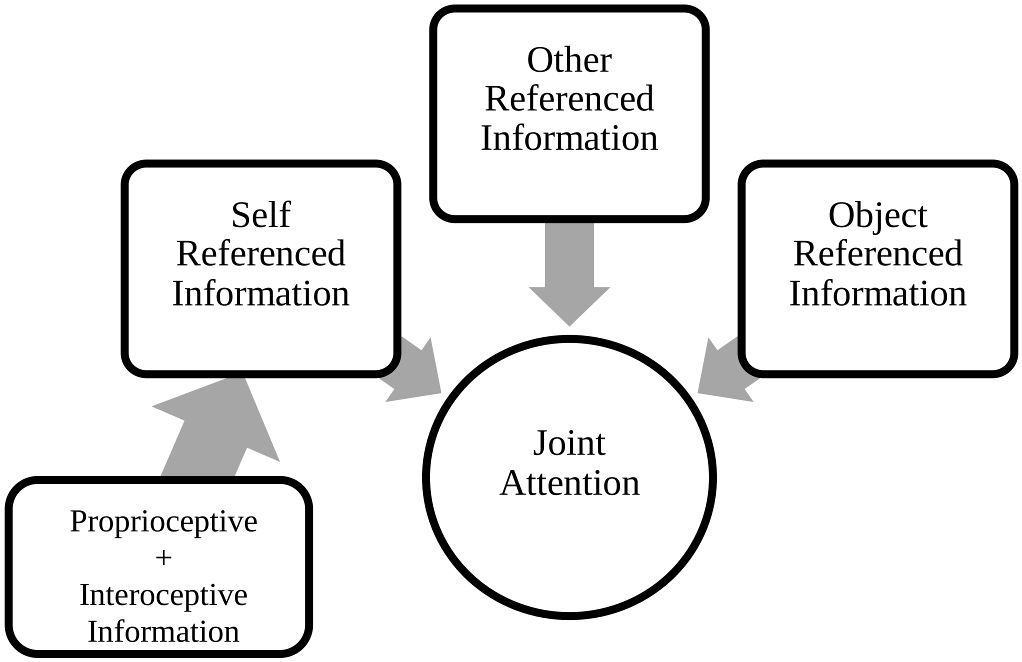

Figure 1. Components of joint attention according to the parallel processing model. Co-activation of proprioceptive and interoceptive information yield a sense of self, and this self-referential awareness is further co-activated with information about other people and objects to yield a shared awareness of social intent.

Joint Attention Summarized. Joint attention manifests with gaze following at 6 months of age, then progresses to gaze alternation, pointing and more complex behaviours related to the sharing of experience by 9 to 15 months. An early deficit in both IJA and RJA skills has been observed in infants at risk of autism, and a persisting IJA deficit may underlie the decreased social interest that characterizes autism in children.

Joint attention is neurocognitively separate from yet still fundamental to the development of language (Bruner & Scaife, 1975). The construct of joint attention has expanded beyond gaze following to include a range of protoimperative and protodeclarative behaviours (e.g. Seibert, 1982). Early theories of joint attention that focused on the mechanism behind gaze following suggested a specialized “eye direction detector” evolved to process information about another’s gaze (Baron Cohen, 1995; Butterworth, 1995). Since the construct of joint attention became known as an indicator of knowledge about others’ mental states, the mechanics of specific types of joint attention behaviour were considered less theoretically salient than what infant understanding could be inferred from the constellations of those behaviours (Tomasello, 1995). Specifically, joint attention behaviour was considered to mark stages of general understanding about others' intentionality. Tomasello (1995) redefined the category of what should be labelled "joint attention" to require actions beyond gaze following. Since gaze following develops earlier than these other markers, he considered the advent of joint attention to occur later (at approximately 12 to 15 months of age).

Neuroimaging and EEG studies yielded a wealth of correlational information about different facets of joint attention behaviours (from gaze following to more complex actions such as pointing) to be studied in both infants and adults. These studies collectively demonstrated that superficially similar joint attention behaviours relied on different neurocognitive systems based on their specific function (e.g. pointing for the purpose of initiating attention versus pointing in imitation). A recent dynamic systems approach to joint attention synthesized this information about the neural correlates of its functional components (Mundy & Jarrold, 2010). This model supports and subsumes a specialized gaze following module similar to that posited in earlier theories, but it characterizes the broader mechanism behind joint attention as a parallel processing of distributed neural networks rather than a more isolated module of joint attention behaviours. As per Tomasello's social cognitive theory, joint attention is thought to reflect a developing understanding of intentionality. However, this is assumed to be a continuous rather than stage-like progression, in the tradition of Thelen and Smith's (2003) theory of dynamic systems (whereby cumulative experience is thought to coalesce into higher order processes). Additionally, the dynamic system model explains the split between IJA and RJA development as an indication of their respective reliance on selective and automatic attention.

Joint Attention Beyond Visual Cues. Although the theoretical explanations of joint attention have been abstracted from the mechanics of visual attention to focus more on the intended social-communicative function of an array of behaviours, visual attention has been by far the dominant modality addressed in the joint attention literature. However useful visual attention is for bootstrapping joint attention, it is not necessary for its acquisition. For example, blind infants are delayed in their acquisition of joint attention, but they still manage to acquire it via touch and hearing (Bigelow, 2003).

Even when vision is not impaired, selective and joint attention development may hinge on the development of other senses. For instance, attention to social sounds (e.g. speech, singing) within a dyadic interaction context is necessarily joint attention (in that two people are coordinating their focus on the relevant social sounds). A decreased tendency to orient to social sounds or to maintain attention on them may be involved in the developmental course of autism. Preschool aged children with autism exhibit greater head turns to non-speech sounds relative to child directed speech than do typically developing controls (Kuhl, Coffey-Corina, Padden & Dawson, 2005); they also spend less time oriented to child directed speech (Paul, Chawarska, Fowler, Cicchetti & Volkmar, 2007). Within an autistic sample, toddlers who attended to child directed speech for longer periods of time were found to have better receptive language skills up to one year later (Paul et al., 2007).

Haptic Communication

Human communication comprises not only visual and auditory stimuli, but also haptic information. Touch is one of the earliest sensory experiences in fetal development, with the kinesthetic and cutaneous systems developing first in the human embryo, followed by the vestibular system and other senses (Diego, Field & Hernandez-Reif, 2004). Fetuses have been repeatedly shown to respond to vibroacoustic stimulation (e.g. Kisilevsky, Muir & Low, 1992). Given the early maturation of touch relative to the other sensory systems, it would follow that this modality would be fundamental to further development.

In one study where preterm infants were given tactile stimulation, they demonstrated a 47% greater weight gain, spent more time in active and alert states, showed more mature behaviours as measured by the Brazelton scale (NBAS), and were even discharged from the hospital 6 days earlier than those without this intervention (Scafidi et al., 1986). The importance of kangaroo care (i.e. skin to skin contact between infant and parent) has been emphasized as a practice guideline for the care of preterm infants by the Canadian Paediatric Society; this type of touch has been demonstrated to improve their performance on measures including cardiorespiratory and temperature stability, sleep patterns, responses to pain, breast feeding and attachment (Jefferies, 2012). Field, Diego & Hernandez-Reif (2007) suggested a potential mechanism for the emotionally regulatory and socially reinforcing elements of touch: that the stimulation of pressure receptors in the skin alters brain activity by increasing serotonin and dopamine, and decreasing cortisol.

In typically developing infants, manual and oral exploration appear to contribute to the early exploration of object properties (e.g. Bushnell & Boudreau, 1991; Stack & Tsonis, 1999). In the social realm, physical contact between mothers and infants appears to be integral to appropriate emotional communication and secure positive attachment (e.g. Ainsworth, Blehar, Waters & Wall, 1978; Bowlby, 1969). Analyses of mother-infant interactions revealed that maternal touch occurred in spontaneous play up to 61% of the time (Symons & Moran, 1987) and that infant touch (of any kind of stimulus, including self and mother) occurred 85% of the time (Moszkowski & Stack, 2007).

The still-face procedure (Tronick, Als, Adamson, Wise & Brazelton, 1978) has been valuable in exploring the association between touch and affect. This procedure is split into three brief (e.g. 1 minute) periods. First, the mother interacts normally with the infant. Second, she assumes a neutral, nonresponsive, "still" face and ceases any vocal or tactile stimulation. Finally, the dyad resumes normal interaction. Across numerous studies, a classic still face effect has been observed; during the "still face" (SF) segment, infants decrease gazing and smiling at their mothers and increase negative affect and vocalizations (e.g. Adamson & Frick, 2003). Stack and Muir (1990) demonstrated that infants were not distressed by a modified SF period in which maternal touch was allowed; they showed increased smiling and maintained normal levels of gaze to their mothers. Furthermore, mothers can intentionally use touch to elicit specific infant responses such as smiling (Stack & LePage, 1996), or looking at their mothers' hands (Stack & Muir, 1992). More recently, Jean and Stack (2009) showed that maternal touch during the transition period immediately after SF down-regulated the subsequent negative affect of infants. Studies of 4 and 7 month old infants were also able to use touch to reinforce gaze toward an experimenter's expressionless face (LePage & Stack, 1997; as cited in Stack, 2010). In sum, these studies illustrate that infants are both sensitive to and reinforced by touch.

Outside of the still-face paradigm, Dickson, Walker and Fogel (1997) used the Baby FACS coding scheme to code for basic, play and Duchenne smiles during physical play, object play, vocal play and book reading. They found that physical play with tactile stimulation elicited the most "play" type of smiling (45% of the time). Fogel and colleagues (2006) also found longer durations and higher amplitudes of smiles when parents tickled their infants rather than playing peek-a-boo with them.

Types of Touch. In the context of dyadic interactions, infants appear to prefer rhythmic touch rather than nonrhythmic touch. Perez and Gerwitz (2004) compared relative reinforcement of leg kicking in 2 to 5 month old infants in response to three kinds of maternal touch (poking, stroking and tickling) across two levels of pressure (mild and intense). Stroking was operationalized as rhythmic and continuous touch with one hand, poking was defined as the continuous touch of one finger, and ticking was the arrhthymic touch of fingertips. All touch occurred on the infants' limbs or abdomen. Poking, especially intense poking, was the least preferred type of touch. Intense stroking was the most preferred touch, as indicated by increased rates of leg kicking.

Mothers have been observed to use different patterns of touch in various contexts of interactions. For example, when asked to elicit infant smiling, they used more active types of touch (such as lifting or tickling) with greater intensity and speed and across a larger surface area of the body (Stack, 2001). Infants also vary their touch behaviour based on context. Moszkowski and Stack (2007) showed that 5.5 month olds touched themselves more and used more active and soothing touch behaviours (e.g. stroking, fingering, patting and pulling) during the SF portion of a typical still-face procedure. Before and after this SF segment, the same infants were observed to touch their mothers more and to use more passive (static) touches.

Overall, certain patterns of touch seem to be socially appropriate within different types of interaction (e.g. tickling is better received in an active play context). Rhythmic stroking, in particular, appears to drive the affective regulation and reinforcement potential associated with touch.

Haptic Contributions to Joint Attention. Bigelow (2003) observed two blind infants longitudinally and reported two specifically tactile behaviours that she categorized as related to joint attention. She noticed that these children would tactually scan their caregivers' bodies toward their caregiver's hands in order to find objects. A later developing behaviour (and one that seems more conservatively related to joint attention) was cooperation with an adult in the joint manipulation of an object.

Despite a dearth of systematic examination of the haptic contributions in directing joint attention, tactile stimulation is likely a significant contributor to initiating joint attention in naturalistic settings. Most infant research takes place with the interacting dyad seated face to face, but so much of infant development takes place as the infant physically explores his or her surroundings. Imagine a young child seeking the attention of a parent who is in conversation with another adult. Visual and auditory strategies for obtaining attention may be less efficient (due to the visual and auditory information already dominating the parent's attention) and perhaps less socially appropriate (in children old enough to know not to interrupt) than even a subtle touch cue. Research in the field of ergonomics suggests that adults are more effectively able to direct attention without disrupting ongoing information processing when they are faced with tactile rather than visual interruptions (Hopp, Smith, Clegg & Heggestad, 2005). In a more "noisy", less restricted, and more inherently interesting environment than a typical lab setting, it is possible that infants would employ touch to reorient their parents' attention to themselves prior to showing off, pointing to, or reaching out for an object.

Finally, the reinforcing nature of certain types of touch suggests that social exchanges containing more rhythmic touch may also encourage more displays of infant engagement in the interaction (e.g. via the more motivation-dependent IJA behaviours). This hypothetical association would be particularly relevant if it could be applied to the persistent IJA deficit found in autism.

Multimodal Perception

Humans explore the world through sight, sound, smell, taste and touch. Some information is only relevant to only one of these senses. The redness of an apple is an example of this “unimodal” information. In contrast, “multimodal” stimulation is that which engages two or more senses in synchrony, yielding “amodal” information which is inherently available to more than one sense (Bahrick & Lickliter, 2004). For instance, the movement of a passing car can be both seen and heard. Adults often fill in the gaps when a typically multimodal scenario is experienced through only one modality (e.g. hearing a vehicle approach and inferring that it is a truck rather than a car). Infants can also apply bimodally obtained information to unimodal domains. Bahrick and Lickliter (2000) habituated five month old infants to a bimodal (audiovisual) presentation of a hammer striking in a particular rhythm. These infants were dishabituated to the subsequent unimodal presentation of a novel rhythm, but not to a unimodal presentation of the original rhythm.

Gibson (1969) suggested that a sensitivity to fixed intersensory relations is a crucial component for perceptual development and learning. From the time they are born, infants turn their heads in the direction of sounds to visually match the sound to its source (Muir & Clifton, 1985) and they expect sounds to move along with their associated objects (Morrongiello, Fenwick & Chance, 1998). At three weeks of age, they associate visual and auditory stimuli by attending to stimulus intensity (Lewkowicz & Turkewitz, 1980). Spelke (1981) showed that four month old infants perceived bouncing objects bimodally via the temporal synchrony of sound and sight cues. Rosenblum, Schmuckler and Johnson (1997) elicited the McGurk effect in the same age group, demonstrating that bimodal perception also applies in the realm of speech perception. By five to seven months of age, infants are able to match voices to faces based on gender, affect and age cues (Bahrick, Netto & Hernandez-Reif, 1998).

In the chaotic noise of the natural world, multimodal stimulation is so common that it may provide an external structure for early cognition (Smith & Gasser, 2005). For instance, any form of self motion would produce amodal cues from the temporal and intensity changes common to the proprioceptive and interoceptive systems. Most of the time, this would occur in concert with other systems such as vision or hearing. As mentioned in the overview of theories about joint attention, the co-activation of the proprioceptive system with other sensory information may underlie an infant's ability to differentiate himself from others (e.g. Rochat & Morgan, 1995).

One of the fundamental tasks of development is to detect relevant information while ignoring irrelevant stimuli; an attentional bias to amodal information could be invaluable for this task. For example, this bias might foster preferential learning about dynamic (versus static) objects and sounds. Intuitively, this makes sense: dynamic objects (e.g. cars) are more likely to approach us, without waiting to be approached. This category also includes animate and intentional beings (e.g. family pets; people) which are often amenable to more complex interactions.

The Intersensory Redundancy Hypothesis. Bahrick and Lickliter and their colleagues put forth the "intersensory redundancy hypothesis" to describe the aforementioned bias; it posits that selective attention is driven to the amodal aspects of events which have been redundantly specified across the senses (e.g. Bahrick, Lickliter, Castellanos & Vaillant-Molina, 2010). In other words, it is particularly salient to us when our senses converge on the same information. Temporal synchrony, being the most global type of amodal information, has been described as the “glue” that binds cross-modal stimulation into the perception of objects or events (e.g. Lewkowicz, 2000, 2010). The “ventriloquism effect” illustrates the primacy of temporal synchrony; temporally synchronous sound and movement override spatial information about the origin of sound, driving the illusion that the sound is originating somewhere else (e.g. a ventriloquist’s dummy). This effect has been demonstrated in infants as young as 2 months old (Morrongiello, Fenwick & Nutley, 1998).

An important implication of the intersensory redundancy hypothesis is that the presence or absence intersensory redundancy should impact perceptual learning. Bahrick and Lickliter (2009) predicted four specific ways that this could occur.

First, the basic assumption of “intersensory facilitation” suggests that multimodal stimulation promotes the perceptual processing of amodal properties (at the expense of non-redundant properties) to a greater extent than does unimodal stimulation. This prediction has been supported by studies showing that rhythm, tempo and affective expressions are all detected better when they are presented in audiovisual synchrony, versus as auditory or visual stimulation alone (Bahrick & Lickliter, 2000; Bahrick, Flom & Lickliter, 2002; Flom & Bahrick, 2007).

A second assumption, termed “unimodal facilitation” posits the inverse: that non-redundant, modality-specific properties are selectively attended to and processed more easily when the stimulation is unimodally presented. The reasoning behind this hypothesis is that the (more salient) redundant information is not available to dominate attention in the case of unimodal stimulation. Indeed, infants were better able to discriminate and to remember the orientation of a moving object in unimodal (visual) stimulation, and especially with asynchronous (audiovisual) stimulation, than they could when presented with synchronous audiovisual stimulation (Bahrick, Lickliter & Flom, 2006).

Third, developmental improvements in perceptual differentiation, attentional flexibility, and the efficiency of processing lead to both amodal and modality-specific properties being detected with ease across unimodal and multimodal stimulation (Bahrick, 2010). Bahrick (2010) emphasized that this transition is driven by a hierarchy of attentional salience. Because most information is presented in a multimodal context, younger infants show a dominant intersensory facilitation effect. Once intersensory facilitation promotes the "unitization" of information into discrete objects and events, familiarity with these objects and events frees up attentional resources to explore the less immediately salient unimodal properties in the context of multimodal stimulation. Bahrick and Lickliter (2004) supported this hypothesis by showing that 5 month olds, but not 3 month olds, could detect the orientation of a moving object presented multimodally. Additionally, 8 month olds, but not 5 month olds, could detect rhythm from a unimodal presentation of a moving object.

Although the third prediction of the intersensory redundancy hypothesis posits that patterns of intersensory and unimodal facilitation become less evident with development, their effects on attention appear to be dependent on the relative difficulty of the task in question. The last general prediction of the intersensory redundancy hypothesis is that these two types of attentional facilitation are most pronounced for difficult tasks, relative to the expertise of the perceiver, and thus are apparent throughout the lifespan (Bahrick, 2010). By increasing the difficulty of a tempo discrimination task, Bahrick, Lickliter, Castellanos and Vaillant-Molina (2010) demonstrated intersensory facilitation in 5 month olds, an age group previously shown to perform at ceiling on more simple tempo discrimination tasks in both unimodal and bimodal conditions (e.g. Bahrick & Lickliter, 2004).

Intersensory Redundancy in Social Interaction. Reciprocal social interactions are an abundant source of intersensory redundancy, given that they are coordinated both spatially and temporally (Bahrick, 2010). Caregiver-infant interactions are often characterized by "dyadic synchrony": a bidirectional coordination of gaze, touch, vocalization and affect which occurs along the amodal dimensions of temporal sequence, spatial location and intensity level (Jaffe, Beebe, Feldstein, Crown & Jasnow, 2001). This early synchrony has been positively associated with measures of joint attention, attachment, regulation of emotion and arousal, and later communicative competence (Harrist & Waugh, 2002). Caregivers also exploit the intersensory facilitation effect when older infants are learning object names. Gogate, Bahrick and Watson (2000) observed that mothers embed novel names for objects within multimodal stimulation (such as the synchronous naming and showing of objects) and that they further match this use of temporal synchrony to their infants' level of lexical expertise.

Beyond the meanings of words, the auditory and visual components of speech both carry information about emotion (via changes in temporal patterns and intensity) and communicative intent (via prosodic patterns such as rhythm, tempo and/or intensity shifts) (Cooper & Aslin, 1990). Infant-directed speech exaggerates this information with vocal (Cooper, 1997), facial and gestural cues (Gogate, Walker-Andrews & Bahrick, 2001), as well as providing more repetition, longer pauses, and wider pitch excursions (Fernald, 1989). The result is a well-documented infant preference for this form of communication (e.g. Cooper, 1997). In addition to speech, the infant-directed exaggeration of prosodic cues extends to singing. For example, mothers emphasized the phrasing structure of songs by lengthening stressed syllables and pauses (Trainor, Clark, Huntley & Adam, 1997). Trainor (1996) observed that these exaggerations occur only in the presence of an infant, supporting her theory that infant-directed singing serves to instruct infants about the organization of auditory patterns. Longhi (2009) studied infants' physical responses to their mothers' singing and found that by 7-8 months of age, infants synchronized their movements with the upbeats stressed by their mothers; furthermore, they also produced more frequent synchronized behaviours at the beginning or end of a musical phrase, reflecting some knowledge of the higher order musical structure.

As described by Bahrick (2010), Castellanos, Shulman and Bahrick (2004) demonstrated that the early processing of speech prosody is facilitated by intersensory redundancy. They habituated 4 and 6 month old infants to the same phrases with different prosodic patterns (either implying approval or conveying prohibition) and found that a change in prosody was only detected by the 4 month old infants when the speech was presented in an audiovisual format. In contrast, the 6 month old infants were additionally able to distinguish the prosodic changes in a unimodal (auditory only) format of presentation. Similarly, Flom and Bahrick (2007) described a developmental trajectory for the discrimination of emotions (happy, sad or angry) in which the minimal requirement for successful emotion discrimination was an audiovisual presentation format at 4 months, a unimodal auditory presentation format at 5 months, and a unimodal visual presentation at 8 months.

Taken together, these findings suggest that infants rely on multimodal information for the tasks that lie at the edge of their social expertise. As infants begin to express joint attention behaviours, it seems likely that a multimodal milieu would foster success throughout this next level of difficulty in processing (triadic) social interaction. Joint attention requires that an infant attend to another person's intentions. Since intentions are not static across the duration of an interaction, infants' attentional orienting to them could be helped by attending to the dynamic cues associated with intentionality, such as speech prosody and emotion. In a typically developing population, intersensory redundancy appears to prioritize these dynamic features of interaction. For this reason, it is expected that intersensory redundancy will help infants to more frequently notice others' intentions and perhaps motivate them to expend more effort to maintain their attention to this important information.

Trimodal Stimulation and Joint Attention. Recall that the majority of caregiver-infant interaction includes some form of touch, in addition to visual and vocal communication. Although the intersensory redundancy hypothesis has been well-researched in studies employing visual and auditory stimuli (Farzin, Charles & Rivera, 2009; Flom & Bahrick, 2010; Kobayashi, Hiraki & Hasegawa, 2005), other sense pairings have been significantly less studied.
One goal of the current study was to address the dearth of multimodal literature involving haptic stimulation. It was contended that the synchronized addition of artificial haptic stimulation would yield similar attentional benefits to those demonstrated in studies of other synchronized modalities. The haptic stimulation provided in the current study was temporally synchronous to the mother's vocal (and, presumably, facial/gestural) prosody, with rising and falling patterns of pitch matched by corresponding vibrotactile information arranged in a vertical spatial array on the infant's back.

This study seeks to establish whether the benefits of intersensory redundancy could be observed in more complex and applied measures, beyond the discrimination of basic amodal properties. Gogate, Bahrick and Watson's (2000) work exploring the impact of multimodal stimulation on object naming suggests that multimodal cues remain salient in social interaction beyond the initial detection of others' emotions. If multimodal stimulation can aid in the detection of basic emotions (e.g. happy, sad, angry) and prosodic cues (e.g. prohibitive versus approving), it stands to reason that it would also facilitate the detection of more nuanced markers of others' dynamic intentional states.

Of particular interest in this study were joint attention behaviours. It was hypothesized that the third (haptic) modality would renew the salience of the speaker and would strongly focus the infants' attention on the social interaction such that they become more engaged and display more overt social communicative behaviours overall. This would be reflected across joint attention measures, regardless of whether the behaviour in question was infant-initiated. Touch has been associated with better emotion regulation and even with the presence of positive emotion in otherwise distressing situations (e.g. still-face, inoculations). Rhythmic touch, in particular, seems to be a reinforcing stimulus for infants. Given that the trimodal stimulation included rhythmic touch, it should yield gains in those joint attention behaviours that are dependant on infants' motivation. The final avenue used to explore infants' social-communicative response to the additional synchronized haptic stimulation was the frequency of their rhythmic physical responses to maternal singing. Infants were expected to show more frequent rhythmic motions in response to the synchronized trimodal experience of song due to the increased salience of its prosodic features and also due to their motivation to maintain a presumably enjoyable experience.

The synchronized vibrotactile touch could also produce incremental benefits to caregivers' spontaneous touch when they sooth their infants during the third phase of a still-face procedure. Specifically, it was predicted that infants experiencing synchronized touch would display positive emotions sooner after a still-face period because their dyadic synchrony would be restored through additional cues.

Purpose and Hypotheses

The overarching goal of this study was to give a first impression of the impact of trimodal synchrony (comprising natural visual and auditory cues, as well as rhythmic vibrotactile stimulation) on social communication. The primary observational component of this study was a semi-structured measure of joint attention behaviours based on the Early Social Communication Scales (Mundy et al., 2003; see Methods section for more details). To evaluate whether trimodally synchronized singing was afforded similar attentional benefits as trimodally synchronized speech, a frequency count of infants' physical rhythmic responses to maternal singing was obtained. The secondary observational component of this study was a brief still-face procedure. This was used to evaluate the potential for affective regulation associated with trimodal stimulation.

Relative to a control group that received temporally asynchronous vibrotactile stimulation (i.e. to their mothers' infant-directed speech and expressions/gestures), infants that received trimodally synchronous stimulation were hypothesized to 1) respond overtly to more of the joint attention bids made by their caregivers, 2) initiate more joint attention bids themselves, 3) more frequently respond to maternal singing in a rhythmic, physical manner, and 4) show a shorter latency to the expression of positive emotion after a period of still-face.

Methods

Participants

Based on their infants' age, a list of parents were generated from those who had previously provided their information to the CHILD Lab during a general recruitment session. Caregivers of infants who are between 11-12 months of age were contacted with more information about the specifics of this study. To limit the variability in vocal range within the study, only female caregivers were allowed to participate with their infants. Five infants per experimental condition were tested, for a total of ten infants across the study. Three males and two females were assigned to each condition. They ranged from 11.2 to 11.8 months in age. Two additional infants participated in the tasks without receiving any vibrotactile stimulation; they were excluded from the data analysis because the BabyVibe system malfunctioned upon their arrival.

Materials

The BabyVibe system is based, in part, on the Ryerson emoti-chair technology (Karam, Russo & Fels, 2009). It comprises a lapel microphone, worn by the caregiver, and an adjustable battery-powered vest, worn by the infant, with a bank (18) of small vibrational motors similar to those used in modern cellular phones (see Figures 2 and 3). Because the microphone is wirelessly connected to a receiver embedded in the vest, the pattern of vibration running along the infant's back varies with the pitch and volume of the caregiver's voice. The BabyVibe system was first presented at the 2011 biennial meeting of Society for Research in Child Development (Boudreau, Russo, Stein, 2011). To ensure the safety of this new technology, the vest system has been evaluated according to provincial guidelines and has met CSA standards (Model: Milk Vest S/N: 02082010) for medical grade equipment (see Appendix A for details).

Figure 2. The BabyVibe system.

Figure 3. A three dimensional perspective of the BabyVibe system.

The Early Social Communication Scales, or ESCS (Mundy, et al., 2003), is a research instrument designed to measure individual differences in early social communication via 15 to 25 minutes of structured observation for infants aged 8 to 30 months. This study employed an abridged and modified version of the ESCS. Generally, infants were afforded opportunities to ask for attention (e.g. for help to obtain an interesting toy) or to respond to bids for their attention (e.g. to look where their caregiver is pointing) while they explored a standardized toy set. One major modification of the ESCS procedure was that the caregiver, rather than the experimenter, interacted with the infant. This was intended to prevent the distraction of an extra person in the room, and to allow the infant the comfort of interacting with a known person. Infants also prefer their mother's voice over strangers' due to unique features such as signature tunes (Bergeson & Trehub, 2007), so the experimenter's voice, lacking these nuances, could have decreased the potential efficacy of the vest. The experimenter was able to observe the interactions of the caregiver-infant dyad via a one-way mirror looking into the testing room. The caregiver wore a wireless earpiece so that the experimenter could unobtrusively communicate instructions during the session.

The traditional ESCS employs repetition of the same types of activities, plus a flexible schedule of administration, in order to ensure that infants are scored at their best performance. Pilot testing of the ESCS with two infants prior to the study showed that 1) the tasks from the ESCS took approximately twice as long when they required instruction to the mother prior to their enaction, 2) after approximately 15 minutes, infants were tired and fussy enough to end the experimental session. For these reasons, and to maintain the full range of stimulation afforded by ESCS, only one of each type of task was performed in this study. Because there was so much variability stemming from other factors, the order of tasks was also kept consistent across all infants in the study. The task order was as follows: turn taking, object spectacle, response to social invitation, social interaction, gaze following, book presentation and plastic jar task (see Figure 4 and Procedure section for task descriptions).

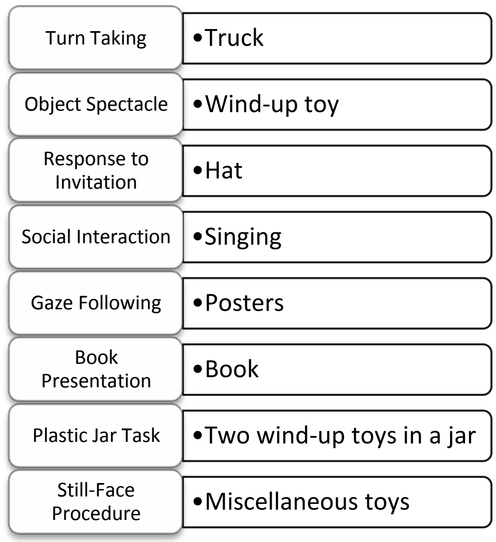

Figure 4. The order of experimental tasks and relevant materials.

Procedure

Upon entering the lab, infants and caregivers were allowed the opportunity to become habituated to the lab space and with the experimenter. The informed consent process was explained, and the option of pausing or stopping the experiment at any time was discussed (see Appendix B for consent form). The experimenter engaged the infant in play while explaining and demonstrating the BabyVibe system to the parent. Once the infant seemed relaxed, the experimenter and parent removed any bulky clothing from the infant, and placed him or her in the BabyVibe system. The caregiver and infant were given a few more minutes to acclimatize to the BabyVibe system while the experimenter explained the communication system (i.e. observation via one way mirror and earpiece) to the parent, and gave a brief overview of the rest of the experiment. Once the caregiver had all questions answered, and both infant and caregiver seemed comfortable and ready to continue, the experimenter escorted them to the next room.

A labelled box containing the standardized toy set for the ESCS portion of the study was set up in the testing room prior to the study (see Figure 5). The caregiver was instructed to sit within arm's reach of this box. The infant sat in a high chair across a small table from his or her caregiver. The experimental condition (synchronous versus asynchronous stimulation) would be previously determined by a research assistant, to maintain the experimenter's blindness to condition. Regardless of condition, the receiver in the vest was attached to wiring that could feed the signal through a delay pedal. In the synchronous condition, the research assistant left the delay pedal turned off, so that it would have no effect on the vibrations of the BabyVibe system. In the asynchronous (control) condition, the research assistant would turn on the delay pedal so that the signal to the BabyVibe system would be delayed. The delay between hearing the mother's voice and feeling its corresponding vibrations was set to 800ms. This delay was thought to be more than long enough to dissociate the two sensations as even a 200ms delay is enough for adults to distinguish the motion of two separate stimuli (e.g. Scholl & Nakayama, 2002).

Two digital video cameras were focused on the caregiver and the infant, respectively. After setting each camera to start recording, the experimenter exited to the adjacent room, where she was able to observe the caregiver-infant interactions. The experimenter began by talking the caregiver through the ESCS procedure. The caregiver was asked to perform certain actions (e.g. point to a poster) and to naturally attempt to elicit certain behaviours (e.g. try to get your baby to pass you the ball) as they were required. For each participant, an attempt was made to follow the specific ESCS task administration guidelines. However, absolute standardization may violate the ecological validity of a social interaction measure such as the ESCS (Mundy, et al., 2003). Therefore, the guidelines are not strict, and some variation was expected (e.g. allowing the infant to play with preferred toys for a longer duration than is suggested in the ESCS manual). Additionally, because vocal interaction was so crucial to this study, mothers were given the instruction to talk and interact with their infant as normally as possible, given the activities that they were being asked to complete.

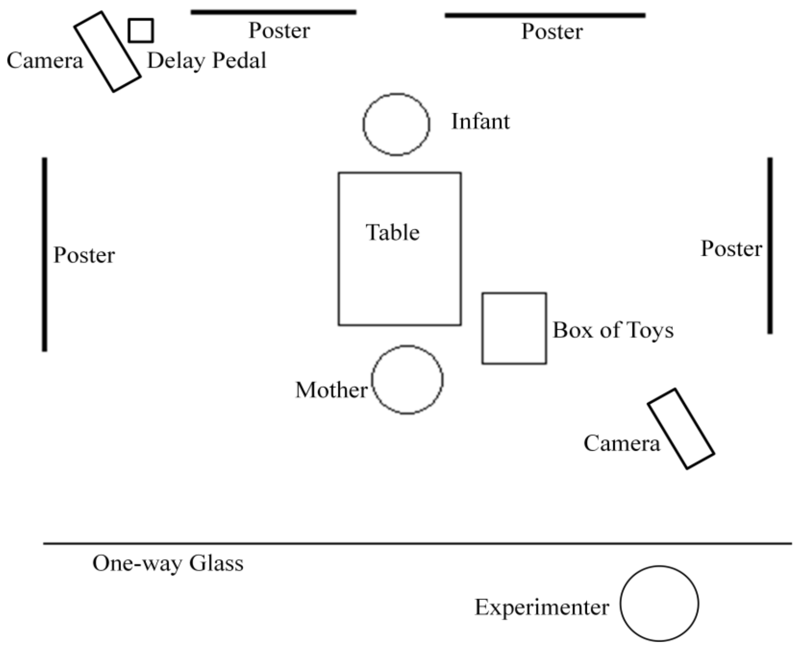

Figure 5. Physical layout of the experimental set up.

The ESCS procedure began with a turn taking task. Parents were instructed to place a toy truck in front of their infant and to wait with their hands open to catch it. If the infant passed the truck to his or her mother, she would be instructed to try to maintain the turn taking until the experimenter counted either 12 turns (i.e. instances of the baby passing the truck) or 3 drops (i.e. instances of the baby dropping the truck on the floor). If the infant did not spontaneously pass the truck, parents were instructed to first ask for, and then to take the truck in order to try to initiate a turn taking game themselves. If the infant neither passed nor dropped the truck, parents were allowed 3 opportunities to retrieve the truck and try to initiate the game again. In between the tasks, parents were asked to clear the table of all toys.

In the object spectacle task, parents were asked to activate a wind-up toy outside of the infant's reach. They were instructed to pass the toy to the infant once the experimenter observed a bid for it (e.g. reaching) or once the toy ceased its activity. Infants were allowed to examine the toy for a brief period, then parents were instructed to ask for it back. Upon retrieval of the toy, these actions were repeated twice more (i.e. activating the toy out of reach, allowing the child to play, requesting it back).

In the response to social invitation task, parents were told to place a hat in front of their infant so that he or she could briefly play with it, then to lean down as far as possible and ask their infant to play. If the infant did not move the hat toward the caregiver's head, this request was repeated two more times and finally the caregiver was asked to briefly place the hat on the infant's head and then to ask to play one more time.

The social interaction task required parents to sing a few bars of a simple children's song (e.g. The Itsy Bitsy Spider), along with the appropriate gestures, and to pause singing approximately 10 seconds into the song. Parents were instructed to wait approximately 5 seconds before returning to the song. This stopping and starting was repeated twice more during the song. Because singing could engage more of the caregiver's vocal range (and thus more of the BabyVibe system's tactile range), it was thought to potentially render the BabyVibe system more salient to the infant. To explore this possibility, each caregiver was asked to use as much of their vocal range as possible while singing, and to emphasize the high and low notes of the song.

To elicit gaze following, parents were instructed to look and point to four different posters arranged around the room. One poster was located to the right of the infant, one to the infant's left, one behind and slightly to the left of the infant, and one was behind and slightly to the right of the infant. The posters were always presented in the following order: left, behind-left, right, behind-right.

In the book presentation task, parents were asked to open a picture book in front of the infant. For approximately 20 seconds, infants were given the opportunity to explore the book, with parents acknowledging their behaviour (e.g. talking about dogs if the infant touched a picture of a dog), but not trying to direct their attention. Next, parents were instructed to direct their infant's attention to specific pictures in the book; they pointed to a picture on the left side of the book, then to one on the right side, and then turned the page twice to repeat these two points for a minimum of 6 points in total.

For the plastic jar task, two wind-up toys were placed inside a transparent plastic jar prior to the study. Parents were talked through the steps of shaking the jar, pouring out the toys outside of their infants reach, securing the toys back inside the jar, and then passing the jar to their infant. Infants were allowed approximately 10 seconds to examine the jar. After 10 seconds, or once the infant attempted to give the jar back to his or her parent, the parent was instructed to remove one of the toys and to put away the jar with the other toy. Next, parents wound up the remaining toy outside of their infant's reach, following the same instructions as in the object spectacle task. Once this was completed, parents were told to put away this toy and to retrieve the jar with the other toy. Again, they were asked to shake the jar, pour it out, put the toy back inside, close the jar tightly and pass it to their infant. After 10 seconds or an attempt to give the jar back to the parent, the jar was put away. The object spectacle instructions were followed one final time with this last toy.

Subsequent to the ESCS portion of the study, the experimenter reminded the caregiver about the importance of remaining fully neutral and disengaged from the infant during the still-face procedure. The caregiver was allowed approximately one minute to engage the infant in normal play. To maximize the caregivers' vocalizations during this procedure, no toys were allowed on the table during this time. The experimenter then instructed the caregiver when to start and when to stop neutrally ignoring the infant, according to a stopwatch used to time 45 seconds. Infants' emotions were coded according to their overt gestures, vocalizations and expressions throughout the still face segment, and through the first minute of free interaction after the still-face segment finished. The pilot tested infants were unable to participate in the still-face procedure as they stopped participation before the ESCS based tasks were completed. As the first few infants in the current study participated in the still-face procedure, it became clear to the experimenter that their fatigue and overall negative affect was impacting their affective regulation. Faced with high levels of infant distress post-still-face, caregivers would get up and hold their infants, removing the BabyVibe system before it could be evaluated during the one minute of post-still-face re-engagement. In an attempt to partially ameliorate this effect after the first three infants in the study, toys were provided throughout the still-face procedure.

Coding

From video recordings across the tasks, the coder classified the infants' behaviour into three mutually exclusive categories, based on their communicative function. As per Mundy et al. (2003), canonical Joint Attention Behaviours are those that demonstrate an infant's use of nonverbal behaviours to share the experience of objects or events with others. Of interest in this category were the frequencies with which the infant uses eye contact, pointing and showing to initiate shared attention (IJA), as well as the infant's ability to respond to bids for joint attention by following the caregiver's line of sight and pointing gestures (RJA). Behavioural Requests are the nonverbal behaviours that an infant used to elicit aid in obtaining objects or events (i.e. initiating behavioural responses, or IBR). Infants used eye contact, reaching, giving or pointing to elicit aid. Responses to their caregivers' gestural or verbal requests were also of interest (i.e. responding to behavioural requests, or RBR). Together, these suggest an understanding of intentionality via responses to a caregiver's goal directed behaviour and/or through the infants' use of joint attentional bids for their own instrumental purposes. Social Interaction Behaviours indicate playful, turn-taking interactions with others (e.g. rolling a ball back and forth), theoretically intended to bring another's attentional focus to the self, with the pleasure of interaction as the primary goal (Seibert, Hogan & Mundy, 1987). Again, infants could initiate or respond to turn-taking interactions (i.e. initiating social interactions, or ISI, and responding to social interactions, or RSI). Overall, infant behaviour was coded in terms of category, as well as whether it was an initiation of, or a response to, interaction with the caregiver. This coding system therefore yielded 6 overall composite scores (IJA, RJA, IBR, RBR, ISI and RSI) that together marked a wide range of joint attention behaviours that were present across the various tasks. All of these behaviours were initially coded according to the ESCS coding scheme (see Table 1 for more information), while taking into consideration that the repetition of the typical ESCS format was not present in this study (e.g. percentage scores were divided by the number of trials completed in the current study, rather than the number of trials that a typical ESCS presentation would have had).

Table 1

Summary of Coded Behaviours for ESCS Composite Scores.

Score	Behaviours	Relevant Tasks
IJA (sum)	Eye Contact*, Alternating Eye Contact, Pointing, Showing Toys	Any object based task
RJA (%)	Following Points	Book Presentation, Gaze Following
IBR (sum)	Eye Contact*, Reaching, Pointing, Giving Toys	Any object based task
RBR (%)	Giving OR Overtly Refusing Toys Upon Request	Any object based task
ISI (sum)	Initiation of Turn Taking, Teases, Drops †	Any object based task
RSI (sum)	Moves Hat Toward Head, Maintains Turn Taking, Eye Contact* and/or Physical Responses to Paused Singing	Social Interaction, any object based task

* Eye Contact was coded as only one of IJA, IBR or RSI, depending on the context in which it occurred. Please see the ESCS manual (Mundy, et al., 2003) for more details.
† Drops were included in the recoded, but not the original, ISI scores.

Another marker of infants' social-communicative response to the additional synchronized haptic stimulation was the frequency of their physical responses to maternal singing. More infants were expected to show rhythmic motions in response to the synchronized trimodal experience of song due to the increased salience of its prosodic features and also due to their motivation to maintain a presumably enjoyable experience. This behaviour was counted as present if the infants started to move along with the rhythm of their mothers' singing.

During the administration of this study, infants' global emotional state appeared to impact their performance across the ESCS-based tasks. To explore this possibility, infants' emotions were rated as positive (0), negative (2) or neutral (1), within each task. For a rating of positive affect, the infant would have to display overt positive emotional expressions for more than 75% of the task duration. Similarly, a negative rating required more than 75% of the task duration to be associated with overtly negative emotional expressions. If tasks did not fit the criteria for either a positive or a negative rating, they were labelled as neutral. The mean of these ratings across tasks yielded a global emotional score for each infant.

The emotion regulation variable was operationalized as the duration of time until the infants' first expression of positive emotion after the still-face period. To code for this, and to ensure that the still-face procedure was having the expected pattern of positive/neutral to negative to positive/neutral affect, each infant's affect was coded to show their individual pattern of affect across the phases of the still-face procedure. For the still-face phase and the minute of normal play immediately after still-face, three scores indicated the total number of seconds that an infant spent showing positive, negative and neutral affect. For example, for the 45 seconds of still-face, a typical infant might spend 3 seconds showing positive affect, 15 seconds showing neutral affect and 27 seconds showing negative affect. In addition to these six scores, the coder also recorded the duration of time between the end of the still-face segment and the appearance of the first infant expression of positive emotion during the final minute of normal play. Shorter latencies prior to positive affect would indicate more effective emotion regulation.

Results

Data Exploration and Descriptive Statistics

Emotion Regulation Data. Significant distress was observed during the still-face procedure for the first three infants in this study. To partially ameliorate this, such that caregivers would remain seated and stop removing the BabyVibe system before the final minute of the procedure was complete, toys were provided throughout the procedure. Although this strategy prevented further attrition from the task, this initially inconsistent presentation of toys decreased the already small sample of infants in each (experimental versus control) condition. Of the remaining infants (who all had toys available to them), one outlier (in the experimental condition) was so completely unaffected by the still-face procedure that she displayed absolutely no negative affect and smiled throughout it, and two (also in the experimental condition) faced maternal violations of the still-face protocol (i.e. one mother moved and another laughed at the frustrated noises that the infant was producing). This left only one infant in the experimental condition who had a typical still-face experience and prevented any rigorous observation or statistical comparison of the effects of temporally synchronized haptic stimulation on emotion regulation. The data from the still-face procedure is provided in Table 2.

Tests of Normality. Descriptive statistics were calculated for each remaining dependent variable, as well as for the Average Affect variable, in order to evaluate the normality of their distributions. Outliers were present within two Joint Attention measures: one infant scored relatively high on initiating joint attention (IJA) and one infant scored very low on responding to joint attention (RJA). Although both were further than two standard deviations from the mean performance on their respective tasks, these outliers were not initially removed in consideration of the very small sample size.

Table 2

Duration Data for the Affective States of Participants in the Still-Face Procedure.

	During Still Face			After Still Face				
	Positive (sec)	Neutral (sec)	Negative (sec)	Positive (sec)	Neutral (sec)	Negative (sec)	Latency to Positive (sec)	Procedure Violations (freq)
SYN	0	26	19	0	38	22	60	1
	23	22	0	20	40	0	24	1
	0	37	8	0	60	0	60	0
	0	36	9	0	52	8	60	2
ASYN	0	39	6	0	60	0	60	0
	0	41	4	16	44	0	0	0
	0	22	23	0	44	16	60	0
	0	45	0	17	43	0	31	0

SYN = Synchronous Condition (Experimental), ASYN = Asynchronous Condition (Control)

In small samples, it has been suggested that the $p < .01$ criterion be used to evaluate skewness and kurtosis (Field, 2005). Given the small sample size of this study, the cut off criterion of $p < .01$ was used. Under this criterion, none of the variables examined were found to have significant skew or kurtosis in their distributions. The Rhythm variable was excluded from these initial analyses because it was originally coded as a binary measure and thus could not be considered normally distributed.

Upon exploring the same data graphically, it was apparent that the distribution of responses to joint attention (RJA) was skewed negatively. This indicates that most of the infants in the study performed well when following directive points (i.e. to posters and pictures in a book). Their scores on this variable therefore clustered closer to the high end of the distribution. In fact, of the ten babies tested, only two scored less than 50% correct on this measure. No transformations were applied to the data given that this skew was not significant (and because it was likely driven by one of the outlier scores), but the restricted range within these data should be noted.

Using the Shapiro-Wilk test for normality, only the Initiating Social Interaction (ISI) distribution was significantly not normal at the $p < .05$ level. Closer examination of the data showed that the range of this variable was severely restricted. These data were recoded in order to examine a broader range of performance.

Recoding the ISI Data. The ISI data are composite scores pertaining to task initiation and teases. As described in the coding section and the ESCS manual (Mundy, et al., 2003), infants were given a score of 1 if they initiated the turn taking task (or 0 if not). A score of 2 for (high level) teasing indicated that, at least once over the course of the study, the infants engaged in some forbidden activity while making eye contact with the mother and displaying positive affect. A (low level) tease score of 1 indicated this activity was present but that it only ever occurred with neutral, rather than positive, affect. Added together, these behaviours are reflected by scores ranging from 0-3. These coding guidelines were taken directly from the ESCS, but the highly restricted distribution renders this particular composite scoring method uninformative.

To allow for a more nuanced analysis, a new composite measure was calculated by adding the frequency of high level teases plus the frequency of low level teases to the (unchanged) turn taking initiation score. The frequency of "drops" (i.e. forbidden activity accompanied by eye contact during a display of *negative* emotion) was also included in the new composite. The reason for this addition was the experimenter's observation that this behaviour unfailingly elicited a very familiar pattern of social interaction, however emotionally negative for its participants. Specifically, the mother would get up from her chair, walk to pick up the toy, often sigh or comment on the frequency of this occurrence, and then return to her seat.

The distribution of the recoded ISI data were not significant for tests of kurtosis or skew. They were also normally distributed according to the Shapiro-Wilk test. All of the subsequent statistical analyses were performed using the new ISI composite in place of the previous one.

Main Effects of Joint Attention

Infant Initiated Behaviours. Three of the six composite scores measure the infants' attempts to initiate communication with their parents. Infants in the experimental condition were expected to outperform those in the control group: increased attention to the interaction, plus the reward value of rhythmic stimulation, was presumed to motivate infant attempts to initiate more interaction. Scores for initiating joint attention (IJA) were not significantly different across the experimental conditions, t (4.28) = 0.48, p = 0.64, *ns.* Scores for initiating behavioral responses (IBR) were also not significant, t (5.44) = -0.13, p = 0.89. There was actually a slight reversal of the expected pattern in this measure, with the mean performance for the control group (M = 19.2, SD = 5.35) slightly surpassing that of the experimental group (M = 18.4, SD = 12.38). The difference in the recoded scores for initiating social interaction (ISI) was marginally significant in the expected direction, t (8) = 2.05, p = 0.07 (see Figure 6).

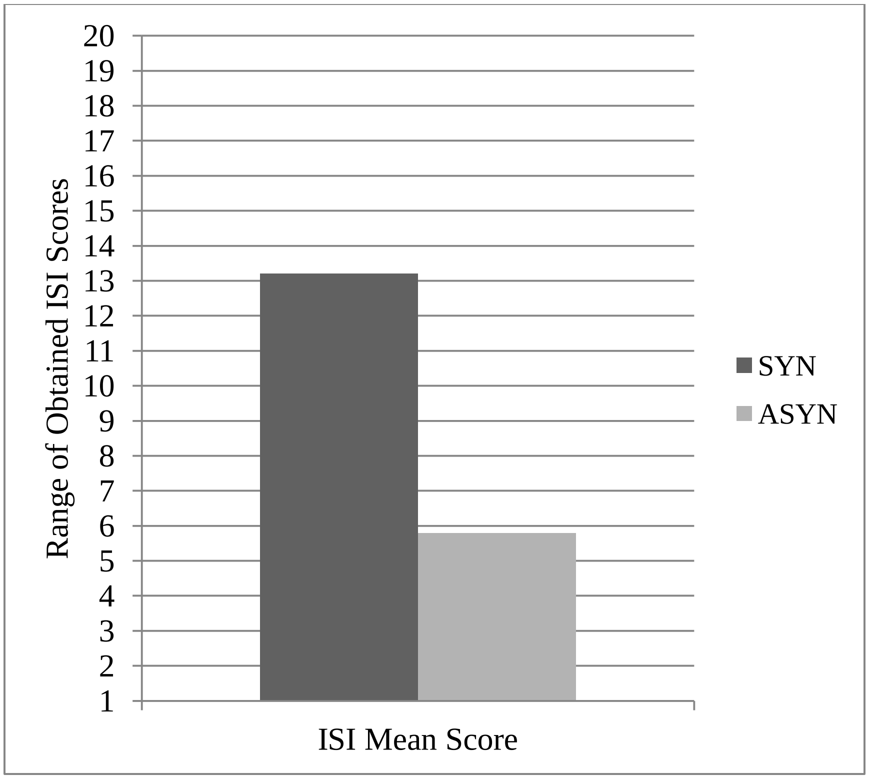

Figure 6. An illustration of the presence and direction of the difference in mean ISI performance between the synchronous (SYN) and asynchronous (ASYN) groups. The Y axis shows the range of the scores obtained across the two groups.

Infant Responsive Behaviours. The other three composite scores based on the ESCS measured infants' responsiveness to their parents' communication. Infants in the experimental condition were expected to outperform those in the control group, again because their increased attention to the interaction would foster more cooperative behaviour in order to maintain the interaction. Scores for responding to social interaction (RSI) were not significantly difference across the two conditions, t (8) = 0.81, p = 0.44, *ns*. There was also no significant difference between the groups responses to joint attention (RJA), t (8) = -0.63, p = 0.54, *ns*. There was another reversal from the expected pattern of results, with the control group (M = 77.5, SD = 18.21) outperforming the experimental group (M = 67.3, SD = 30.96) on this measure. This reversal was likely driven by the presence of the low-scoring outlier in the experimental group. An exploratory t test performed without the outlier remained not significant, t (7) = 0.22, p = 0.82, *ns*, but the reversal was eliminated. Without the outlier, the experimental group yielded a mean of 80 (SD = 14.25). The last score in this section measured the infants' responsiveness to their parents' behavioural requests (RBR). On this score, the experimental group (M = 96.5, SD = 4.04) significantly outperformed the control group (M = 70.2, SD = 12.71), t (4.96) = 4.35, p < 0.01, r = .8 (see Figure 7). It should be noted that one infant in the experimental group was excluded from this analysis. This infant was never given the opportunity to respond to a behavioural request and therefore could not be scored on this measure (he gave the toys back or dropped them on the floor before his mother had the chance to ask for them). A summary of the main effects for the ESCS-based composite scores is provided in Table 3.

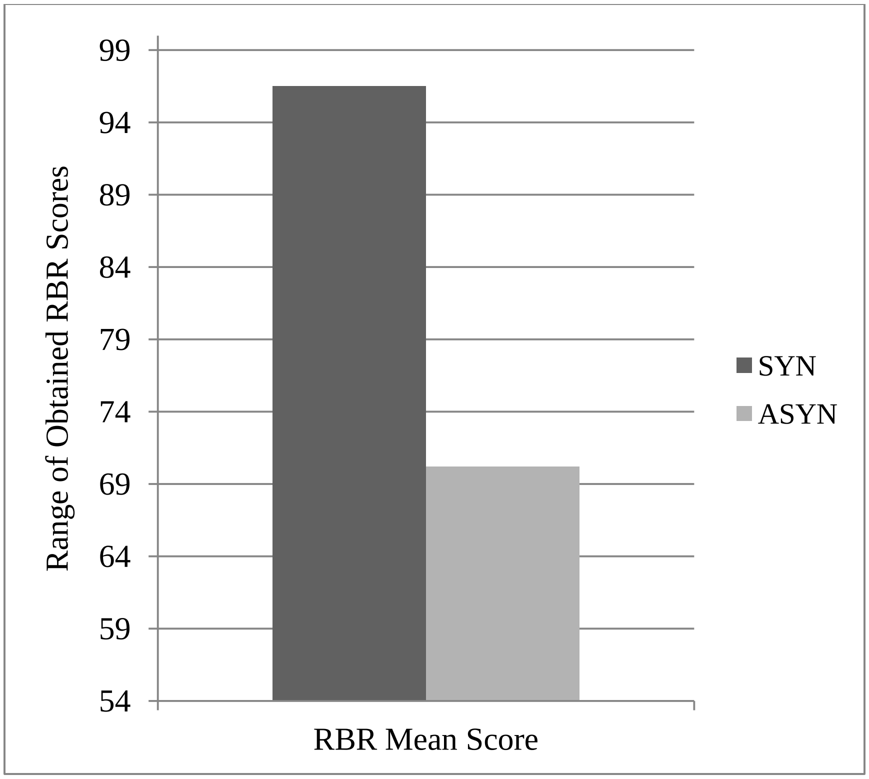

Figure 7. An illustration of the presence and direction of the difference in mean RBR performance between the synchronous (SYN) and asynchronous (ASYN) groups. The Y axis reflects the range of scores actually obtained across the two groups. Although the potential scores for this measure ranged from 0 to 100 percent correct, the scores obtained ranged from 54 to 100 percent correct.

One additional measure of infant responsiveness (Rhythm) was not based on the ESCS; this was scored as the presence or absence of an infant's rhythmic movement while listening to his or her mother sing. Graphical examination of these data indicated that the presence of this behaviour was divided equally between the two conditions and did not warrant further analysis.

Table 3

Summary of Main Effects for ESCS Composite Scores

Composite Scores	t	Sig. (2-tailed)	Mean Difference (SYN-ASYN)	95% Confidence Interval of the Difference	
				Lower	Upper
IJA	0.489	0.649	4.2	-19.029	27.429
IBR	-0.133	0.898	-0.8	-14.713	13.113
ISI*	2.054	0.074	7.4	-0.908	15.708
RSI	0.811	0.441	1.0	-1.843	3.84303
RJA	-0.635	0.543	-10.2	-47.246	26.8464
RBR	**4.358**	**0.007**	**26.3**	**10.756**	**41.844**

*This analysis reflects the recoded ISI scores
IJA = Initiating Joint Attention, IBR = Initiating Behavioural Response, ISI = Initiating Social Interaction, RSI = Responding to Social Interaction, RJA = Responding to Joint Attention, RBR = Responding to Behavioural Requests, SYN = Synchronous Condition (Experimental), ASYN = Asynchronous Condition (Control)

Supplemental Analyses

Gender. To ensure that the significant finding in the RBR measure was not driven by a hidden gender effect, a 2 (condition: experimental, control) X 2 (gender: male, female) ANOVA was conducted on the RBR scores. The interaction term was not significant, F (1, 5) = 0.01, p = 0.94, *ns*, and neither was the main effect of gender, F (1, 5) = 0.01, p = 0.94, *ns*. Similarly, a 2 (condition: experimental, control) X 2 (gender: male, female) ANOVA was conducted on the ISI scores. Again, the interaction term was not significant, F (1, 6) = 0.32, p = 0.58, *ns,* and neither was the main effect of gender, F (1, 6) = 1.21, p = 0.31, *ns.*

Global Emotional State. During the administration of this study, infants' global emotion state appeared to impact their performance across the tasks. To explore this possibility, infants, infants' emotions were rated as positive (0), negative (2) or neutral (1), within each task. The mean of these ratings across tasks yielded a global emotional score for each infant (see Table 4).

Table 4

Ratings of Emotional State Across Conditions and Tasks.

	Tasks							Global Emotional State (per participant)
	TT	OS	RTI	SI	GF	BP	PJ	
SYN	1	1	1	2	1	2	2	1.43
	1	1	1	0	0	1	1	0.71
	0	1	2	0	1	1	1	0.86
	0	0	0	0	1	1	0	0.29
	1	1	1	1	1	1	1	1.0
ASYN	1	1	1	1	2	2	1	1.29
	1	2	1	2	1	1	2	1.43
	0	0	0	0	0	2	1	0.43
	0	0	1	0	1	0	1	0.43
	1	0	2	1	1	1	1	1.0
Mean	0.6	1.0	1.0	0.7	1.0	1.2	1.1	0.89

SYN = Synchronous Condition (Experimental), ASYN = Asynchronous Condition (Control)
Ratings: 0 = Positive, 1 = Neutral, 2 = Negative
Tasks: TT = Turn Taking, OS = Object Spectacle, RTI = Response to Invitation, SI = Social Interaction, GF = Gaze Following, BP = Book Presentation, PJ = Plastic Jar Task

A correlation to global emotional state was calculated for each of the dependent variables. No significant correlations were found with IJA, $r(8) = -0.53$, $p = 0.11$, *ns*, RJA, $r(8) = 0.09$, $p = 0.79$, *ns*, RBR, $r(7) = -0.15$, $p = 0.69$, *ns*, ISI, $r(8) = 0.21$, $p = 0.54$, *ns*, or RSI $r(8) = -0.34$, $p = 0.33$, *ns*. The correlation between the global emotional state and the IBR scores was significant, $r(8) = -0.67$, $p < 0.05$. Further exploration of this relationship was undertaken using ANCOVA. There was still no significant effect of experimental condition on IBR scores after controlling for the effect of emotional state, $F(1, 7) = 0.12$, $p = 0.78$, *ns*.

Discussion

The goal of the present study was to provide a first look at the impact of a supportive system for trimodal stimulation on behaviours related to social communication. The original experimental design included two observational components, one corresponding to joint attention behaviours and the other reflecting the regulation of affect. To investigate whether infants would derive attentional benefits from the synchronized addition of vibrotactile stimulation, a semi-structured set of tasks were used to elicit joint attention behaviours. A measure of infants' physical responses to the rhythm of maternal singing was included to investigate whether the hypothesized attentional benefits of trimodal stimulation would extend to increase the overt dyadic synchrony previously demonstrated in musical contexts (e.g. Longhi, 2009). To evaluate the effects of trimodal stimulation on the regulation of affect, a brief still-face procedure was included. As discussed in the results section, this procedure was ultimately excluded from statistical analyses on the basis of its excessively varied implementation. The results of these measures are addressed in greater detail below. Lastly, specific methodological implications and limitations are discussed, followed by an outline of potential future directions and the conclusions of the present study.

Interpretation of Results

The ESCS based coding of joint attention split the observed behaviours by their communicative intent, as well as according to who initiated the behaviour (infant or caregiver). Canonical joint attention behaviours, in which both parties shared interest in, and attentional focus on, an external object or event, were coded as IJA and RJA. Neither of these two (initiating or responding) scores were significantly different when compared across the experimental conditions. Instrumental joint attention behaviours comprised the initiation of, or the response to, attentional bids that had the purpose of eliciting some helpful behaviour response from the other. For example, reaching for a toy would elicit the helpful behaviour of moving the toy closer. These were coded as IBR and RBR, respectively. Although infants did not show any significant differences in their IBR frequencies across conditions, those in the experimental (synchronous) condition responded to their parents' goal-oriented bids for their attention significantly more (RBR). Joint attention bids intended to share and maintain the pleasure of a social interaction were coded as ISI (for infant initiated bids) and RSI (for responses to parent initiated bids for attention). Infants in the experimental condition showed more frequent bids for initiating familiar patterns of social interaction, and this effect was marginally significant, but only after recalculating the scores to include negative patterns of social interaction. Only one general hypothesis was put forth regarding these joint attention scores: that those in the experimental group would outperform those in the control group on each of the composite scores.

Although the initiating and responding behaviours were not directly compared, the obtained pattern of results supports Mundy and Jarrold's (2010) two system theory of joint attention. They suggested that the initiation of joint attention behaviours hinges on motivation. Infants would only initiate joint attention if they were enjoying an interaction and motivated to prolong it. In accordance with this theory, drawing attention to the dynamics on a neutral or unpleasant interaction would not elicit more joint attention behaviours from infants. How, then, can the ISI finding be explained? If infants were unhappy with the current interaction, it would make sense that they would not only abstain from further engagement in it, but that they might also attempt to shift the interaction to something different. Although global emotional state was not found to significantly correlate with performance on any specific composite score, it should be noted that means of emotional ratings per task were all neutral or slightly negative, except for the turn-taking and social interaction (singing) tasks. These latter two tasks, particularly the singing task, were not specifically designed to elicit IJA or IBR behaviours (versus the object spectacle and plastic jar tasks, in which the infant is faced with an interesting object that he or she is unable to activate without assistance).

The marginal effect of ISI was found only after including disruptive and affectively negative behaviours (i.e. expressing negative affect while dropping objects in order to watch their parents pick them up). Therefore, the ISI behaviour seemed to still be hinged on motivation, but it was perhaps more aversive than appetitive in origin. Of the three composite scores related to infant-initiated joint attention, only this recoded ISI behaviour corresponded to potential attempts to disrupt an interaction. In this context, initiating a behavioural response (IBR) essentially reflected a request for an out of reach object that was already the current focus of the caregiver. If other toys had been visible in the testing room, reaches for or points to toys outside of the interaction at hand might have reflected a similar pattern of results as in ISI. Similarly, a remotely activated toy outside of the task at hand might have elicited IJA behaviours from the infant, for the purpose of drawing his or her caregiver's attention away from the unpleasant or boring activity and toward a shared interest.

An alternative explanation for the ISI effect is that the task that it most depends on (turn-taking) was overall more positively experienced and therefore more engaging. However, only two infants scored a point for initiating turn-taking behaviour (both in the experimental condition); this score was more dependent on the cross-task frequency count of teasing behaviour and of the frustrated dropping of toys.

Infant responses to their caregiver's attentional bids were close to ceiling performance for the RJA and RBR composites. Only one measure (RBR) yielded a significant difference in performance between the experimental and control conditions. It is surely possible that the small sample and correspondingly low statistical power of this study were inadequate to demonstrate an effect. Another potential explanation for this finding lies in the relative complexity of each type of attentional bid. RJA scores were based on infants' ability to follow the gaze and pointing of their caregivers to various posters and pictures. Gaze following behaviour is the earliest observed type of joint attention, appearing at approximately 6 months of age (Scaife & Bruner, 1975). RBR scores were based on the infants' overt responses to their caregivers' requests for them to pass them objects. If an infant passed the requested object, or obviously refused to pass it (by moving it further out of the caregiver's reach or shaking their head "no"), this was counted as a successful trial. To request an object, caregivers verbally asked for it back, usually with an accompanying open palm gesture. Infants could therefore infer their caregiver's intention (to obtain the object) by observing her behaviour. RSI scores reflected three types of responses that were thought to maintain a familiar pattern of social interaction. First, infants were scored for the number of turns that they used to maintain the turn-taking game. Second, infants were scored on their socially appropriate play with a familiar object (i.e. did they move the hat toward the caregiver's head). Third, a frequency count of infant requests for their caregiver to continue singing was recorded. These three behaviours all require a greater understanding of the interaction than that required for the RBR response. For a high RSI score, infants must predict and evaluate how another person will respond to a range of behavioural alternatives. Beyond noticing that their caregiver wants to do something with a toy (as in RBR), turn taking would be facilitated by the knowledge of why the caregiver wants the truck. Playing with the hat in a socially expected manner would require some recognition of the typical social intention to wear hats, rather than to merely obtain them. Using vocalizations and gestures to elicit more singing from their caregiver implies that infants seem to have some awareness that the caregiver will interpret these signals appropriately and comply; after all, no concrete object is there to physically refer to, and these requests are timed and executed more exactly than simple expressions of pleasure or displeasure (i.e. immediately after, rather than during, an enjoyable experience).

Overall, RJA behaviour appears to require the least amount of inference about others' mental states, and RSI behaviour seems to require the most complex predictions of another's potential reactions to one's own potential actions. RBR behaviours involve a more restricted range of responses (giving objects, ignoring the request, denying the request) and require a less complex inference for overt compliance or noncompliance (i.e. it does not matter why a caregiver wants an object, all the infant needs to know is that the object is desired), implying an intermediate level of difficulty. The intersensory redundancy hypothesis posits that intersensory facilitation occurs throughout the lifespan, but only makes a difference in performance on tasks that are relatively difficult for the perceiver (Bahrick, 2010). For this reason, the similar RJA scores between groups in the current study may reflect the ease of this behavioural response, relative to the expertise of the infants. Given the substantial deviations of the current study from the typical presentation of the ESCS, the RSI scores obtained by this study would not be reasonably comparable to the normative samples provided in the supporting literature for the ESCS measure. However, to avoid potential ceiling effects, the ESCS was specifically chosen for its broad range of age applicability (from slightly younger children to those almost three times the age of the current sample). It may be that the RSI scores reflect a level of difficulty that is too high for intersensory facilitation to have any significant effect at 11 months. For instance, only one infant in the current sample attempted to put the hat on his caregiver's head. If intersensory facilitation was found to affect older infants or toddlers, it could be due to facilitated recognition (via prosodic cues) of another's preferences or expectations for the infants' behaviour.

The equivalent distribution of rhythmic engagement across the conditions was particularly surprising. One explanation is that singing may be so inherently salient in infancy that it does not benefit from attentional cues beyond what is naturally available. However, different results may have been obtained if this variable had been coded in terms of duration, rather than according to its overall presence or absence for each infant.

Unfortunately, no statistical analyses were possible for the still-face component of this study. Therefore, no solid conclusions may be drawn regarding the impact of the trimodal stimulation on emotion regulation. It is interesting to note that maternal violations of the still-face procedure only occurred within the experimental condition. The raw data pertaining to the still-face procedure are provided in Appendix D.

In summary, two statistically promising results were obtained, suggesting that synchronized tactile stimulation may be a valuable intervention to support the development of joint attention. Furthermore, the pattern of obtained results is consistent with theories from three different bodies of literature, pointing the way towards a new path for future research at their convergence. As per the joint attention theories that suggest a dissociation between IJA and RJA behaviours in the context of positive motivation, no significant results were found when infants' attention was directed in tasks designed to elicit IJA related behaviours. Since the experimental tasks were found to elicit unexpectedly negative emotionality (implying less positive motivation than normal) and since RJA related behaviours are thought to be less dependent on positive motivation, it explains why the statistical significance was found within one of the three RJA related scores. The fact that statistical significance was obtained only on the RBR score fit with the fourth tenet of the intersensory redundancy hypothesis (i.e., that interesensory facilitation depends on task difficulty relative to expertise), in that the tasks designed to elicit RBR seem to require more complex social knowledge than those for the RJA score, but less than those for the RSI score.

Methodological Limitations and Future Directions

This was a novel and exploratory study with a very small sample size; the most obvious next step is to increase the sample and observe whether the same pattern of results is obtained. Given that motivation seems to be key for many joint attention measures, a more targeted selection of tasks may reduce the effects of fatigue on affect. During the warm-up phase, parents frequently commented that the weight of the BabyVibe system was substantial, and the experimenter observed a few of the infants struggling to maintain an upright, seated position while wearing it. A more compact and lighter version of the system would likely contribute to decreased fatigue as well.

Although the global emotional state was not correlated with any particular composite score in the current study, it should be noted that the coding of this indicator may not have accurately reflected the infants' motivation within the context of specific tasks, or even groups of tasks. On average, infants tended to enjoy the singing and turn-taking activities, but were emotionally neutral or slightly negative in response to the other tasks. The composite scores did not map directly on to the tasks, but were observed across groups of tasks. A more exact measure of affect in conjunction with the behaviours composing each composite score would give a more nuanced description of how and when affect and motivation come into play with joint attention behaviours.

Of course, including a standardized still-face procedure when the infants are alert and engaged would give valuable information regarding the potential for emotion regulation that the current study was unable to evaluate. Beyond the use of still-face, an additional control group may be added to examine the affective responses across tasks between those wearing a vest with no stimulation to the original two groups. Of the two infants who wore the vest without any vibrotactile stimulation, one displayed a global emotional state on par with the average of the infants in this study. The other showed a global emotional state that was more negative than the most unhappy infant included in either of the two conditions. If the weight or discomfort of wearing the BabyVibe system interfered with the soothing and pleasurable effects of the vibration, infants wearing the vest without the benefit of any (synchronous or asynchronous) vibration would be expected to show significantly more negative affect across the tasks. Of course, a larger sample would be required to properly evaluate this idea.

The use of the mother's voice in the current study required compromises such as the attenuated length and lack of repetition in the ESCS tasks. It is possible that a more traditional ESCS set up (i.e. where the infant would interact directly with an experimenter) would allow for a longer and more observationally robust measure.

Overall, this study was very ambitious in attempting to evaluate the potential for improved emotion regulation and various joint attention behaviours on the basis of a theory that had not only never been tested with artificially synchronized tactile stimulation, but also had been only theoretically extended beyond experimental observations in 8 month old infants. Perhaps a simplified approach to exploring these phenomena in younger infants, using simpler tasks and/or with bimodal (artificially synchronized touch plus either visual or auditory) stimulation would be helpful in establishing a more solid body of evidence prior to exploring broader applications in later development.

Conclusions

This study demonstrated the benefit of synchronized artificial tactile stimulation on at least one major facet of joint attention in typically developing infants. With this stimulation, infants were significantly more likely to respond to their parents' behavioural requests. The broader impact of this finding is that synchronized tactile stimulation may be a fruitful avenue for future research to explore supportive devices for disorders involving joint attention deficits (e.g. autism spectrum disorders) or to engage the attention of typically developing infants in a more robust manner. It is possible that the remaining metrics of joint attention would also be positively influenced by synchronized tactile stimulation; future work on this question would benefit from a larger sample size to ensure adequate power. This novel study contributes to the connection of three important bodies of literature in developmental science: joint attention, tactile stimulation and intersensory redundancy. The intersection of these fields appears to hold great promise for the development of supportive communication technologies in early life.

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Appendix A:

BabyVibe Safety Evaluation

PS

FIELD EVALUATION REPORT
MEDICAL EQUIPMENT

DATE	July 20, 2010	OFFICE	Toronto	QFE 32041-28
REPORT BY	Jack Leung	ATTENTION	Mr. Chong	
CUSTOMER	Hospital For Sick Children	Location of Inspection	555 UNIVERSITY AVE., TOR., ONT., M5G 1X8, On	
PRODUCT	Speaker vest			
Manufacturer's Name	The child lab	Cat/ Model No	Milk Vest	

Electrical Rating 5 V ☐AC ☒DC	dcHz	250m ☒A ☐W ☐VA	n/aPh	n/aHP
Warning/Danger Notices ☐ See Alterations ☒ See Notes	☐ Cord Connected ☐ Permanently Connected ☒ Battery Operated	n/aWire + GND	Class II	Type B

DECLARATION

The following technical requirements were used in the evaluation of the product covered in this report.

CSA standard(s)C22.2 No(s)601.1 as a guide ☒**Provincial Guidelines** ☒**CSA Model Code SPE 1000**

UL standard(s) ☐**CEC Code** ☐**NEC Code**

Test Equipment Used ☒**Dielectric Tester-#5019** ☒**Safety Analyzer#5045** ☐**Other**

ALTERATIONS ☐ **NONE REQUIRED- THIS MODEL IS IN COMPLIANCE WITH ABOVE LISTED REQUIREMENTS**

WHEN IMPLEMENTATION OF THE ALTERATIONS IDENTIFIED CANNOT BE COMPLETED DURING THE INSPECTION VISIT, YOU ARE REQUIRED TO CONTACT QPS IN A REASONABLE AMOUNT OF TIME AFTER COMPLETION FOR A FOLLOW-UP INSPECTION

FOLLOW-UP INSPECTION REQUIRED: ☐**YES** ☒ **NO The alterations listed below have been incorporated in the labeled product**

1.	**Provide battery fuses as close to the positive terminals as possible rated as 0.5A** - O.K.
2	**Provide nameplate with electrical rating model and s/n** - EMAIL PIC JUL 29/10
	TBD

Notes:	
1.	**Unit is battery operated with 4x1.5V alkaline batteries AAA type**
2.	
3.	
4	
5	
6	
7	
8	
9	

Note: Evaluation made under the Field Evaluation Service shall not be considered as the equivalent of Certification.
Ontario regulations require Manufacturers of electrical equipment selling products for the Ontario Market to register their company with ESA
Equipment specifications and Calibration Information is kept on file at QPS and is traceable through the Unique ID number.
The inspection report shall only be reproduced in full with the approval of the inspection body and the client.

QSD 102MP Rev 04 Issue Date: 10/05 Rev Date: 5/09

DATE	July 20, 2010	OFFICE	Toronto	QFE 32041-28

TESTS				
Dielectric Strength	500V ☒ AC ☐ DC	☒ PASS ☐ FAIL, SEE ALTERATIONS ☐ PENDING		
Between Lines and Patient Leads	V ☐ AC ☐ DC	☐ PASS ☐ FAIL, SEE ALTERATIONS ☐ PENDING ☒ N/A		
Between Ground and Patient Leads	V ☐ AC ☐ DC	☐ PASS ☐ FAIL, SEE ALTERATIONS ☐ PENDING ☒ N/A		
Flame test	Colour	☐ TOP ☐ SIDE ☐ BOTTOM		☐ PASS ☐ FAIL, SEE ALTERATIONS ☒ SEE NOTES
Strain Relief	☐ PASS ☐ FAIL, SEE ALTERATIONS ☐ PENDING ☒ SEE NOTES	**Accessibility to Live Parts**		☒ PASS ☐ FAIL, SEE ALTERATIONS ☐ PENDING ☐ SEE NOTES
Leakage Current see table mA	☐ PASS ☐ FAIL, See Alterations ☐ SEE NOTES	Maximum Risk Current see table µA Maximum Patient Leads Risk Current n/a µA		

		Leakage Current in µA			
		Polarity			
		Normal		Reverse	
Unit Serial Number	**Label Number**	GC/NC	GO/NO	GC/NC	GO/NO
See attached	See attached	Max 14			

Note: Evaluation made under the Field Evaluation Service shall not be considered as the equivalent of Certification.
Ontario regulations require Manufacturers of electrical equipment selling products for the Ontario Market to register their company with ESA
Equipment specifications and Calibration Information is kept on file at QPS and is traceable through the Unique ID number.
The inspection report shall only be reproduced in full with the approval of the inspection body and the client.

Multiple Serial Number Form

Inspection Date: July 20, 2010	Inspection Number: QFE 32041-28
Serial Number	**Label Number**
20-07-10	QHS55254

Appendix B:

Consent Form

Cognition • Health • Infancy
Learning • Development

Study Name:	______________
Researcher:	______________
Participant Number:	__________
Date:	______________

PARTICIPANT CONSENT FORM

RESEARCH PROJECT TITLE: The Effects of Multimodal Interaction on Joint Attention

PURPOSE: The purpose of the study is to help us understand whether stimulation across multiple senses can enhance joint attention and social interaction in infants.

This consent form, a copy of which will be left with you for your reference, is only part of the process of informed consent. It should give you the basic idea of what the research is about and what your participation will involve. If you would like more detail about something mentioned here, or information not included here, you should feel free to ask at any time before, during or after the study. Please take the time to read this carefully and to understand any accompanying information. If you have questions or concerns regarding your participation in research, please contact the Ryerson University Research Ethics Board.

PROCEDURE: We are developing a new study to explore how babies between 6-24 months regulate their social and emotional connection to their moms. To support these important social-emotional links, we have developed a vibrating vest designed by faculty at Ryerson. Our vest is similar to the vibrating Fischer Price chairs that are marketed to calm down infants and toddlers. With our vest, however, your voice will generate the vibration with a little microphone that wirelessly transmits voice patterns to the vest. During this pilot session, you will wear the microphone while your baby wears the vest. You will be asked to interact with your baby by talking to him or her as you explore various toys together. We are interested in observing your baby's reaction to your voice as he or she wears the vest and interacts with you. There are no right or wrong answers. Sometimes babies are very interested in the toys at the lab and sometimes they are not as interested. Both of these are normal responses and do not say anything about your child's development. We ask that you try to engage your baby's attention with the toys as you would during a normal playtime session. After a brief warm-up period, you will be asked to engage your baby's attention in a few semi-structured activities (e.g. rolling a ball back and forth, pointing to pictures on the wall). The researcher will be able to observe you and your infant through a one way mirror, and will communicate what to do next through a wireless headset that you will wear. During these activities, you will be asked not to respond to your infant for a period of two minutes. Infants typically try to get their caregivers' attention during this period, and may appear somewhat fussy. After the two minute period has elapsed, you will be asked to play with your infant as you would at home. Lastly, you will exit to the waiting room and debrief with the researcher for a few minutes. Between the warm up period and the debriefing, the semi-structured part of the study should last approximately 30 minutes and will be video-taped for analysis purposes at a later date. Including the warm up and debriefing, we expect that you would be in our lab for no more than 1 hour.

POTENTIAL RISKS AND BENEFITS: The only potential risk for participation is that your baby may become disinterested in the task and display more fussiness than is usual for him or her. However, you are free to take a break to address any needs of their infant or to discontinue the session at any time. The researcher will also closely monitor your infant's readiness to continue.

As for the potential benefits, you have the opportunity to learn more about infant development. In addition, we expect that this session will be fun for your infant as he or she can explore various toys with you. Importantly, although not a direct benefit to participants, the findings from this pilot session will help us in developing our future studies of multimodal interaction. This has the potential to extend previous research and contribute to the question concerning how joint attention develops in infancy.

CONFIDENTIALITY: Any information that is obtained in connection with this study will remain strictly confidential. Your privacy and that of your infant will be respected. Should you at any time wish not to be contacted for future studies, please tell a member of the lab, and we will be happy to remove your name from contact list. All records will be referred to in the study using pseudonyms and study codes which will be securely stored on a local password-protected network and locked in the CHILD lab. The questionnaires and any other hard copy information pertaining to this study will be stored in a separate locked filing cabinet from the consent forms in the laboratory. Sessions are video-taped in order to allow the researcher to examine the records of observations at a future date. All video-recordings will be used strictly for research purposes and can only be accessed by those directly involved in the study. These images, like the rest of your child's information, are stored separately from information identifying your child. Most academic journals require raw data to be stored for 5 years post-publication. Therefore, the data will be stored for this period of time before it will be destroyed.

PARTICIPATION: Your participation is voluntary. You are not under any obligation to answer any questions. If at any time you wish to withdraw from this study and session, you may do so without any consequences by simply notifying the researcher. You also have the option of removing your infant's records of observation from the study or requesting that the session not be video-taped. Your choice of whether or not to participate will not influence your future relations with Ryerson University.

ADDITIONAL INFORMATION: Because of the unique needs of infants, a variety of special procedures are in place to ensure your baby is safe and comfortable during each component of the study. In the waiting area, the toys provided for the infants to play with are age-appropriate. All of the materials used during the experiment are designed and built to be safe for babies with smooth rounded edges and the use of non-toxic paint. All toys are sterilized with a baby-safe cleaning agent after each session with an individual infant. In addition, the tasks are designed to be very engaging for infants at this age. The trials are conducted in a "game-like" fashion which infants typically enjoy. Infants will remain with their caregiver at all times. The caregiver and researcher will continually monitor the baby's emotional state and readiness to continue. The sessions can also be paused to address any feeding or changing issues that arise and a clean and private area of the lab is provided for these purposes.

FEEDBACK: We hope that you are interested in the research and we will be happy to answer any further questions you might have about it at any time. If you wish to be informed about the results of this study, please leave your phone number and/or e-mail address and you will be contacted upon the completion of this project. If you do not wish to be contacted and are still interested in the results of the study then you may obtain information about the results by contacting us.

COMPENSATION: As a token of our appreciation for taking part in our study, you and your child will receive a small gift bag containing a small children's book or toy to take home with them for their efforts. You and your child will receive this complimentary gift regardless of whether your child completes the study.

RESEARCHERS:

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CONSENT: I agree to have my son/daughter, ________________________________ , participate in the study described above. I have read the description of the study and I understand the details of the procedure. As part of my consent, I agree to be videotaped during the experimental session. I realize that I may withdraw my child from the study at any time if I wish to do so.

______________________________	______________________________
Name of Parent/Guardian	Signature of Parent/Guardian
______________________________	______________________________
Signature of Researcher	Date