Multisensory Integration in Social and Nonsocial Events and Emerging Language in Toddlers

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ABSTRACT

Multisensory integration enables young children to combine information across their senses to create rich, coordinated perceptual experiences. Events with high intersensory redundancy *across* the senses provide salient experiences which aid in the integration process and facilitate perceptual learning. Thus, this study's first objective was to evaluate if toddlers' multisensory integration abilities generalize across social/nonsocial conditions, and if multisensory integration abilities predict 24-month-old's language development. Additionally, previous research has not examined contextual factors, such as socioeconomic status or parenting behaviors, that may influence the development of multisensory integration skills. As such, this study's second aim was to evaluate whether maternal sensitivity and SES moderate the proposed relationship between multisensory integration and language outcomes. Results indicated that toddlers' multisensory integration abilities, $F(1,33) = 4.191$, $p = .049$, but not their general attention control skills, differed as a function of condition (social or nonsocial), and that social multisensory integration significantly predicted toddlers' expressive vocabularies at 24-months old, $\beta = .530$, $p = .007$. However, no evidence was found to suggest that SES or maternal sensitivity moderated the detected relationship between multisensory integration abilities and language outcomes; rather, mothers' maternal sensitivity scores directly predicted toddlers' expressive language outcomes, $\beta = .320$, $p = .044$, in addition to their social multisensory integration skills. These findings suggest that at 24-months of age, both sensitive maternal behaviors and the ability to integrate social multisensory information are important to the development of early expressive language outcomes.

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GENERAL AUDIENCE ABSTRACT

Multisensory integration allows children to make sense of information received across their senses. Previous research has shown that events containing simultaneous and overlapping sensory information aid children in learning about objects. However, research has yet to evaluate whether children's' multisensory integration abilities are related to language learning. Thus, this study's first goal was to look at whether toddlers are equally skilled at integrating multisensory information in social and nonsocial contexts, and if multisensory integration skills are related to toddlers' language skills. This study's second goal was to examine whether parenting behaviors and/or familial access to resources (i.e., socioeconomic status) play a role in the hypothesized relationship between multisensory integration and language in toddlerhood. Results indicated that toddlers show better multisensory integration abilities when viewing social as opposed to nonsocial sensory information, and that social multisensory integration skills were significantly related to their language skills. Also, maternal parenting behaviors, but not socioeconomic status, were significantly related to toddlers' language abilities. These findings suggest that at 24-months of age, both sensitive maternal parenting and the ability to integrate social multisensory information are important to the development of language in toddlerhood.

Table of Contents

1. Introduction

Over the first few years of life, children learn and adapt at a rapid rate as they frequently encounter both frustrations and successes in beginning to navigate their environment. Among the many challenging problems children undertake, language learning is one of the more remarkable and complex of those tasks (Yu, Ballard, & Aslin, 2005). To become language competent, infants need to not only detect/recognize their own native language, but also to interpret and eventually produce language. In fact, to do so requires that an infant be able to identify sounds as speech and to spatially locate the speaker, all before she is able to infer meaning from the speech itself (Gomez & Gerken, 2000). Clearly, an important and yet often overlooked first step for language development is a child's ability to attend to and to stay focused on communicative partners. It is for this reason that selective attention is a critical and foundational component of language learning and cognitive development (Bahrick & Todd, 2018). Thus, the primary aim of this study was to examine if toddlers' early attention and perceptual skills (i.e. multisensory integration abilities) when viewing both social and nonsocial dynamic displays predict language development.

Selective attention can be operationalized as the integration of information obtained via an infant's visual, auditory, and motor systems, observed through behaviors such as grasping or orienting the head/body (Bahrick & Todd, 2018). Children who exhibit significant difficulties processing and integrating information across visual and auditory domains are often candidates for Specific Language Impairments (SLI) or developmental disorders (Spaulding, Plante, & Vance, 2008). In these instances, children demonstrate marked challenges in sustained attention under high attentional load tasks, or in integrating multisensory information (Bahrick & Todd, 2018). However, it is important to note that the literature reveals much variability in attention-related multisensory processing, even among typically developing children, which is as of yet largely unaccounted for (Mahone & Schneider, 2012). Therefore, the reason to look at attention and multisensory integration in typically developing toddlers is twofold: first, to more comprehensively understand both the social and environmental factors that may facilitate or inhibit these processes; and second, to elucidate early warning signs for children with perceptual difficulties who may be at risk for SLI or developmental disorders in the future.

Naturally occurring events are frequently multisensory in nature, meaning that they concurrently provide information across sensory systems (Bahrick & Lickliter, 2004). For example, a child stacking blocks with her mother will simultaneously receive auditory, visual, and tactile information. But how do young children, with limited attention capabilities and developing perceptual systems, integrate information across the senses to learn about objects and events in their environment? According to Bahrick and Lickliter's (2004) Intersensory Redundancy Hypothesis (IRH), infants are able to perceive a unitary experience of a multisensory event by detecting amodal information, defined as "synchrony, rhythm, tempo, and intensity" across sensory modalities (p. 137). In other words, the senses provide overlapping, concurrent stimulation that allow infants to selectively attend to an individual, integrative event (Bahrick, Lickliter, & Flom, 2004). Such overlapping information is referred to as amodal because the nature of what is perceived is not tied to just one sensory input (e.g., intensity can be seen, heard, and/or felt by the perceiver). Therefore, in returning to the previous example, the sight, sound, and touch of blocks being stacked are concurrent and originate from the same location, whereas the speech and facial expressions from the child's mother share rhythmic and temporal synchronicity about the activity.

Given the importance of multisensory integration in learning about the perceptual properties of objects nested within larger events (e.g., a parent-child interaction), it is reasonable to question whether multisensory integration is also predictive of language outcomes. Previous research has demonstrated that infants are able to rapidly and efficiently identify sources of intersensory redundancy, and that this leads to greater perceptual learning than exposure to unimodal events, especially among young infants (Bahrick & Lickliter, 2004). For example, Bahrick and Lickliter (2004) found that 5-month old infants are able to detect temporal and rhythmic changes, also known as amodal discrimination, in dynamic object presentations. In this study, 5-month-olds viewed and heard a toy hammer hitting a surface. After several presentations, the infants then experienced either a bimodal tempo change (i.e. infants observed the hammer visually and auditorily change tempo) or a unimodal tempo change (i.e. infants observed the hammer visually change tempo without sound). The results indicated that at 5 months, infants were equally capable of discriminating a change in both the bimodal (audio-visual) and unimodal (visual) condition. In contrast, while 3-month old infants were able to notice the change in the bimodal condition, they failed to detect the same changes in a unimodal (visual) only condition, as measured by visual fixations. That is, without redundant sensory information, younger infants, but not older infants, were unable to detect amodal changes in non-social events.

Evidently, as infants become more experienced perceivers and attenders, they rely less on intersensory redundancy in order to make inferences about their environment. However, it would stand to reason that as events become more challenging and complex, the ability to detect amodal changes in events also becomes more difficult because it requires greater perceptual differentiation and increased attentional resources (Bahrick et al., 2010). For example, Bahrick et al. (2010) found that as task difficulty increased, 5-month-old infants reverted to relying on intersensory redundant, bimodal conditions, as opposed to unimodal conditions, in order to perceive more subtle tempo changes. These results suggest that the ability to integrate multisensory information and to perceive changes in amodal information develops across childhood and is significantly influenced by task complexity. Therefore, it stands to reason that the ability to integrate multisensory information may play a critical role in language development, given the inherent complexity and challenges involved in language learning. However, research has yet to evaluate whether toddlers' abilities to integrate multisensory information in tasks of varying complexities predict subsequent word learning.

Developing Multisensory Integration of Social and Nonsocial Events

The ability to integrate multisensory information requires that a young child must first allocate her attention to a particular event. Thus, over the course of early childhood, attention skills continuously coalesce and improve. This allows children to more effectively engage in effortful attention control, which engenders more complex play, superior motor-control, and increased word learning (Ruff & Lawson, 1990). In order to learn about specific objects in an information-rich environment, and/or to focus on an interaction with a social partner, not only must children focus their attention to a source of interest, but they must also inhibit attention toward irrelevant albeit concurrent events (Fisher, Godwin, & Seltman, 2014).

In a study conducted by Richards (2010), English-learning 12-, 18- and 24-month-old infants watched short "Sesame Street" clips that were presented normally in English, normally in Spanish, or with a backwards audio track in English. Thus, the children were presented with two of three clips that were incomprehensible to them (Spanish and backwards English).

Interestingly, infants attended equally to the English and Spanish speaking video clips and only looked significantly less frequently and for a shorter duration at the backwards English clip, which highlights two critical findings. First, this demonstrates that infants in this age range are motivated to selectively attend to visual+auditory streams that involve language and typical speech patterns, regardless of whether the lexical information is accessible to them. Second, that infants in this age range are aware of and less engaged by mismatched intersensory information, which suggests that multisensory integration and attention are vital, interdependent process that together may play an integral role in the development of early language abilities.

Previous research has also suggested that sustained attention is driven by a combination of exogenous (i.e. automatic, stimulus-based features) and endogenous factors (i.e. intentional, directed features based on goals or prior knowledge) (Fisher, Godwin, & Seltman, 2014; Tummeltshammer, Mareschal, & Kirkham, 2014). Moreover, it has been shown that over the course of infancy and toddlerhood, there is a gradual shift from highly exogenous-driven attention to more endogenous (i.e., voluntary) attention. For example, Tummeltshammer Mareschal and Kirkham (2014) report that very young infants will orient to highly salient, "attractive" objects, and often have difficulty diverting their attention. In contrast, 9-month olds are able to not only suppress attention toward peripheral distracting objects, but in a given experiment they can also learn that looking toward distractor objects stops the movement of a more attractive, central stimulus on a TV screen, as indicated by the frequency and duration of eye-gaze. These findings illustrate that in addition to exhibiting increased attention and inhibitory control skills, infants begin to associate their attentional behaviors with an ability to manipulate and predict information about their environment.

Young children are frequently exposed to environments with numerous novel objects and speakers, in addition to a multitude of competing sights and sounds (Kannass & Oakes, 2008). Thus, dynamic, multisensory laboratory displays containing multiple competing events may be more representative of children's natural environments. Starting early in life, infants frequently encounter objects in their environment and learn about objects' spatial and perceptual properties. For example, eye tracking technology illustrates that 4-month-olds are able to make visual predictions about where an object traveling in a linear pattern will be when briefly occluded, and that 7-month-olds can individuate similar-looking objects by their auditory properties (Brower & Wilcox, 2011; Kubicek, Jovanovic, & Schwarzer, 2017). Thus, by two years of age, toddlers have had numerous interactions with objects that elicit multisensory information and are skilled at processing dynamic displays of objects.

In order to become competent social partners, however, children must also be able to both process and maintain attention toward social events, such as dynamic, audiovisual displays of speakers, even in high attention competition environments. Research suggests that faces and voices are highly salient during early development, resulting in a preference for social events in comparison to nonsocial events that is evident as early as 3 months of age (Bahrick et al., 2014). For example, starting in 5-month-olds, research has found greater cortical activation in response to social dynamic events, such as a female playing "peek-a-boo," in comparison to nonsocial dynamic events, such as mechanical toys moving (Lloyd-Fox et al., 2009). In summary, the literature suggests that by two years of age, many toddlers are skilled at processing dynamic face+voice and object+sound events. In the current study, multisensory integration abilities were assessed in both social and nonsocial conditions to evaluate if multisensory integration abilities generalize across conditions, and to examine whether social, nonsocial, or both social and nonsocial multisensory integration abilities predict toddlers' language outcomes.

Environmental Factors that May Influence Multisensory Integration

In addition to the child-centered skills (e.g., focused attention) discussed above, other contextual factors may also play a role in either promoting or attenuating their emerging success in multisensory processing. It was predicted that aspects of early experiences that are associated with children's developmental milieu and circumstances (e.g., socioeconomic status) as well as characteristics of their caretakers (e.g., maternal sensitivity) may co-act in ways that affect the hypothesized relationship between toddlers' multisensory perception and language outcomes.

Socioeconomic status (SES). Socioeconomic status, a proxy variable that represents social class, influences early childhood development as it captures individuals' access to resources (American Psychological Association, 2018). Notable differences have been observed in the cognitive functioning and linguistic abilities in children from low socioeconomic status families. For example, research has shown that by 10-months of age, low-SES infants demonstrate deficits in language (i.e. speech comprehension and expressive language) and attention control capabilities (e.g., orienting attention and inhibiting attention to inferring cues), in addition to reduced oral and manual object exploration behaviors (Hackman et al., 2014; Clearfield, et al., 2013; Demir & Kuntay, 2014). Moreover, Hoff (in Bornstein & Bradley, 2003) suggests that observed SES-related differences in parenting practices and the language learning environment (i.e. the frequency of explicit maternal object labeling and book reading activities) influence children's developing language abilities by 2-years of age.

Demir and Kuntay's (2014) review of longitudinal studies suggest that SES-related deficits may have a cascading effect on development, such that early impairments in attention control and speech-processing abilities hinder later language and cognitive development. As such, an additional aim of this study was to examine whether SES moderates the predicted relationship between toddlers' developing multisensory skills and language development.

Maternal sensitivity. In early infancy, attention is heavily influenced by an infant's caregiver as cognitive control capabilities are underdeveloped. For example, when an infant is engaged in a distressing event, a mother might redirect her infant's attention as a means of soothing her child (Rothbart, Sheese, Rueda, & Posner, 2011). As cortical executive function networks develop across infancy and into toddlerhood, children gain increased volitional attention and cognitive control, which aids in the ability to selectively attend to one's environment and integrate multisensory information (Rothbart, Sheese, Rueda, & Posner, 2011). It is therefore not surprising that many toddlers can redirect their own attention to a comforting toy, for example, when experiencing a distressing event. Thus, it appears that caregivers' sensitivity to their infants' environment and appropriate engagement with their child may play a critical role in shaping cognitive development and early attentional strategies. Just as infant attention and perceptual development is not an individual, isolated process, neither is language development. Infants frequently learn about themselves and their environment through interactions with others.

In any given context, there are many ways that a caretaker can respond to, or initiate an action with her child, thereby facilitating a shared experience. For example, a mother could use an infant-directed style and bring an object closer to the child's point of view, and/or she could point to an object her child is looking at and provide rich, descriptive information about its properties. Conversely, she could interrupt her child's attention toward a toy to show him/her a new object, or in a moment of distress, she could unintentionally disregard her child's bid for attention. In these examples, what varies is not only the mother's response (or lack thereof) to her child, but also the way in which the mother engages in a manner that is sensitive to her child's interests and attention. Maternal sensitivity can therefore be understood as a mother's ability to behave in a manner that is contingent, cooperative, and accessible during parent-child interactions (Meins, et al. 2001).

Although toddlers spend a considerable amount of their time within the home environment (Perlman et al., 2014), as of 2019, no studies appear to have specifically investigated the role maternal sensitivity may play on children's developing multisensory integration system. Research has found that parenting behaviors influence language development, but most of these studies have assessed either general parenting behaviors (e.g., parent-child book reading) or parental language (e.g., quantity of negative or intrusive utterances). Only a few studies have reported a link between maternally sensitive behavior and language development, such as Tamis-Lemonda, Bornstein, and Baumwell's (2001) research examining maternal responsivity during infants' first year of life as it influences later language outcomes.

In contrast, the existing literature examining maternal sensitivity with respect to language development has more frequently been conducted in at-risk child populations, such as with children with developmental delays or auditory/verbal disorders (Baker et al., 2010; Neuhauser et al., 2018; Quittner et al., 2013). By far, most of the maternal sensitivity literature has focused on infant attachment, affect regulation, and early attention development (Kogan & Carter, 1996; Mastergeorge, et al., 2014; Meins, et al. 2001). Given the inherent frustrations children experience when faced with the task of language learning, however, it stands to reason that maternal sensitivity may support and sculpt language outcomes by providing children with increased opportunities to experience language-relevant, multisensory information in a social context. Thus, as a secondary focus, this study has integrated concepts across cognitive, linguistic, and social domains of psychology to uniquely evaluate the contribution of maternal sensitivity on the proposed relationship between multisensory integration and emerging language in typically developing toddlers.

Current Study

The current study sought to examine relations between toddlers' social and nonsocial multisensory integration abilities and subsequent language skills using two novel developmental protocols (the MAAP and the IPEP; Bahrick & Todd, 2018). These protocols provide a useful platform with which to examine toddlers' differential abilities to integrate multisensory information in both social and nonsocial contexts. Specifically, this study aimed to evaluate both toddlers' multisensory integration and attention skills when viewing complex and dynamic, audiovisual displays. First, it was hypothesized that toddlers would display superior multisensory integration abilities during social events, and that social multisensory integration abilities, as opposed to nonsocial multisensory integration abilities, would be predictive of toddlers' vocabularies. In this sense, it was predicted that there would be a positive relationship between toddlers' ability to integrate multisensory information and language development, such that toddlers who demonstrated deficits in the multisensory integration tasks would exhibit below average vocabularies and toddlers with strong multisensory integration abilities would exhibit high vocabularies. Second, it was hypothesized that maternal sensitivity and socioeconomic status would moderate this relationship.

2. Method

Participants

The final sample consisted of 41, 24-month-olds and their mothers (Toddlers' Mean age = 23.8 months, range = 22-26 months, 22 females). All toddlers were born full-term and had no known developmental difficulties or hearing/vision impairments. An additional five toddlers participated but were excluded from the analyses due to fussiness (n = 4) or equipment failure (n = 1). Among the final sample, 80% of the toddlers were Caucasian and 90% of the toddlers had at least one parent with a 4-year college degree or higher. Toddlers and their mothers were recruited in Blacksburg and Roanoke and surrounding areas. Parents were compensated $30 and toddlers picked out a small toy for their family’s participation. The research protocol (“Multisensory Integration in Social and Non-social Events and Emerging Language in Toddlers”, protocol number: 18-254) was approved by the Institutional Review Board at Virginia Tech (see Appendix A).

Measures

Multinet demographic questionnaire. The demographic questionnaire (Appendix B) included a set of questions that assessed aspects about the child’s environment, in addition to information such as the child’s gender, race/ethnicity, and date of birth.

Socioeconomic Status (SES). Socioeconomic status was measured by assessing familial income and both mothers’ and fathers’ education as reported on the demographic questionnaire (Appendix B). Using a 7-point scale, the caretaker reported their familial income (ranging from less than $5,000 to $200,000 or more). Using a 6-point scale, the caretaker reported the mother’s and father’s highest level of educational attainment (ranging from Grades 1-8 to doctoral degree), which was averaged to generate a familial education value. A composite SES score was constructed by combining the familial income and education values, with possible scores ranging from 2 (low) – 13 (high).

MacArthur-Bates Communicative Development Inventories (MCDI). Early language skills (i.e., expressive vocabulary) were assessed via parent report using the MacArthur-Bates Communicative Development Inventories, Words and Sentences form (MCDI-W&S). The MCDI-W&S is a vocabulary checklist of 680-items divided into 22 semantic categories that is normed for children 16–30 months of age. Parents were instructed to mark only the words their child understands and says. Toddlers' expressive vocabulary scores were generated using the MCDI Scoring Program software which computes vocabulary percentiles standardized by participants' age and gender. The MCDI has established high reliability and external validity in studies of both late-talking and normal language-developing toddlers (Heilmann et al., 2005).

Primary Experimental Tasks

The Multisensory Attention Assessment Protocol (MAAP).

***Stimuli and apparatus*.** Toddlers' multisensory attention skills were measured using the MAAP (Bahrick & Todd, 2018). On each trial, toddlers viewed two lateral, 12s events (23.5cm x 15cm each, framed by 1cm of black space) while they heard a soundtrack that was synchronous with only one of the two lateral events. The lateral displays depicted two types of events: 1) Social – women telling children's stories using infant-directed speech, or 2) Nonsocial – objects (e.g., wooden blocks, spools, and metal nuts) hitting a surface in an erratic pattern. Toddlers viewed 12 social trials and 12 nonsocial trials, resulting in a total of 24 trials. Two pairs of actresses were used for the social events, and two pairs of objects were used for the nonsocial events, resulting in four actresses or objects for each event type. The videos were bright, colorful, and made to be attention-capturing for young children. Digital video clips of three geometric animations (i.e. a floating shape that morphs from a ball to a square, multiple spirals, and expanding and contracting lines and angles) were presented in the center of the screen for 3s in order to orient toddlers' attention at the start of each trial. These images were counterbalanced across the different event types, and a different animation was presented for each block of trials.

Indices in MAAP. The MAAP measures three primary domains of interest: intersensory matching, attention maintenance, and speed of shifting (Bahrick & Todd, 2018). In this protocol, the intersensory matching index directly measured toddlers' multisensory integration capabilities, while the attention maintenance and speed of shifting indices measured children's broader attentional control abilities. Thus, although attention control is thought to be related to multisensory integration, measures of toddlers' attention control are nonetheless conceptually distinct from their multisensory integration skills.

Intersensory matching refers to toddlers' ability to both detect and sustain attention to the synchronous, audiovisual matched event. The proportion of intersensory matching is calculated for each trial by dividing the total looking time to the matched audiovisual event by the total looking time to the screen. Therefore, on the scale from 0 to 1, toddlers with larger intersensory matching values represent children who are more skilled in integrating multisensory information. *Attention maintenance* refers to toddlers' sustained attention to the lateral social/nonsocial events. The proportion of attention maintenance is calculated for each trial by dividing the total looking time to either of the two lateral events (i.e., the matched or mis-matched event) by the length of the trial. Thus, on the scale from 0 to 1, a larger attention maintenance value represents greater attention control (i.e., less time looking elsewhere on the screen or away). Lastly, *speed of attention shifting* captures toddlers' speed in orienting attention. In other words, at the start of every trial, if the toddler was fixated in the space between the two speakers or the two objects, the time it took her/him to re-fixate on either side constituted their speed of shifting (in seconds). As such, lower values on this index indicate faster attention shifting abilities. For a speed of attention shifting value to be calculated for a participant, at the start of any given trial toddlers needed to be fixated on the center space, and 33% of the trials needed to have useable attention shifting data.

Intersensory Processing Efficiency Protocol (IPEP).

***Stimuli and apparatus*.** Toddlers' multisensory attention skills were also measured using the IPEP (Bahrick & Todd, 2018). At the start and end of each trial, children viewed a silent, colorful looming smiley-face for 2 seconds. During each trial, children viewed a 3x2 grid of 6 dynamic events (15x12cm each, separated from one another by 1cm of black space), in addition to hearing an audio track that matched only one of the six events. Children viewed a total of 48, 8s trials (24 social, 24 nonsocial). In the social condition, all 6 events were different faces of similar looking women telling a children's story. In the nonsocial condition, all 6 events were different objects hitting a flat surface in separate, randomized patterns. For each trial, the naturally synchronized audio track was played for the duration of the trial event (8 seconds). Thus, the IPEP is an audiovisual search task that requires visually locating a sound-synchronized target event amidst 5 asynchronous distractor events.

Indices in IPEP. The IPEP measures three domains of interest: selection accuracy, intersensory matching, and speed of matching (Bahrick & Todd, 2018). In contrast to the MAAP, all three IPEP indices measure toddlers' multisensory integration abilities. *Selection accuracy* measures how frequently toddlers find the target audiovisual match amidst the six events across all trials. It is calculated by dividing the number of trials for which the child attended to the target event by the total number of trials. Therefore, across trials, toddlers with larger selection accuracy values found the correct, audiovisual match more often than toddlers with smaller values. *Intersensory matching* measures the proportion of time toddlers maintained attention to the matched target event. Intersensory matching is calculated by dividing the total looking time to the target event by the total looking time to the screen for each trial. That is, higher values represent superior multisensory integration. The third index, *speed of matching*, measures the speed with which toddlers locate the audiovisual match. Speed of matching is calculated by the latency to locate and fixate (0.5 seconds) on the target event as measured in seconds.

Secondary Experimental Task

Maternal Sensitivity. A 10-minute mother-child free-play interaction was recorded as a means of observing maternal sensitivity. Mother-toddler dyads were seated at a children's table in the testing room where they were given a fabric bin that contained 3 toys: a "Duck and Goose: Colors" book, a plush penguin toy, and a colorful fabric block that had a cylindrical hole in the middle. Maternal sensitivity was scored using an adapted coding scheme for assessing maternal behavior (Calkins, Hungerford, & Dedmon, 2004; Perry, Calkins, & Bell, 2016; Cuevas, Deater-Deckard, Kim-Spoon, Watson, Morasch, & Bell, 2014; Appendix C). Four dimensions of maternal sensitivity were evaluated: Attention Facilitation, Maternal Intrusiveness, Maternal Positive Affect, and Maternal Negative Affect.

The first dimension, *Attentional Facilitation*, addressed the extent and appropriateness of the mother's attention directing and responsive behaviors, such as drawing attention to an object of interest verbally or handing the child an object of interest. The second dimension, *Maternal Intrusiveness*, captured the extent to which the mother exhibited over-controlling behavior or interacted without regard to the child's physical or verbal cues. The third dimension, *Maternal Positive Affect*, captured how much positive affect the mother utilized as expressed by her tone of voice or facial expressions. The fourth dimension, *Maternal Negative Affect*, captured how much negative affect the mother utilized as expressed by her tone of voice or facial expressions. Each dimension was independently coded offline and a score was generated for each dimension per one minute across the ten-minute free-play session. Maternal intrusiveness and maternal negative affect were reversed scored, and an aggregate value for each dimension was derived by averaging the ten scores. A maternal sensitivity composite value was generated by summing the aggregated dimension values. Maternal sensitivity scores could range from 4 (lowest possible score) to 16 (highest possible score).

Procedure

Prior to their scheduled appointments, families were mailed the parent-report measure on language (MCDI) and instructed to bring their completed paperwork with them to their appointment. Families were brought into the infant playroom where the lead researcher provided the caregiver(s) with an in-depth description of the study and obtain informed consent. Meanwhile, a research assistant played with the child with a set of colorful, age-appropriate toys to help the child warm up to the new environment. This experiment utilized a within-subjects design, whereby all toddlers participated in the maternal sensitivity task and viewed both the

IPEP and MAAP. Presentations of the IPEP and the MAAP (social and nonsocial blocks) were counterbalanced, and infants were randomly assigned to presentation orders to control for ordering effects. All mother-toddler dyads participated in the maternal sensitivity task in between presentations of the MAAP and IPEP.

Once escorted into the testing room, the child was seated either on his/her mother's lap or in a cushioned highchair approximately 65-cm away from a large monitor (Samsung, 34 inch), which was centered between two loudspeakers. All sound levels were set at 68 dB SPL and were tested prior to each appointment. Attached to the bottom center area of the monitor was a Tobii Pro X2-60 portable eye tracker running at 60 Hz which was connected to a laptop. The Tobii Pro X2-60 is a dual camera system, which makes it more resistant to toddler head movement. For sessions where the child was seated in the highchair (n = 6) the mother was seated diagonally to and slightly away from the child to ensure that the child was not distracted by the mother's presence during testing. For sessions where the child was seated in the mother's lap (n = 35), mothers were asked to wear black-out glasses so as not to influence the child's looking behavior and to ensure that the eye-tracker was calibrated to the child's eyes. Prior to the multisensory video presentations, a 9-point calibration procedure was conducted where children saw a red dot move to each calibration point. During this time, a nearby research assistant asked children, "Can you find the red dot with your eyes? Where is it going next?" in a friendly and playful manner, and praised children for attending. Calibration outputs were inspected using Tobii-Studio software and, if necessary, individual points were recalibrated. Eye-tracking calibration was deemed acceptable if at least 4 points were captured. The monitor/loudspeaker configuration and calibration procedure were the same for both the MAAP and IPEP, and both the primary and secondary experimental tasks were video recorded each session.

At the start of the MAAP, in the center of the screen children viewed a colorful, silent moving shape for 3 seconds followed by two side-by-side lateral (social or non-social) dynamic events for 12 seconds (display subtended 25° visual angle), with a synchronous soundtrack that matched only one of the two lateral events. On each trial, only one of the two lateral events was synchronous with the soundtrack while the other event was asynchronous (i.e., 3 seconds out of sync with the soundtrack). The social and nonsocial blocks each contained 12 trials. Thus, the entire MAAP sequence contained 24, 15s trials (i.e., a 3s attention getter and a 12s lateral, audiovisual display), resulting in a total run time of 360 seconds (6 minutes). The presentation order of whether social or nonsocial condition occurred first was counterbalanced across participants, which resulted in two testing orders, with toddlers randomly assigned to this order. The sound-synchronous event was presented an equal number of times on the left and right sides within each testing order, and the soundtrack was not synchronous with the same side more than two times in a row.

After the first multisensory protocol, the child and caregiver were seated at a children's table with the designated maternal sensitivity toys for the parent-toddler free-play task. The only instructions provided to mothers were to "please play with your child as you normally would." Upon completion of the maternal sensitivity task, the child and his/her caregiver were invited to take a brief, 5-minute break before the second multisensory protocol began.

At the start of the IPEP, in the center of the screen children viewed a silent, looming smiley-face for 2 seconds followed by a 3 x 2 grid of 6 dynamic visual events (social or nonsocial; display subtended 25° visual angle), in addition to having heard a soundtrack synchronized to only one (the target) event for 8 seconds. The smiley-face proceeded and followed each individual event for 2 seconds. There were 4 counterbalanced trial blocks (i.e., 2 social blocks and 2 nonsocial blocks) and each block contained 12, 8-second events, resulting in a total of 48 trials across blocks. Thus, the IPEP sequence ran for a total of 480 seconds (8 minutes). The soundtrack to each of the 6 faces/objects was played (in one of several random orders) in each block.

After testing, the toddler and his/her caregiver were escorted back to the infant playroom. A research assistant engaged the toddler with a set of toys while the caregiver completed the demographic form (Appendix B) and the MCDI if they had not been able to complete it prior to their appointment. Caregivers were also given the option of taking this paperwork with them to be completed at home. In this case, caregivers were given a prepared envelope (i.e., stamped with a return address) containing the paperwork. At the end of the appointment, the caregiver was given $30 and the child was permitted to pick out a small toy from the iLEAP toy bin to express gratitude for their participation.

Offline Coding and Interrater Reliability

For the MAAP video recordings, two trained research assistants independently coded toddler looking behavior using Simple Video Coder, a python-based video annotation software (Barto, Bird, Hamilton, & Fink, 2018). Looking behavior was coded as looks to the left, right, center, or away with respect to the screen. Research assistants coded the MAAP recordings without audio and therefore were blind to the testing order. High interrater reliability was achieved (Cronbach's Alpha value = .86).

For the maternal sensitivity task, two trained research assistants independently coded the free-play interaction for the following 4 dimensions: *Attention Facilitation, Maternal*

Intrusiveness, Maternal Positive Affect, and Maternal Negative Affect. Maternal sensitivity was coded in ten, 1-minute epochs on a 4-point scale (1 – low, 4 – high) for each dimension. Each dimension was averaged across the 10 epochs and then the dimensions were summed to generate a composite maternal sensitivity score for each toddlers' mother. To evaluate interrater-reliability, the lead researcher coded maternal sensitivity for 14 of the mother-toddler free-play sessions (30%), whereby Cronbach's Alpha values of .77 and .75 were achieved.

3. Results

Data Preparation and Demographic Analyses

As the MAAP and IPEP indices all measure unique aspects of toddler's multisensory integration or attention abilities, some indices were composited within the two protocols. However, before this compositing, all values were z-scored given the heterogeneity of their underlying scales. Additionally, speed of shifting for both the MAAP and the IPEP across conditions (social and nonsocial) was reversed scored by taking the absolute value of the z-score. For the MAAP, attention maintenance and speed of shifting were composited for social and nonsocial conditions separately to create two attentional control values (i.e., $MAAP_{ATT\_SOCIAL}$, $MAAP_{ATT\_NONSOCIAL}$). For the IPEP, all three indices were composited (accuracy in selecting, accuracy in matching, and speed of matching) for each condition separately to create two multisensory integration values (i.e., $IPEP_{SOCIAL}$, $IPEP_{NONSOCIAL}$). Last, in order to generate a composite SES score for each toddler, familial education and familial income values were first z-scored and then summed.

Preliminary analyses were run to examine whether there were sex differences across primary variables. Independent sample t-tests indicated that most multisensory integration scores (MAAP and IPEP) did not differ as a function of sex: $IPEP_{SOCIAL}$, $t(24) = -.349$, $p = .730$; $IPEP_{NONSOCIAL}$, $t(24) = -.765$, $p = .452$; $MAAP_{ATT\_NONSOCIAL}$, $t(33) = 1.101$, $p = .279$; $MAAP_{MATCHING\_SOCIAL}$, $t(38) = -1.255$, $p = .217$; $MAAP_{MATCHING\_NONSOCIAL}$, $t(34) = 1.502$, $p = .142$. However, toddlers' attentional control abilities when viewing social trials on the MAAP did differ as a function of sex: $MAAP_{ATT\_SOCIAL}$, $t(37) = 2.638$, $p = .012$. Given that toddlers' attention control scores are a composite value, a second independent sample t-test was conducted to examine which social attention index varied as a function of sex. Results indicated that speed of shifting varied as a function of sex, $t(37) = 3.01$, $p = .005$, with girls ($M = 1.03$ seconds, $SD = .347$) shifting faster to the lateral events on social trials in comparison to boys ($M = 1.42$ seconds, $SD = .460$). In contrast, attention maintenance did not differ as a function of sex, $t(38) = .277$, $p = .783$. Given that the majority of the dependent variables of interest showed no sex differences, sex was not included as a variable in the primary analyses presented below.

Multisensory Integration and Attention Control in MAAP and IPEP

The first hypothesis was that toddlers would demonstrate superior multisensory integration (MSI) scores as a function of condition in both MAAP and IPEP tasks (i.e., social > nonsocial). Results will be presented for each of these tasks separately below[1] (see table 2). First, toddlers' intersensory matching in MAAP was examined using a 2 x 2 mixed analysis of variance (ANOVA) with condition (social, nonsocial) as the within subjects' factor and presentation order (MAAP first, IPEP first) as the between subjects' factors. Results indicated a statistically significant main effect of condition, $F(1,33) = 4.191$, $p = .049$, whereby toddlers' fixated on the intersensory match longer when viewing social trials ($M = .44$, $SD = .11$) in comparison to nonsocial trials ($M = .39$, $SD = .08$; see figure 1). There was no significant main effect of presentation order, $F(1,33) = 0.046$, $p = .831$, nor an interaction between condition and order ($F(1,33) = 1.015$, $p = .32$). For toddlers' attention control, similar analyses were conducted, and no significant main effects or interactions were found (all p's > .05; see figures 1 and 2)

To examine toddlers' MSI abilities when viewing IPEP, a mixed 2 x 2 ANOVA was run with condition (social, nonsocial) as the within subjects' factor and presentation order (MAAP

[1] Results did not differ as a function of whether analyses were run with indices independently or as composites.

first, IPEP first) as the between subjects' factor. In contrast to the results with MAAP, results with IPEP indicated no statistically significant main effect of condition, $F(1,25) = .217$, $p = .645$, or presentation order, $F(1,25) = .264$, $p = .612$, or their interaction, $F(1,25) = .602$, $p = .446$.

Multisensory Integration and Attention Control in relation to Language Skills

The second hypothesis was that toddlers' social, but not nonsocial, multisensory integration and attention control abilities would predict their expressive vocabulary scores. First, bivariate correlations were conducted between all primary variables of interest, which included: $IPEP_{SOCIAL}$, $IPEP_{NONSOCIAL}$, $MAAP_{MATCHING\_SOCIAL}$, $MAAP_{\_MATCHING\_NONSOCIAL}$, $MAAP_{ATT\_SOCIAL}$, $MAAP_{ATT\_NONSOCIAL}$, and MCDI (see table 1). Regarding intraprotocol correlations, $MAAP_{\_MATCHING\_SOCIAL}$ was significantly correlated with $MAAP_{ATT\_SOCIAL}$ ($r = .61$, $p < .000$) and $MAAP_{\_MATCHING\_NONSOCIAL}$ was significantly correlated with $MAAP_{ATT\_NONSOCIAL}$ ($r = .37$, $p = .031$). Next, results indicated that $MAAP_{MATCHING\_SOCIAL}$ ($r = .521$, $p = .001$) and $MAAP_{ATT\_SOCIAL}$ ($r = .345$, $p = .031$) were significantly correlated with toddlers' MCDI scores. However, $IPEP_{SOCIAL}$, $IPEP_{NONSOCIAL}$, $MAAP_{\_MATCHING\_NONSOCIAL}$, $MAAP_{ATT\_NONSOCIAL}$ were not significantly correlated with toddlers' expressive vocabularies (all p's > .05). Given that IPEP composite scores were not significantly correlated with MCDI scores in either condition, IPEP was excluded from subsequent analyses. Next, to more directly evaluate this second hypothesis, a linear multiple regression was conducted to predict toddlers' expressive vocabularies based on their MAAP scores.

In the linear multiple regression, $MAAP_{MATCHING\_SOCIAL}$, $MAAP_{MATCHING\_NONSOCIAL}$, $MAAP_{ATT\_SOCIAL}$, and $MAAP_{ATT\_NONSOCIAL}$ were manually entered into the first block of the linear regression with MCDI percentile score as the dependent variable[2]. The overall regression model was statistically significant, $F(4, 29) = 4.048$, $p = .01$, with an adjusted R^2 value of .27 (see table 4). Although the overall model was significant, only $\text{MAAP}_{\text{MATCHING\_SOCIAL}}$ significantly predicted expressive vocabulary, $\beta = .530$, $p = .007$, but not $\text{MAAP}_{\text{MATCHING\_NONSOCIAL}}$, $\beta = .190$, $p = .245$, $\text{MAAP}_{\text{ATT\_SOCIAL}}$, $\beta = .072$, $p = .696$, or $\text{MAAP}_{\text{ATT\_NONSOCIAL}}$, $\beta = -.083$, $p = .611$.

Do SES and Maternal Sensitivity Moderate the Relationship between MSI and Language?

Finally, the third hypothesis was that SES and maternal sensitivity would moderate the relationship between toddlers' MSI abilities and expressive vocabularies. A frequency distribution of toddlers' SES values demonstrated that there was a left skewed distribution of the data (SES Mean = 10, Range = 4.5 – 13). Z-scoring and Log_{10} manipulations were applied to normalize the distribution, yet these corrections resulted in a skewed, leptokurtic distribution. Additionally, bivariate correlations showed that SES was not significantly correlated with the primary variables (see table 1). A frequency distribution of toddlers' maternal sensitivity (MS) values showed that there was also a left skewed distribution of the data (MS Mean = 14.68, Range = 11.86 - 16). To normalize the data z-scoring was applied, however the distribution remained left skewed. Although MS did not meet normality assumptions, it was significantly correlated with toddlers' MCDI ($r = .422$, $p = .010$), $\text{MAAP}_{\text{MATCH\_SOCIAL}}$ ($r = .366$, $p = .016$), and $\text{MAAP}_{\text{ATT\_SOCIAL}}$ scores ($r = .348$, $p = .033$).

To directly evaluate the third hypothesis, a linear multiple regression was conducted, whereby social intersensory matching (MAAP), social attention control (MAAP), and maternal

[2] Given that toddlers' MCDI percentiles were normed based on their age and sex, these variables were not entered into the regression equation.

sensitivity were manually entered into the first block, and their interaction terms were entered into the second block. The first regression model was significant, $F(3, 31) = 6.171$, $p = .002$, with an adjusted R^2 value of .334. In this model, both $MAAP_{MATCH\_SOCIAL}$, $\beta = .498$, $p = .005$, and MS, $\beta = .321$, $p = .046$, significantly predicted expressive vocabulary, but $MAAP_{ATT\_SOCIAL}$ did not, $\beta = .159$, $p = .320$. The second regression model indicated that the interaction terms were not significant, and the addition of the interaction terms did not account for a significant change to the model's overall fit, R^2 change = .012 (see table 5). Additional regression analyses were conducted to evaluate possible interactions between maternal sensitivity and the MAAP nonsocial variables, and between SES and both the social and nonsocial MAAP variables. However, none of these models, nor the predictors entered into the models, were statistically significant (all p's > .05).

4. Discussion

The purpose of this study was to examine relationships between toddlers' multisensory integration abilities and their language skills using two recently established developmental protocols (the MAAP and the IPEP; Bahrick & Todd, 2018). Because SES values and the IPEP indices were not predictive of language development, both SES and the IPEP will be discussed below in the limitations section. Thus, the interpretations below are only stemming from performance on the MAAP as an indicator of multisensory integration skill, and the relationship between this skill and toddlers' MCDI and maternal sensitivity scores.

Social/Nonsocial Multisensory Integration and Attention Control Abilities

First, this study aimed to evaluate if there were differences between 24-month-olds' multisensory integration and attention control skills (i.e. intersensory matching, attention maintenance, and speed of attention shifting) when viewing social and nonsocial events. It was hypothesized that toddlers would demonstrate superior multisensory integration and attention control abilities when viewing social AV events compared to nonsocial AV events. This hypothesis was partially supported, as the results indicated a statistically significant difference between toddlers' social and nonsocial intersensory matching abilities, whereby toddlers fixated on the audiovisual matched event longer when viewing MAAP social trials. However, this was only the case for multisensory integration and not the more general measurements of attention control. That is, there were no significant differences across social and nonsocial conditions for toddlers' speed of shifting and attention maintenance. These findings replicate those of Bahrick, Todd, and Soska (2018) who found that intersensory matching on the MAAP was greatest for 2-

to 5-year-old children when viewing social events, and that there were no significant differences in attention maintenance or speed of shifting across social and nonsocial conditions.

One contributing factor to the advantage that toddlers demonstrated for multisensory integration in a social context is the emergence of cooperative play in this age frame. For example, previous research has demonstrated that by two-years of age, children are engaging less frequently in solitary or exploratory play with objects and increasingly engaging in socially oriented, symbolic or coordinated play (Brownell, Ramani, & Zerwas, 2006; Smith, 1978; Soska & Adolph, 2014). Thus, this transition from less social to more social play affords 24-month-olds more opportunities to experience temporally synchronous, social audiovisual events, thereby facilitating the development of social multisensory integration abilities.

In contrast, results from this study indicated that toddlers' attention control abilities (as measured by attention maintenance and speed of shifting) were not significantly different between social and nonsocial conditions. This is not to suggest that 24-month-olds have a lack of preference for viewing social or nonsocial events, nor that social and nonsocial events equally facilitate learning. Rather, in this study, when presented with either social or nonsocial trials, toddlers were able to shift and maintain their attention to the lateral events in both conditions. One possible explanation for this stems from children's early and long-standing control of attention from infancy through older ages. Research by Rothbart, Sheese, Rueda, and Posner (2011) has shown that by 4- to 5-months of age, typically developing infants are capable of volitional attention control due to the structural maturity of frontal and parietal cortical areas. As such, over the first few years of life, children have likely had extensive experience selecting and sustaining attention toward information in their environment, both of a social and non-social nature. Previous research has shown that children frequently attend to and learn from social cues (e.g., ostensive gestures or gaze following) as these events are highly salient in early development (see Mundy & Jarrold, 2010, for a review on the development of social cognition and social learning). However, Barry, Graf Estes, and Rivera (2015) found that 9-month-olds could attend to both dynamic and perceptually engaging social cues (i.e. faces turning) and nonsocial cues (i.e., moving geometric shapes), thereby advocating for a domain-general attention mechanism. Thus, previous findings support the notion that the 24-month-olds in this study who were skilled at shifting and maintaining attention toward social events were equally capable of doing so toward nonsocial events.

Multisensory Integration and Language Development

The second purpose of this study was to examine the relationship between toddlers' multisensory integration and language development. It was hypothesized that toddlers' social, but not nonsocial, MSI abilities would predict expressive language skills. This hypothesis was supported, as results indicated that toddlers' social MSI was the only factor that significantly predicted expressive vocabulary. In other words, toddlers' who looked longer at the intersensory matched event had higher expressive vocabularies. These findings also support previous work by Bahrick, Todd, and Soska (2018), who found that higher intersensory matching on social trials was related to higher expressive and receptive vocabularies among 2- to 5-year-old children.

Recent literature has suggested that during the first year of life, infants shift in attending more to the mouth as opposed to the eyes of a speaker when viewing dynamic, social events, with some studies finding that this shift in attention and facial scanning patterns is related to later productive vocabulary (Lewkowicz & Hansen-Tift, 2012; Tenenbaum, Sobel, Sheinkopf, Malle,

& Morgan, 2015; Tsang, Atagi, & Johnson, 2018). Given that faces and in particular, mouths, provide temporally synchronous and redundant audiovisual speech cues, it therefore follows that the ability to integrate social multisensory information would facilitate language learning in toddlerhood. In contrast, since language is socially communicative and typically embedded within social contexts, the ability to integrate nonsocial multisensory information may facilitate learning in nonsocial domains, such as learning about the perceptual properties of object.

Interestingly, in this study, social attention control was not significantly predictive of expressive vocabulary, although it was correlated with both expressive vocabulary and social intersensory matching. This was a surprising finding, as research has found that sustained attention to speech and prosodic information, inherently social in nature, is related to language development (Diego-Balaguer, Martinez-Alvarez, & Pons, 2016; Vouloumanos & Curtin, 2014). However, it is possible that because social attention control and intersensory matching were correlated with each other, social attention did not account for significant variance in expressive vocabulary above and beyond toddlers' multisensory integration abilities.

It is important to note that while attention control and multisensory integration are related, they are nevertheless distinct and separate constructs. Talsma, Senkowski, Soto-Faraco, and Woldorff's (2010) review highlights the fact that when multiple events are competing for processing resources, such as the two competing lateral displays in the MAAP, attention control is vital in facilitating the effective processing of events. However, the ability to successfully detect and integrate sensory information from temporally synchronous events is unique to multisensory integration. For example, one could imagine that a toddler with strong attention control, but weak multisensory integration skills might effectively maintain his/her attention to the mis-matched AV event; thereby missing linguistically-useful and intersensory redundant cues associated with the natural pairing of a speaker's facial movement and speech. In support of this notion, Bahrick, Todd, and Soska (2018) generated several structural equation models, showing that the model with best fit was one whereby attention maintenance predicts multisensory integration, which in turn predicts vocabulary in 2- to 5-year-old children. In this sense, multisensory integration is an essential mechanism in the well-established relationship between attention control and language development.

Multisensory Integration within the Parent-Child Context

Finally, this study is novel in its evaluation of maternal sensitivity with respect to 24-month-olds' multisensory integration and developing language skills. While it was predicted that mothers' maternal sensitivity scores would moderate the detected relationship between toddlers' MSI and expressive vocabulary, this hypothesis was not supported. Maternal sensitivity, but not the interaction between maternal sensitivity and social intersensory matching, significantly predicted toddlers' expressive vocabularies. Longitudinal research observing unstructured parent-child play interactions has documented links between maternally sensitive behavior and children's later language outcomes. For example, Tamis-Lemonda, Bornstein, and Baumwell (2001) reported that even when controlling for child-centric factors, maternal responsiveness at 9 and 13 months predicted multiple language milestones (e.g., first-vocalizations and first use of language to talk about the past) over the course of early child development. Moreover, Leigh, Nievar, and Nathans' (2011) findings suggest that regarding expressive language, maternal sensitivity becomes increasingly important as children develop as indicated by the increased effect size of maternal sensitivity during toddlerhood (24 months) in comparison to infancy (15 months). Thus, in accordance with previous research, the findings from this study found that maternal sensitivity played an important role in supporting the development of children's early productive vocabulary. However, these findings also suggest that multisensory integration did not differently relate to language outcomes depending on the level of maternal sensitivity that toddlers were exposed to.

Given that social environments, and in particular maternal behaviors, influence attention, cognition, and language development in infancy, it was hypothesized that maternal sensitivity would moderate the relationship between multisensory integration and language outcomes. Yet, the results from this study found no evidence that maternal sensitivity was moderating this relationship; rather, both multisensory integration and maternal sensitivity directly influenced toddlers' productive vocabularies. Although there was a statistically significant correlation between toddlers' MSI and mothers' MS scores, analyses indicated that there is significant variation to detect independent effects of these variables on language development. Therefore, maternal sensitivity may not be moderating the relationship between MSI and language as it is exerting direct influence on toddlers' expressive language skills.

Research on joint attention, another method of examining parental attention facilitation and responsiveness, suggests that moments of joint attention are vital to the development of both social cognition and language (Mundy and Jarrold, 2010). In contrast to maternal sensitivity, however, joint attention captures the bi-directional and co-coordinated aspects of mother-child interactions, including face to face dynamic exchanges. In this sense, the child is getting targeted opportunities to perceive multisensory synchronicity between maternal visual and auditory speech through moments of socially coordinated attention. Thus, one interpretation of this study's findings is that the coordination of mother-toddler interactions and the alignment of goals in a social context may be more important with respect to the relationship between multisensory integration and language development than maternal sensitivity alone. As such, a future direction would be to examine whether the relationship between multisensory integration and language is influenced by joint attention.

A second interpretation of this study's findings is that maternal sensitivity did not play a moderating role because multisensory integration abilities develop independently of the maternal factors articulated above. There is evidence that humans' sensory systems are exposed to concurrent, multimodal stimulation in the prenatal environment (see review by Lickliter, 2012). For instance, when a pregnant mother speaks, a fetus may simultaneously experience temporally synchronous auditory and tactile information (via vibrations in the body). In support of this early integration approach, various studies have demonstrated that some rudimentary multisensory processes are present in very early infancy. For example, 3- to 4-week-old infants can form cross-modal, audiovisual matches using amodal properties (i.e., intensity), while newborns can cross-modally transfer information about objects' shape across visual and tactile systems (Lewkowicz & Turkewitz, 1980; Streri & Gentaz, 2003). Although prenatal contributions to the development of multisensory integration are still not entirely understood, it is possible that these early experiences set the stage postnatally for infants' observed interest in and early abilities processing multisensory events (Lickliter, 2012). In other words, the young infant may enter into postnatal relation with her mother with some degree of multisensory integration already in place. As such, future research should additionally employ longitudinal, prospective designs to evaluate whether children's multisensory integration skills evolve over the course of early development.

Limitations

There are two primary limitations in this study that warrant discussion. First, although this study utilized two novel protocols assessing toddlers' multisensory integration abilities, the IPEP yielded less useable data in comparison to the MAAP. Specifically, across all indices measuring multisensory integration in IPEP, none were significantly different as a function of condition (social vs. nonsocial), nor did they predict expressive vocabulary. However, this particular task was longer in length and higher in task complexity compared to MAAP. As a result, attrition was higher and performance was generally poor (i.e., eye-tracking was not reliable). Therefore, the 24-month-olds had a more difficult time engaging for the full length of this task. It is possible that this sample was too young for a task with these characteristics. To date, the IPEP has only been successful with older children (Bahrick, Soska, & Todd, 2018).

Second, in this sample of 24-month-olds and their mothers, SES was not normally distributed nor was it significantly correlated with any of the primary variables of interest. Given the wealth of developmental research highlighting differences in a wide range of child outcome variables as a function of SES, a second limitation of this study therefore is the lack of SES variability among the final sample. While this study aimed to consider whether a macrolevel feature of toddlers' environments influenced their developing attention, multisensory integration, and language skills, there was very limited variance with respect to children's socioeconomic statuses as indicated by the left skewed distribution. Additionally, it's also possible that the scale used to measure SES was not sensitive enough to capture variance in toddlers' contextual environments. Despite the rising interest in evaluating the role of SES within the field of development science, there is still no general consensus on the definition of SES and considerably less agreement regarding how best to measure it. Thus, although this study utilized a composite of familial education and income, an alternative method of measuring SES, such as assessing parental occupation/employment status or geographic residence, may be better suited to this domain of developmental research.

Table 1. Pearson Correlation Matrix

	1	2	3	4	5	6	7	8	9
1. MAAP$_{ATT_SOCIAL}$	-								
2. MAAP$_{ATT_NONSOCIAL}$ˈ	.106	-							
3. MAAP$_{MATCH\ _SOCIAL}$	.606**	.033	-						
4. MAAP$_{MATCH\ _NONSOCIAL}$ˈ	.041	.366*	.060	-					
5. IPEP$_{SOCIAL}$^	.133	.093	.296	-.124	-				
6. IPEP$_{NONSOCIAL}$^	.359	.092	.172	.458*	-.031	-			
7. MCDI	.345*	.014	.521**	.116	.088	.180	-		
8. SES	.203	-.144	.126	.118	.050	.023	.062	-	
9. Maternal Sensitivity	.348*	.060	.366*	.137	-.231	.038	.420*	.260	-

** p < .01
* p < .05
n = 39
ˈ n = 36
^ n = 25

Table 2. Means and Standard Deviations for MAAP and IPEP

	Social *M(SD)*	Nonsocial *M(SD)*
$MAAP_{MATCH}$	44% (11%)*	39% (8%)
$MAAP_{ATT\_MAINTENANCE}$	59% (14%)	54% (14%)
$MAAP_{SPEED}$	1.21s (.44s)	1.29s (.58s)
$IPEP_{SELECTING}$	45% (19%)	50% (18%)
$IPEP_{MATCHING}$	19% (8%)	20% (6%)
$IPEP_{SPEED}$	2.72s (.89s)	2.04s (1.01s)

* = statistically significant difference as a function of condition ($p < .05$)

Table 3. Means and Standard Deviations for Secondary Variables

	M	*SD*
Maternal Sensitivity	14.71	1.01
Familial Income	$70,100	$17,830
Maternal Education	16.49 years	1.96 years
Paternal Education	16.24 years	2.2 years

Table 4. Regression model to examine whether $MAAP_{MATCH\_SOCIAL}$ predicts MCDI

		Unstandardized Coefficients		Standardized Coefficients					
Model		B	Std. Error	Beta	t	Sig.	Adjusted R^2	Model Sig.	R^2 Change
1	(Constant)	43.92	4.49	--	9.79	.000**	.270	.010*	.358
	$MAAP_{MATCH\_SOCIAL}$	15.74	5.37	.530	2.93	.007**			
	$MAAP_{MATCH\_NONSOCIAL}$	6.12	5.16	.190	1.19	.245			
	$MAAP_{ATT\_SOCIAL}$	1.35	3.43	.072	.395	.696			
	$MAAP_{ATT\_NONSOCIAL}$	-1.66	3.23	-.08	-.52	.611			

a. Dependent Variable: MCDI
* $p < .05$
** $p < .01$

Table 5. Regression model to examine whether MS moderates the relationships between social MAAP variables ($MAAP_{MATCH\_SOCIAL}$, $MAAP_{ATT\_SOCIAL}$) and MCDI

Model		Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	t	Sig.	Adjusted R^2	Model Sig.	R^2 Change
1	(Constant)	42.96	4.37		9.83	.000**	.334	.002**	.398
	MS	9.75	4.66	.321	2.09	.046*			
	$MAAP_{MATCH\_SOCIAL}$	16.34	5.33	.498	3.06	.005**			
	$MAAP_{ATT\_SOCIAL}$	-4.63	4.57	-.159	-1.01	.320			
2	(Constant)	43.7	4.94		8.84	.000**	.296	.013*	.012
	MS	8.93	5.31	.294	1.68	.104			
	$MAAP_{MATCH\_SOCIAL}$	16.77	6.69	.511	2.51	.019*			
	$MAAP_{ATT\_SOCIAL}$	-4.37	4.8	-.15	-.91	.371			
	$MSxMAAP_{MATCH\_SOCIAL}$	.89	9.22	.023	.10	.923			
	$MSxMAAP_{ATT\_SOCIAL}$	-2.6	4.16	-.124	-.62	.539			

a. Dependent Variable: MCDI
* $p < .05$
** $p < .01$

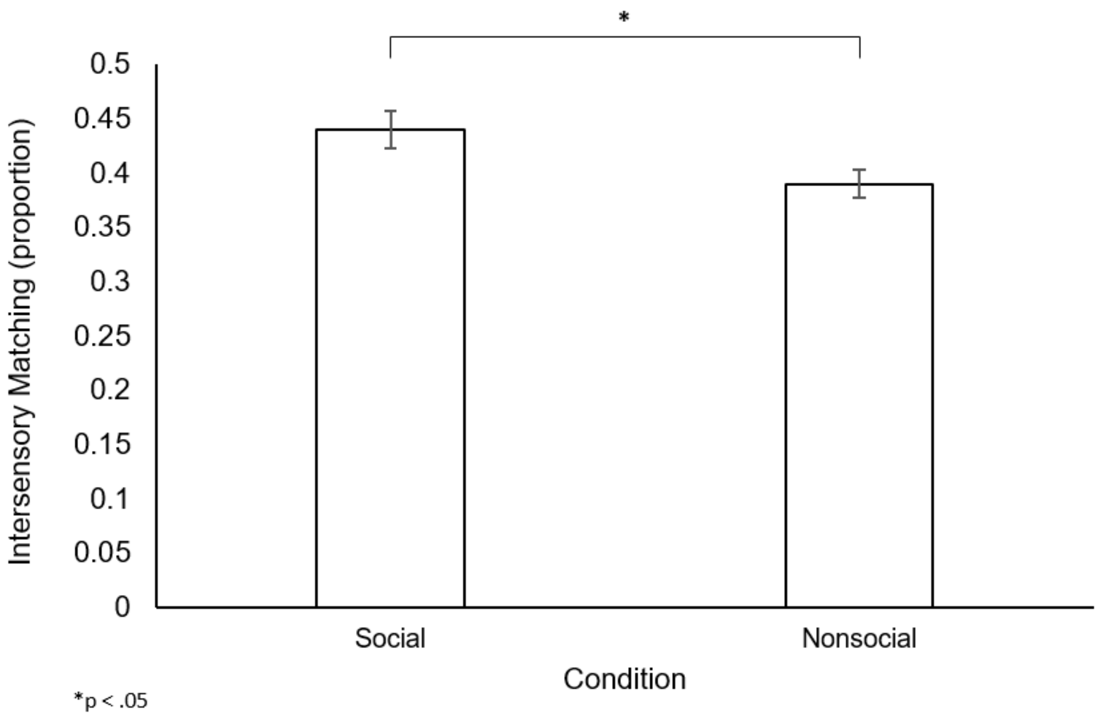

Figure 1. Mean intersensory matching as a function of condition (social, nonsocial). A statistically significant difference was found between social and nonsocial intersensory matching, whereby infants fixated on the intersensory matched event longer when viewing social trials (mean = 44%) in comparison to nonsocial trials (m = 39%).

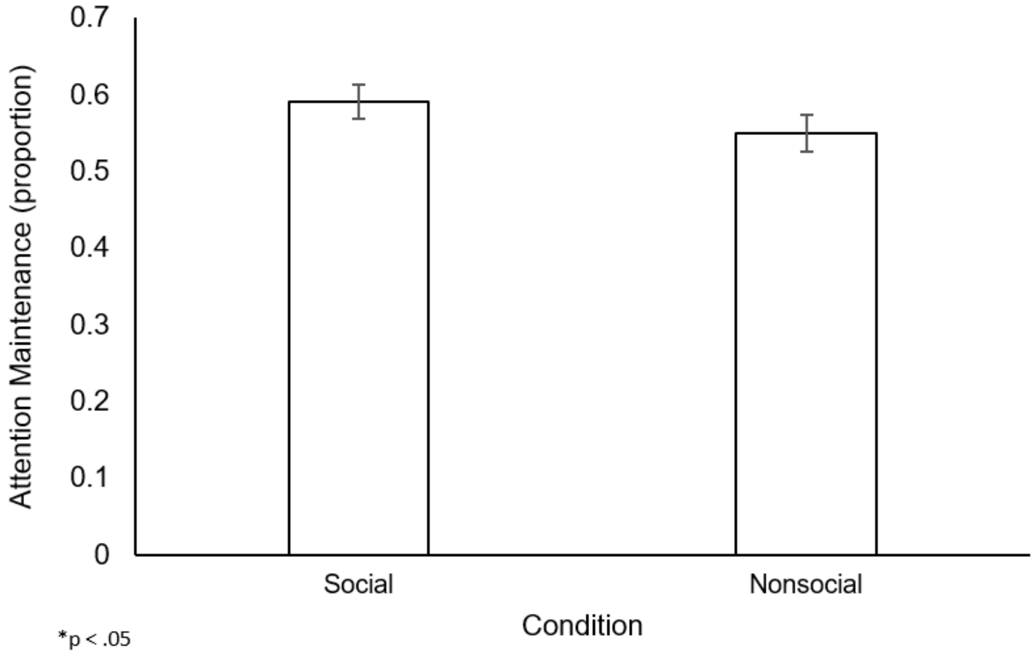

Figure 2. Mean attention maintenance as a function of condition (social, nonsocial). No statistically significant differences were found in toddlers' attention maintenance skills across social and nonsocial trials.

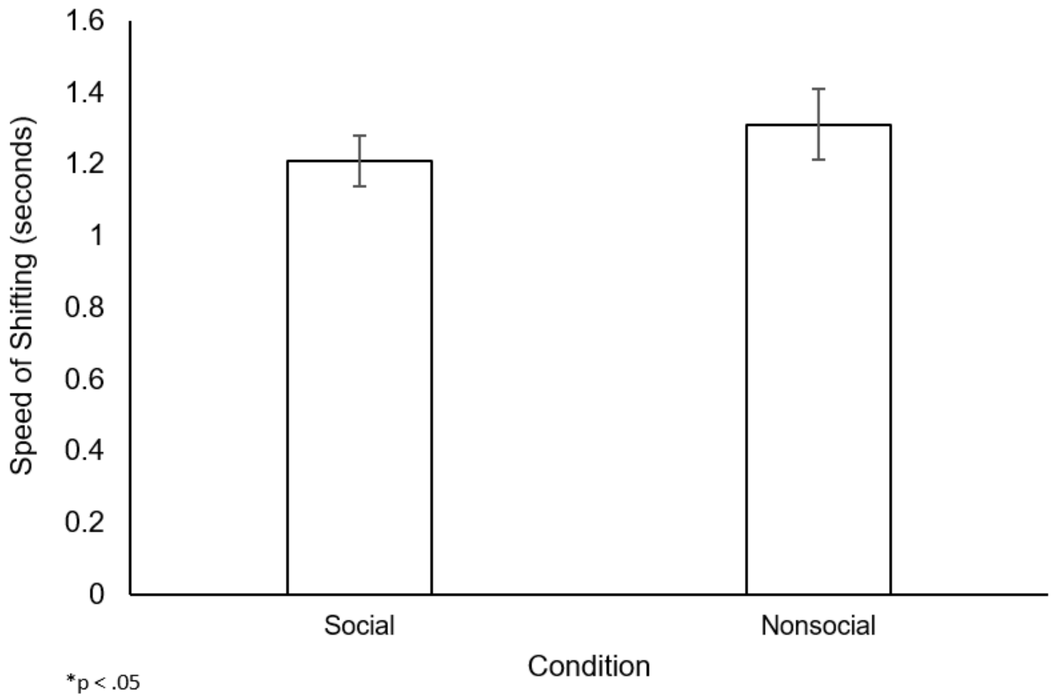

Figure 3. Mean speed of shifting in seconds as a function of condition (social, nonsocial). No statistically significant differences were found in toddlers' speed of shifting abilities across social and nonsocial trials.

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Appendices

Appendix A

VT IRB Approval Letter

Division of Scholarly Integrity and Research Compliance
Institutional Review Board
North End Center, Suite 4120 (MC 0497)
300 Turner Street NW
Blacksburg, Virginia 24061
540/231-3732
irb@vt.edu
http://www.research.vt.edu/sirc/hrpp

MEMORANDUM

DATE: July 31, 2019

TO: Robin Kay Panneton, Madeleine Diane Bruce, Tyler Christine McFayden, Caroline Taylor

FROM: Virginia Tech Institutional Review Board (FWA00000572, expires January 29, 2021)

PROTOCOL TITLE: Multisensory Integration in Social and Non-social Events and Emerging Language in Toddlers

IRB NUMBER: **18-254**

Effective July 31, 2019, the Virginia Tech Institution Review Board (IRB) approved the Continuing Review request for the above-mentioned research protocol.

This approval provides permission to begin the human subject activities outlined in the IRB-approved protocol and supporting documents.

Plans to deviate from the approved protocol and/or supporting documents must be submitted to the IRB as an amendment request and approved by the IRB prior to the implementation of any changes, regardless of how minor, except where necessary to eliminate apparent immediate hazards to the subjects. Report within 5 business days to the IRB any injuries or other unanticipated or adverse events involving risks or harms to human research subjects or others.

All investigators (listed above) are required to comply with the researcher requirements outlined at:

https://secure.research.vt.edu/external/irb/responsibilities.htm

(Please review responsibilities before beginning your research.)

PROTOCOL INFORMATION:

Approved As:	**Expedited, under 45 CFR 46.110 category(ies) 5,6,7**
Protocol Approval Date:	**August 1, 2019**
Protocol Expiration Date:	**July 31, 2020**
Continuing Review Due Date*:	**July 10, 2020**

*Date a Continuing Review application is due to the IRB office if human subject activities covered under this protocol, including data analysis, are to continue beyond the Protocol Expiration Date.

ASSOCIATED FUNDING:

The table on the following page indicates whether grant proposals are related to this protocol, and which of the listed proposals, if any, have been compared to this protocol, if required.

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Appendix B

Demographic Questionnaire

Experimenter________________

MULTINET BACKGROUND QUESTIONNAIRE

FOR OFFICE USE ONLY
Participant ID: ______________________ Age: mos______, days______ Test Date: ___________
Study: ____ Subject #______ Visit #______ Session: _________
Site PI and Location: __________________________________
Other Prior Studies: ____

Section A: Basic information about you and your child.

1. What is your relationship to your child?
   ____ Mother
   ____ Father
   ____ Other, please specify _______________

2. Are you the child's primary caregiver? _____ Yes ____ No
   If you answered No, who is the child's primary caregiver? _______________

3. Sex of your child: ____ Male ____ Female

4. What is your child's date of birth? _______________

Section B: Race, Ethnicity, Nationality. Please check one in each category for each person.
We are required to report these data to the National Institutes of Health (NIH) in this format.

Category 1 (please check one)	**Child**	**Mother**	**Father**
Hispanic or Latino			
Not Hispanic or Latino			
Category 2 (please check one)			
American Indian/Alaska Native			
Asian			
Native Hawaiian or Other Pacific Islander			
Black or African American			
White			
More than one race			

5. What is your country of origin? ________________

6. What is your spouse/partner's country of origin? _______________

1

Experimenter_______________

Section C: Parent education, employment, and income.

The following questions are about you and your partner. Your "partner" refers to any significant figure in your household that plays a major role in helping you raise your child (e.g., spouse, parent, grandparent, other).

7. What is your relationship to your child?
   ____ Mother
   ____ Father
   ____ Other, please specify _______________

   Age: _______________

8. What is your partner's relationship to your child?
   ____ Mother
   ____ Father
   ____ Other, please specify _______________

   Age: _______________

9. What is the highest level of education that you and your spouse/partner have achieved to date?

Please check one category for each person:	**You**	**Your spouse/partner**
8th grade or less		
Some high school (or equivalent)		
High school graduate		
Some vocational/technical training (after high school)		
Completed vocational/technical training (after high school)		
Some college		
Completed college (bachelor's degree)		
Some graduate school		
Completed a master's degree		
Some graduate training beyond a master's degree		
Completed a doctoral degree (e.g., Ph.D., J.D., M.D., PsyD)		

10. Please indicate your current employment status for you and your spouse/partner:

Please check one category for each person:	**You**	**Your spouse/partner**
Full-time		
Part-time		
Retired		
Unemployed		

11. If employed, please indicate your occupation/job title: _______________

12. If employed, please indicate your spouse/partner's occupation/job title: _______________

13. Thinking about your income and the income of everyone who lives in your household and contributes to the household budget, what was the total household income before taxes and deductions in the last tax year? Include all sources of income, including non-legal sources.
    ___ less than $5,000
    ___ $5,000 to $9,999
    ___ $10,000 to $14,999

2

Experimenter________________

___ $15,000 to $19,999
___ $20,000 to $24,999
___ $25,000 to $29,999
___ $30,000 to $39,999
___ $40,000 to $49,999
___ $50,000 to $74,999
___ $75,000 to $99,999
___ $100,000 to $149,999
___ $150,000 to $199,999
___ $200,000 or more

Section D: Languages.

14. What is your and your spouse/partner's preferred language?

Please check only one category for each person:	You	Your spouse/partner
English		
Spanish		
Other (Specify):		
Other (Specify):		

15. What is your and your spouse/partner's native language? Please check *only one*:

Please check only one category for each person:	You	Your spouse/partner
English		
Spanish		
Other (Specify):		
Other (Specify):		

16. What language do you and your spouse/partner usually speak when talking with your child?

Please check only one category for each person:	You	Your spouse/partner
Only English		
More English than Spanish/other language		
Both equally		
More Spanish/other language than English		
Only Spanish/other language		

17. Considering all the people who speak to your child in a typical day, please circle the percentage of time your child hears English (vs. Spanish, or another language, please specify__________________)

100%	90%	80%	70%	60%	50%	40%	30%	20%	10%	0%
Always or almost always English		Usually English			Half the time English/half other language(s)		Sometimes English			Almost never or never English

3

Experimenter________________

Section E: Pregnancy history.

18. When the child's mother was pregnant, about how many prenatal-care visits did she have with a doctor or nurse/mid wife?
    ____ 0
    ____ 1-2
    ____ 3-5
    ____ 4-6
    ____ 7-10
    ____ 11-15
    ____ More than 15

19. During this pregnancy, how often did she drink alcoholic beverages?
    ____ Never
    ____ Less than once a month
    ____ Several times a month
    ____ Several times a week
    ____ Almost every day

20. During this pregnancy, about how many cigarettes did she smoke? (choose the option that comes closest to how much she smoked)
    ____ None
    ____ One pack a day or less
    ____ More than 1 pack a day, but less than 2 packs a day
    ____ 2 or more packs a day

21. Did she take any antidepressant medication during any portion of your pregnancy? ____ Yes ____ No
    If yes, please indicate which medication(s) she took:

    Selective serotonin reuptake inhibitors (SSRIs):
    ____ Zoloft (sertraline)
    ____ Celexa (citalopram)
    ____ Lexapro (escitalopram)
    ____ Prozac, Sarafem (fluoxetine)
    ____ Luvox (fluvoxamine)
    ____ Paxil (paroxetine)

    Serotonin-norepinephrine reuptake inhibitors (SNRIs):
    ____ Effexor (venlafaxine)
    ____ Effexor XR (venlafaxine XR)
    ____ Pristiq (desvenlafaxine)
    ____ Cymbalta (duloxetine)
    ____ Fetzima (levomilnacipran)
    ____ Savella (milnacipran)

    Atypical antidepressants:
    ____ Bupropion (wellbutrin, forfivo XL, aplenzin, zyban)
    ____ Mirtazapine (remeron)
    ____ Nefazodone (serzone)
    ____ Desyrel (trazodone)

____ Vortioxetine (trintellix)

22. What was the child's due date? ______________

23. Was your child born full term? (within a few days of the due date) ____ Yes ____No

24. Was your child born pre-term? (week or more before the due date) ____ Yes ____No
    If yes, how many weeks early (before the due date)?
    ____ 1
    ____ 2
    ____ 3
    ____ 4
    ____ 5
    ____ 6
    ____ 7 or more

25. Was your child born late? (a few days or more after the due date) ____ Yes ____No

26. How many days did your child stay in the hospital after birth? ________________

27. Were any of those days spent in the NICU? ____ Yes ____No
    If yes, then how many? _________________

Section F: Child health.

28. Has your child had any health problems requiring surgery? Yes____ No____
    If so, please describe____

29. Has your child had any hearing and/or vision impairments? Yes____ No____
    If so, please describe____

30. Does your child currently have any hearing or vision impairments? Yes____ No____
    If so, please describe____

31. Has your child been identified with any of the following?
    ____ Autism or autism spectrum disorder
    ____ Language delay
    ____ Cognitive delay
    ____ Reading delay
    ____ Motor impairment
    ____ ADHD
    ____ Other (please describe) _________________

32. In your opinion, does your child exhibit developmental delays? ____ Yes ____No
    If yes, when did you first notice difficulties in development or behavior?___________________
    If yes, what difficulties do you notice? ____

33. Have any of your child's siblings been diagnosed with a developmental delay including autism spectrum disorder

Experimenter________________

(ASD), Asperger Syndrome (AS), or a Specific Language Impairment (SLI)? ____ Yes ____ No
If yes, please describe the age of the sibling and the nature of the delay/diagnosis.
____

Section G: Family structure.

34. Please indicate the total number of adults in the child's household: ____. Please check all that apply:
    ____ Mother
    ____ Father
    ____ Grandparent
    ____ Aunt/uncle
    ____ Other (please specify)

35. Does your child have siblings? ____ Yes ____ No

36. Does your child live with his/her siblings? ____ Yes ____ No
    If yes, how many? ____

37. For siblings who your child lives with, please indicate the number of:
    ____ Older siblings
    ____ Younger siblings
    ____ Same age siblings (e.g., twin, triplet)

38. How often does your child have frequent interaction/contact with children who are not his/her siblings?
    ____ Very frequently (e.g., daily)
    ____ Frequently (e.g., several times a week)
    ____ Occasionally
    ____ Rarely
    ____ Never

Please describe: ____

Section H: Child activities.

39. In the past 3 months, during a typical week, about how many days per week was your child in daycare/preschool?
    Enter the number here (write zero if none): ____

40. In total, about how months has your child been in daycare/preschool?
    Enter the number here (write zero if none): ____

41. Was the daycare/preschool part-time (half a day or less) or full time (almost the entire day)? ______________

42. During daycare/preschool, does your child hear predominantly
    ____ English
    ____ Spanish
    ____ Other language, please specify ________________

6

Experimenter_______________

43. How many hours per day does your child spend using screens in each of the following categories?

	Less than 30 min	30 min to 1 hr	1 hr to 2 hrs	2 hrs to 3 hrs	3 hrs to 4 hrs	More than 4 hrs
Educational TV shows or movies						
Non-educational TV shows or movies						
Watching videos on Youtube or similar services						
Browsing the internet						
Playing games on tables, phones, or computers						

44. How did you hear about the study? (please check all that apply)
____ A friend
____ We phoned you
____ An advertisement
____ We mailed you a letter
____ Social media (Facebook, Instagram, Twitter, etc.)
____ Information provided at a hospital
____ Information provided at a pediatrician or other doctor's office
____ Other (please specify):_______________

45. Additional comments about your child or your visit:
____
____
____

Thank you for your help.

____ Check here if you do not wish to provide some or all of the above information.

The purpose of the above questions is to help us to better understand the results of our studies and to account for differences in responses between participants. Your answers will not affect your child's participation in the study for which you have come today. All answers will be kept confidential.

Appendix C

Maternal Sensitivity Coding Scheme

Maternal Sensitivity Score Sheet

Coder: Date: Subject ID:

	1 min	1 min	1 min	1 min	1 min	1 min	1 min	1 min	1 min	1 min	Score
Facilitates Attention											
Intrusiveness											
Positive Affect											
Negative Affect											
Notes											

1 – no evidence, 2 – low level, 3 – moderate level, 4 – high level