The Effects of Attention on the Mismatch Response of Infants

by

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Abstract

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This study explored the role of attention in the development of tone and vowel perception skills in infants through the use of auditory and visual associative learning and the functional nature of Mismatch Responses (MMRs) in infants. Two different infant MMR responses have been observed to speech sound changes, one positive and the other negative in polarity. Current evidence suggests that the negative MMR is the precursor of the adult MMN, whereas the positive MMR may index recovery from refractoriness or an orienting response. Event Related Potentials (ERPs) were collected to tones (1000Hz vs. 1200 Hz) and Consonant-Vowel-Consonant (CVC) words ([bIp] vs. [bɛp]) in two different conditions designed to focus attention differently. In the contingent condition, a picture of a smiling woman's face always followed occasional deviant auditory stimuli. In the non-contingent condition, the women's face followed 100% of the time in the tone experiment and the women's face randomly followed the standard [bɛp] on half the occasions, and the deviant [bIp] on the other half in the speech experiment. A statistically significant difference was not found between the contingent and non-contingent task in the tone experiment. Both conditions elicited a more negative deviant waveform than the standard waveform at frontal sites. Negative MMRs peaked around 200 ms when attention was focused to the change in the contingent condition for the speech experiment. A significant difference was seen in the amplitude of the MMR to the deviant in the contingent vs. non-contingent conditions (*F* (20, 180) = 2.67, *p* = 0.001). The difference was greatest at left

frontocentral sites. The elicitation of the negative MMR (the assumed precursor of the adult MMN) to this fine-grained phonetic difference appears to require attention in the first year of life. This is most likely because robust representations have not yet been constructed to allow for automatic and preattentive discrimination.

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Chapter I: Introduction

A number of studies suggest that language learning disorders co-occur with auditory and speech processing deficits (Benasich &Tallal, 2002; Tallal, 1976; Wright, Lombardino, King, Puranik, Leonard & Merzenich, 1997). The relationship between these deficits, however, is unclear. Development of good speech perception is likely to be important for good language skills. A breakdown in any of several sub-processes underlying speech perception could contribute to deficits in speech perception and language learning. One such process is the use of attention in discriminating auditory signals. Attention is necessary for many cognitive processes. It plays an important role in the selection and identification of relevant information in the environment. A number of developmental models argue that the proper deployment of attentional resources is important for developing speech perception skills (Jusczyk, 1997; Werker & Curtain, 2005). Examining how infants are allocating attentional resources in speech perception tasks is challenging because of infants' lack of verbal abilities. Electrophysiological measures can aid in this task because they do not require a behavioral response and allow examination of the processes underlying a task. The general aim of this study is to determine if directed attention facilitates processing of different sound properties in infants. Event-related potentials (ERPs) were used to index neural processes that underlie discrimination of tone contrasts (Experiment. 1) and consonant-vowel-consonant (CVC) nonsense words (/bIp/ vs. /bEp/) (Experiment. 2**)** and examine how attention affects discrimination of these sounds in 4-8 month old infants.

1. Background and Significance

1.1. *Models of speech perception*

Normal speech and language development depends on discrimination of acoustic features of speech. Models of infant speech perception suggest that attention plays an important role in speech perception and word recognition development (e.g., Jusczyk, 1997; Werker & Curtin, 2005; 2011). For example, in Jusczyk's (1997) model entitled Word Recognition and Phonetic Structure Acquisition (WRAPSA), the component that is relevant to this study is the role attention plays in developing word recognition skills. The first stage of the WRAPSA model is the acoustic analyses of speech signals by infants, and the output of this stage is information on temporal and spectral features of the signal. Considerable evidence demonstrates that newborn infants are able to discriminate speech sounds differing in temporal or spectral features, suggesting that infants engage in this stage of processing from birth (Jusczyk, 1997). No reference to attention is made in this first stage and it is unclear to what extent attention is necessary to this acoustic analysis.

In the second stage, the output of the first stage is weighted to highlight critical features that are needed for making semantic distinctions between words (phonological categories). Considerable evidence reveals that between six and twelve months of age, infants stop discriminating speech contrasts that are not phonemic in their native language (Best, 1993; Jusczyk, 1997; Kuhl, Williams, Lacerda, 1987). Attention is hypothesized to play a role at this stage, in that infants are claimed to automatically focus their attention on relevant cues in the auditory signal. Evidence that they do this is inferred from the changes observed in speech perception. Direct evidence that attention is necessary to allow for development of phonological categories has not yet been demonstrated, although there are a few studies exposing infants to speech contrasts while they sleep that claim language specific-changes related to this passive experience (Cheour, et al, 2002a).

The third and final stages, occurring between 6 and 12 months of age, are the extraction of patterns in the weighted signal to discover word size units (syllables) in longer stretches of speech and the comparison of the word size chunks to stored memory representations of words in the lexicon (e.g., Friederici, Wessels, 1993; Mandel, Jusczyk, Pisoni, 1995). Attention must play an important role in these later two stages. Infants must be able to attend to important cues in speech to be able to create patterns but Jusczyk does not discuss this in his model.

In summary, Jusczyk (1997) claims that selectively attending to acoustic-phonetic cues influences how speech is perceived, but direct evidence for the role of attention in this process and an understanding of how this mechanism works is absent (See Section 1.2 for role of attention in speech perception).

In a more recent model of speech perception, Werker and Curtin (2005) make reference to attention at multiple levels of speech perception and word learning development. They proposed a framework that assumes that there is rich information encoded from the speech signal. This signal is processed through three dynamic filters, described as 1) initial biases, 2) the developmental level of the child, and 3) task requirements of the ambient language. These filters interact and direct the infant's attention by enhancing or diminishing the physical properties of speech during the formation of representations. These representations are organized into three dimensions: a General Perceptual Plane, a Word Form plane, and a Phonemic Plane. Once these dimensions are established, they also direct attention to the critical information for word learning. Access and organization of these representations are not hierarchically ordered. This model argues for a larger role of attention at multiple levels of speech perception and word learning development. Again, however the underlying mechanisms for directing attention are not clear and there is no direct evidence of how attention is allocated during these levels of speech perception is lacking.

The role of attention in infant speech perception can be inferred from behavioral studies attempting to determine what aspects of the speech signal are particularly salient to young infants. For example, one study showed that infants' attention can be manipulated to focus on different aspects of the speech signal as early as two months of age (Jusczyk, Pisoni, Mullennix, 1992). Infants were familiarized with a series of syllables which shared the same initial consonant and in post training they were presented with an additional syllable that ended with a different vowel (/ʌ/ or /u/), hearing either /bi, ba, bu/ or /bi, ba, bʌ/. It was expected that the infants would have a harder time discriminating a fine-grained difference, /ʌ/ which is highly similar to /a/, versus /u/ which is very dissimilar /to /a, i, ʌ/. This study reveals that with attention 2-month-old infants can make these fine discriminations. However, it is unknown whether such distinctions can be made at a more automatic level. It is challenging to demonstrate these using behavioral methods (although possible, for example, if one showed that a fine-grained distinction influenced discrimination or categorization of a more robust distinction). Electrophysiological methods could be used to test what infants are doing at a pre-attentive level.

In summary, allocating attention to relevant cues is argued to be a critical and necessary step in word learning. However, direct evidence of how attention affects speech discrimination during infancy has not yet been obtained. Furthermore, the attentional mechanisms that an infant might employ in these processes are not defined. There are several ways that attention might influence speech perception in infants: the speech signal saliency probably influences the amount of attention allocated to processing, developmental changes in attentional mechanisms or allocation of resources could influence what information an infant focuses on.

1.2. Attention in speech perception

A recent theoretical model of adult speech perception directly addressed the role of attention in first language speech perception (Strange & Shafer, 2008; Strange, 2011). The Automatic Selective Perception (ASP) model claims that first language (L1) processing in adults reflects automatic detection of phonologically relevant information in the acoustic signal. The perceptual processing of L1 phonetic/phonemic segments is highly automatic due to the extensive experience in L1. In contrast, non-native listeners or second language (L2) learners have greater difficulty with nonnative speech perception and may require additional attentional resources to discriminate the same phonetic contrasts. Strange and Shafer (2008) consider perceptual difficulty as a function of stimulus and task factors and L1/L2 phonological and phonetic similarities and differences. The success of non-native listeners in discriminating speech sounds is dependent on the degree of selective attention (i.e. cognitive effort) that can be engaged in the task. Selected attention on relevant cues differentiating phonemes is necessary for appropriate categorization. The degree of difference between L1 and L2 phonology predicts differences in the amount of attention needed in processing. In the initial stages of speech perception development, whether L1 in infants or L2 in non-native speakers, increased attention may be required to process difficult contrasts until processing becomes an automatic process. One unanswered question is the amount of attention that is needed to develop native-language speech categories in infants.

A number of investigations of children with language impairment suggest that these children do not select relevant cues for good speech perception (Datta, Shafer, Schwartz, Morr & Kurtzberg, 2010; Shafer et al 2005; Sussman, 1993; Ziegler, Pech-Georgel, George, Alario & Lorenzi, 2005). However, it is unclear whether this failure is the result of either incorrect weighting or less automaticity of processing. It is possible that poor selective attention to speech information during infancy contributed to this speech perception deficit and, possibly, language learning delays seen in language impairment. However, direct evidence of how and what type of attention affects speech discrimination during infancy has not been obtained.

During the first year of life, attention is strongly determined by novelty. Infants orient to novel stimuli, and explore the attended stimulus unless presented with another stimulus. Subsequently, higher levels of cortical control increase ability to orient to relevant information (Cohen, Anthony & Ziegler, 1983; Jusczyk, 1997; Rothbart, Posner, Rosicky, 1994). The development of these attentional mechanisms will be considered further below.

1.3. Development of Attention

Developmental models of speech perception may mention attention. However, the authors of these models largely ignore the literature on development of attention, which is necessary for many cognitive processes. Attention plays an important role in the selection and identification of relevant information in the environment (whether speech or non-speech). Selection of relevant information is critical for the development and acquisition of new skills. The process of selecting stimuli to attend to is not only determined by the physical properties of the stimulus but also by the individual's cognitive strategies, motivation, and interest. Auditory attention can be broken down into four somewhat independent components: arousal, orienting, selective and sustained attention (Gomes, Molholm, Christodoulou, Ritter, & Cowan, 2000). For the current study, orienting and selective attention are the most important, but arousal and sustained components will also be introduced to allow the two components of interest to be understood within a broader context.

Arousal

Arousal is a physical and psychological state of readiness (Paashler, 1998, p.90). It is important in regulating attention for information processing. During the first few months of life, the infant's level of arousal changes frequently between being asleep and awake. The development of arousal level is evidenced by more time spent awake and alert. Theories of arousal in adults have reported that there is a dual-level control mechanism, a low-level and higher-level arousal system (Ruff & Rothbart, 1996, p.6). The low-level system is described as physiological arousal mediated by the reticular system. The higher-level system is described as cognitive arousal and can modulate the lower-level system to maintain an optimal level of arousal. The cognitive arousal system develops later than the physiological system, and is seen as the ability to control self-regulatory functions (i.e. thoughts, emotions, actions). Arousal is important in maintaining focus and subsequently in sustained attention. By two-three months of age infants can engage in five-to-ten seconds of sustained attention. This will continue to increase until 18 months of age when it is fully developed (Richards, 2001).

Orienting

Orienting processes include the physiological and behavioral changes that are associated with the detection of a novel stimulus. Orienting alerts the infant to potentially important stimuli in the environment. Newborns have shown the ability to orient to a variety of signals. It is mostly the physical properties of the stimuli that determine if a response will be elicited in newborns. Highly salient stimuli (e.g., loud, bright) result in a strong orienting response in newborns (Richards, 2001).

Novelty becomes increasingly more important in the next few months of life in eliciting a response from infants (Gomes, et al, 2000). In addition, infants show a preference for speech over non-speech sounds. Infants between the ages of 2 and 7 months listened longer to monosyllabic nonsense words versus acoustically similar non-speech sounds. These initial sensitivities might lead infants to orient to speech sounds, and specifically, to novel speech sounds. This process may be a learned or innate capacity to process speech and subsequently learn language (Colombo & Bundy, 1981, Vouloumanos and Werker, 2004). If it is a learned capacity then infants acquire this bias very early on in life.

Selective Attention

As infants develop they begin to show some evidence of selectivity, suggesting that they may differentially weigh stimulus features for further processing (Posner & Raichle, 1994, Fantz, 1961). Selective attention is the process of focusing on a specific stimulus for further processing while ignoring other stimuli. This process becomes more automatic with experience. Initially, selectivity is determined by the intensity of the stimulation. However, over the first few months of life, infants appear to have more control in shifting their attention (Johnson, Posner and Rothbart, 1991). Infants will orient to either a novel or salient event, explore this event by sustaining their attention and gradually shift from one event to another. The allocation of attentional resources decreases over time to novel stimuli as processing becomes more automatic (Posner, M, 2004). This change has been interpreted as indicating an increase in processing speed as infants mature. Infants learn to be more efficient in cognitive processing, and will have a decline in the amount of time necessary to process simple stimuli (Richards, 2001).

Sustained Attention

Sustained attention is the ability to maintain attentional focus over time. Toddlers are able to select what to attend to by observing what others attend to or attention can be more self-generated rather than determined by the novelty of an event (Ruff and Lawson, 1990). In a study by Richards (2001), he found that in 6-month old infants there is decline in the looking to simple patterns compared to younger infants. He proposed that the decline in looking duration indicates an increase in sustained attention, which then leads to more efficient cognitive processing and less amount of time to process simple information. However, Richards, also found an increase in looking duration for 6-month to 2 years-old children to complex and varied visual patterns. The increase in looking time to complex and varied visual patterns shows that infants will select and sustain attention (processing of information) if complexity exists in the stimuli.

In summary, attention literature has shown that humans have limited processing capacity. To deal with this limited processing capacity, we select pieces of information for further processing, but not others. Children go through various stages of attention development before their attention becomes adult like. The first is arousal or how prepared an infant is to process stimuli in general. Orienting involves how resources are directed towards information processing. Sustained attention is a state in which stimuli can be continue to be processed and selective attention is when we process some stimuli, but not others. Each of these varieties of attention changes as a child develops.

1.4 ERPs and attention

Cortical auditory evoked potentials (CAEPs) and Mismatch responses (MMRs) are ERP components that index auditory processing and discrimination. CAEPs are elicited to the physical properties of a stimulus while MMRs serve as an index of cortical discrimination of auditory information (Dehaene-Lambertz & Gigla, 2004; Wunderlicha, Wesson, & Shepard, 2006). Studies using Mismatch Responses (MMRs) have been shown to index discrimination of fine-grained differences in auditory stimuli in infants, children and adults, and can be obtained while the participants' attention is directed elsewhere (e.g. watching a closed captioned video). MMRs are elicited by repeating a standard stimulus with an occasional replacement by a deviant stimulus (oddball paradigm). For the mature, adult mismatch negativity (MMN), the repeating standard stimulus forms a sensory memory trace against which incoming stimuli are compared.

The sensory input from the deviant stimulus is registered as a mismatch, and indexed by a change in neural firing (Näätänan, et al., 2007).

The adult MMN is a negative deflection in the wave of the deviant compared to the standard (Mismatch Negativity, MMN). It can best be seen by subtracting the averaged ERP of the standard from that of the deviant sound. Adult MMN is generally most negative at the fronto-central sites and positive at the mastoids, and peaks between 100-250 ms (Näätänen, Jacobsen and Winkler (2005). It can be elicited by changes in a variety of acoustic features, such as frequency, intensity, duration, and a change in the auditory pattern (Näätänan, et al., 2007). The amplitude and latency of the MMN is related to the size of the difference between the standard and deviant stimuli. The larger the difference is, the greater the amplitude and earlier the latency of the associated MMN to this change (Näätänen, et al., 2007). MMN is generated in auditory cortex (Alho, 1995) with some frontal generator contribution, which is usually stronger in the right than the left hemisphere (Giard, et al. 1990).

In infants, two contrasting results from MMRs in oddball paradigms have been seen in auditory discrimination tasks. Some studies have reported a negativity similar to those seen in adults, but with some differences in latency (Cheour & Leppanen, 2000; Pang, Edmonds, Desjardins, Khan, Trainor, & Taylor, 1998). In contrast, several other studies have observed a positivity elicited to deviant sounds (Positive Mismatch Response, pMMR) (Benasisch et al. 2002; Friederici, Friedrich & Weber, 2002; Leppanen, Eklund, Lyytinen, 1999; Morr, Shafer, Krezer, Kurtzberg, 2002; Shafer, et al., 2011; Winkler & Cowan, 2005).

The negativity observed in infants is usually longer in duration (onset to offset) compared to adult MMN, but the peak has been seen around the same time as adult MMN, 100-250 ms (Ceponiene, E. et al. 2002) or as late as 400-500 ms (Cheour et al. 1999, Friderici, Friedrich & Webber 2002). In one study the amplitude was of considerably greater amplitude than found in adults (Cheour et al. 1998).

The pMMR has been observed around 300-400 ms after change onset. This positive change detection has been seen in response to pitch change (Leppanen, 1997; Morr, 2002), vowel and consonant differences (Choudhury & Benasich, 2010; Dehaiene-Lambertz, 2000; Friederici 2002; Leppanen, 1999; Shafer, et al., 2011; Shafer, Yu, Garrido-Nag, in press) and deviant gaps (silences) (Trainor, 2003).

Both MMN and pMMR in infants show greater amplitude at central and parietal sites than the adult MMN (Morr, Shafer, Kreuzer, Kurtzberg, 2002). To spectral vowel differences, the pMMR is larger at left frontal sites and the MMN at right central sites in four and five-year old children (Shafer, Yu & Datta, 2010).

There have been two types of arguments in the current literature, maturational versus functional, that attempt to account for the difference in the polarity of the mismatch response in infants. One functional argument is that this positive component reflects an orienting response similar to the P3a seen in adults and children, and that it may mask the mismatch negativity response (Kushnerenko, Ceponiene, & Balan, 2002; Morr et al., 2002; Trainor, 2001). P3a is usually elicited by a rare or novel stimulus in a stream of repeating stimuli when the deviant is not a target, and is seen between 250-350ms post change onset (Comerchero, M, & Polich, J, 1999; Kushnerenko, E, Balan, P., Fellman, V., Huotilainen, M, 2002; Polich, 2007). Morr and colleagues (2002) suggested that a positivity was observed in infants aged 2-7 months rather than the negativity that is usually seen in adults, due to a masking of the negativity by the large positivity. In Morr et al.'s second experiment, they used a larger tone difference (1000-Hz versus 2000-Hz tones) and found a negative response followed by the positivity. Morr and colleagues also suggested that in children and infants, attention may be required to discriminate small frequency differences. In their study, the attention of the infants was not directed specifically to the sounds, although the infants were awake.

Other researchers however have suggested that the positivity is a pre-attentive discriminative response, similar to the adult MMN, because it can be observed in sleeping babies (Friederici et al., 2002). ERPs were collected from two-month old infants in two different states of alertness, awake and asleep. Two syllables varying in vowel duration were used. The alertness level of the infants determined the presence of negativity in their response. In the awake infants a positivity followed by a negativity was observed while in asleep babies a positivity was observed at an even more extended time frame than in the awake infants. The positivity was only present for the longer deviant and not for the short deviant. This suggests that the positivity is a reflection of a pre-cognitive aspect of change detection.

Recent findings by Shafer and colleagues support the suggestion that the pMMR reflects pre-attention discrimination (Shafer, et al., 2010; Shafer, et al., 2011; Shafer, et al., in press) indicating that it does not reflect an orienting response. They go further to suggest that the pMMR is an obligatory response indicating new afferent input (i.e. different afferent input) for the deviant. Because the inter-deviant interval is longer than the inter-standard interval, greater recovery of refractoriness is present for the deviant afferent input. Shafer and colleagues observed a robust pMMR to a spectral vowel difference in infants, which declined with age. Around three years of age, many children show a negativity following the positivity between 300 and 400 ms post stimulus change (Shafer, et al., 2011) and by four years of age a significant, robust MMN is present (Shafer, et al., 2010). However, the pMMR is still apparent at left frontal sites in four and five year old children. It appears that there is a developmental trend from a pMMR, reflecting an early form of discrimination, to a nMMN that reflect an adult like discrimination response.

The difference in polarity could also be due to maturational changes in the brain (Trainor, 2003). Considerable development of axons that process information from the ear and brain stem to the auditory cortex occurs perinatally to one year of age (Huttenlocher & Dabholkar, 1997). Deeper layers IV, V, and VI show more rapid development after 4 months of age than for superficial layers II and III. The axonal density increases up to at least 5 years of age indicating that the maturation of the auditory system continues into early childhood (Moore, 2002). From the third trimester to about three months of age, the marginal layer, Layer I composed of an intracortical axonal system, is probably responsible for early speech discrimination given that there is an absence of mature axons in the deeper cortical layers. Information is conducted through the brainstem at 26 to 28th week of gestation, which can account for the accurate stimulus discrimination in younger infants (Moore, 2002) as well some contribution of the cerebral cortex (Dekaban, 1970). These rapid changes in the maturing brain could conceivably affect potentials collected during an auditory discrimination task. However, it is difficult to pinpoint the developmental timetable of auditory discrimination skills and the development of auditory brain areas, which remain largely unknown. The maturational changes in the brain cannot account for overlap in ages when negative MMRs and pMMRs have been reported in various studies. A pMMR has been reported as early as 2-3 months (Dehaene-Lambertz, Dehaene, 1994) through the first year 8-12 months (Morr, 2002) and up to five or six years of age (Shafer, et al., 2010). MMN has been reported in newborns (Cheour, 1999), at 6 months (Cheour, 1998), and in some bilingual infants and toddlers (Shafer et al, 2011).

The factors that lead to pMMR versus MMN discriminative responses need to be determined. One suggestion is that both stimulus salience and attention influence which responses are observed (Shafer, et al., 2011; in press). However, it is generally difficult to ascertain how infants are allocating attentional resources during speech perception tasks. Determining the role of attention on these MMRs would help us to understand their functional significance, and this in turn would help understand how infants' speech discrimination abilities develop.

Although attention modulation of the infant MMRs has not yet been directly investigated, attention has been reported to modulate the MMN in both adults and children (Gomes, Molholm, Ritter, Kurtzberg, Cowan & Herbert, 1999; Sussman, 2007; Woldorff, 1991; Naatanen, 1993). The negativity to a difficult contrast increased in amplitude with attention in children but not in adults in a study by Gomes et al. (2000). Three sequences of tones containing standards (1000 Hz) and three deviants (1050, 1200, and 1500 Hz) were used. There were three conditions: participants ignoring the sounds, participants listening to the sounds and responding to all three deviants, and then participants again ignoring the sounds. Results showed that attention only had an effect on the MMNs elicited by the hard deviant (1050 Hz) in children. The MMN was larger when the children were attending to the stimuli than when they were ignoring them. However, there was no effect of attention on the two easier deviants in children. In adults, attention had no effect on any of the three deviants. It is suggested that auditory discrimination may not be as automatic as we previously thought and that attention may be required for hard-to-discriminate stimuli.

In infants, the processing of auditory stimuli may be less automatic than in adults. They may need to initially focus attention on the auditory stimuli to be able to discriminate them, particularly if they include difficult contrasts. However, this issue has not been directly addressed, partly due to limitations of behavioral methods. A re-analysis by Datta, Garrido, Morr, Kurtzberg & Shafer (2005) was done on data from Morr's (2002) study. This was done to determine whether the negativity and positivity in 2 – 7 month old infants, in response to tones (1000 and 1200 Hz), can be dissociated to assess whether: a) the positivity is a reflection of an orienting response or a discriminative response, and b) the negative MMR is being masked by the pMMR. After dividing the stimuli into those presented in the first half versus the second half of the study, a significant difference was seen in the positivity. The positive component in the infant data was significantly reduced over time. This lends support to the hypotheses that some portion of the positivity in the pMMR is an orienting response. Specifically, as the infants habituate to the stimuli, they orient less to the change. Filtering out the positive component using a 3-Hz high-pass filter led to the presence of a negative deflection wave that was significant for the first and second half of the study, supporting that these two responses overlap in time. Weber, Hahne, Friedrich, & Friederici (2003) found that when they manipulated the filter setting they used for their infant data, they were able to show a nMMR. Using a bandpass filter (1-15 Hz) vs. a high pass filter, they were able to filter out the slow wave activity (pMMR). It appears that the positive and negative MMR overlap and with the use of appropriate filter setting, the negativity is uncovered.

1.5 Contingency and context in attention

The goal of this study is to further understand the role of attention in auditory processing of infants. Attention can easily be manipulated in adults by creating tasks that will require them to attend to or ignore a stimulus by introducing a secondary difficult task in a different modality. In infants, however, direct manipulation of attention is not as easy, but can be done. It is difficult to verbally direct infants on what tasks they need to attend to.

In this study, we will use cross-modal associations of visual and auditory information to manipulate attention. Crossmodal processing can facilitate the discrimination of sound contrasts by directing attention to one modality by using the other modality as a positive reinforcement. Associative learning will be built between the auditory and visual stimuli to enhance attention to the speech changes. Learning occurs as a result of one stimulus being presented in relation to another. The association allows for prediction of when something is going to occur. Thus, processing of a stimulus in one modality can be facilitated through another modality.

Kaplan (1991) has expanded this account by specifically looking at how an auditory stimulus facilitates the processing of a visual stimulus in infants using a bimodal presentation method. It has been seen in a number of behavioral paradigms that the infant's response to visual stimuli can be modulated by sounds (Culp, 1975, Scheuneman

& Jenkins, 1991). The cross-modal effects are mediated by changes in the infant's state of arousal. Kaplan reported that the pairing of a tone with a picture of a face could increase fixation time on the face. She argued that this effect was the result of an associative form of learning. There is an increase of attentional response, and thus, an increase in fixation. In addition, studies suggest that there is increased responsiveness to stimuli that have a positive reinforcement value (Groves & Thompson, 1970). These findings support the claim that cross-modal pairing of an auditory with a visual stimulus will lead to increased attention to both the auditory and visual stimuli that are associated, if the association is positive. A modified version of Kaplan's cross modal attention paradigm will be used in the current study to manipulate attention in infants and to determine in what manner infant MMR components are modulated by attention. The visual stimuli will be used to direct attention to the change in the auditory stimuli. The assumption is that infants will perceive the changes in auditory stimuli as a result of higher-level discrimination. The subsequent reinforcement of the visual stimuli will help sustain attention to the differences in the sounds being presented.

1.6 Influence of attention on obligatory auditory components

The most prominent components of the event-related potentials (ERPs) found in children are the P1 (P100) and N2, while the P1 and N1 are prominent in adults. The P100 should be present regardless of attention. However, the P100 could be used to determine whether there is any general enhancement of auditory processing related to attention. In the adult and child literature, increased attention to auditory stimuli leads to an increase in negativity (the processing negativity, PN or Nd) between 80 and 140 ms (e.g., Shafer, Ponton, Datta, et al., 2007). Thus, an enhancement of attention may actually be observed as a decrease in positivity of the P100 for the standards when attention is focused to the auditory stimuli vs. when attention is randomly focused. The Negative Central (Nc) can also serve as an index of attention in infants. Nc is a late negative ERP component that is greatest at fronto-central sites (Vaughan & Kurtzberg, 1992). It is usually seen around 400-450 with the greatest amplitude to infrequently presented stimuli. If the frequently or infrequently presented stimuli are already familiar to the infant, the Nc component does not differ. This component appears to index learning and memory (Nelson & Collins, 1992). It may be that the Nc is a precursor of the adult N2. However, the auditory Nc may be masked by the obligatory components to the visual stimuli since the onset of the visual stimuli is 450 ms after the offset of the auditory stimuli in this study. More recently, Shafer and colleagues observed an increase in positivity to standard stimuli in the final position of a train of 10 stimuli in 6-month old infants (Shafer, Yu and Garrido-Nag, in press). The increased positivity could be an orienting P3a response, since the final position may draw more attention than other positions.

1.7 Significance

It is important to understand how attention to speech affects the ability to discriminate speech sounds, and subsequently to learn language-specific speech categories. It is necessary, however, to first identify measures that reveal how infants are allocating attentional resources during speech perception tasks. This dissertation study provided a first step towards this goal by determining how the infant negative and positive MMRs elicited to auditory and speech sound discrimination are affected by selective and sustained attention. It will then be possible in future studies to make inferences about what infants are doing with their attentional resources when listening to speech sounds under various task conditions. These ERP components will then be useful for studying speech perception in clinical populations who are known to have both deficits in attention and language, such as children at risk for autism or language impairment. It is possible that atypical attention to speech sounds during the first year of life contributes to the language learning deficits observed in these children.

General Aims:

The overall aim of this research was to gain a greater understanding of the role selective and sustained attention plays in the development of speech perception. The first step towards fulfilling this aim was to develop objective measures of how infants focus their attention. This study examined ERP responses to sound changes under different attentional conditions. The objectives of the study were to:

a. Establish a method for examining attentional modulation of infant ERP correlates to sound change. This will allow us to look at the level of automaticity of speech discrimination. If presented with a complex speech contrast, will attention make a difference in the infant's discriminative response? These data will provide a baseline for understanding how typical 4-8-month old infants attend to these speech sounds. Future studies will be able to examine these processes in different age groups and at-risk populations

b. Determine the functional nature of the positive versus negative MMR in infants; in particular, to what extent these measures are influenced by attention.

c. Examine whether attention affects discrimination of speech as indexed by infant MMRs; specifically, whether the positivity indexes pre-attentive response to a stimulus change or whether attention is independent of a discriminative response. This information is crucial for understanding the development of neural mechanisms for speech perception

The general hypotheses of this study were:

1. Associative learning between auditory and visual stimuli will lead to the modulation of

MMR responses in infants. In particular, pairing of a sound change with a visual reward will draw attention to the sound change. Pairing of the visual with the auditory change (contingent) will result in an increase in amplitude in either the positive or negative MMRs compared to randomized pairing of the visual with either change or non-change auditory stimuli (non-contingent).

a. If the pMMR is similar to the adult P3a component, for all participants, we expect to see a positive mismatch response to the deviant stimulus for both conditions and stimuli (Morr et al., 2002, Shafer et al., 2011). The positive MMR will show increased amplitude in the contingent condition compared to non-contingent condition indicating greater attention is allotted to the deviant sound in this condition, which reflects attention to an infrequent change.

b. The negative MMR will show increased amplitude, if attention to the stimuli strengthens a weak representation of the relevant information, as suggested in Hisagi, et al. (2010) and Shafer, et al. (2012). In infants, an MMN-like response has been reported (Cheour et al., 1998). It is similar to the adult MMN with differences in latency. In infants, the onset is later and the duration is longer, 200-400 millisecond. We expect that the negativity will be larger in the contingent condition because the infant's attention is directed to the change in sounds.

c. If there is an increase in negativity, related to b. and if the positive MMR is the P3a, the P3a should follow the nMMR (see Shafer, et al., 2010). The adult P3a indexes orienting to a stimulus. It is a greater positivity to the deviant sounds and is elicited by a rare or novel stimulus when the deviant is not the target sound. The peak latency is around 250-350 ms (Kushnerenko, et al., 2002). It has been suggested that the positivity seen as the infant’s response to a discrimination task, pMMR, is a reflection of an orienting response to the deviant sound.

Chapter 2: Methodology

2.1 Overview

The principal aim of this study is to examine the role attention plays in speech perception, specifically whether directing attention to a speech contrast leads to evidence of more robust discrimination in infants. This aim was accomplished by creating a forward pairing of an auditory stimulus with a visual stimulus to encourage the infant to attend to a stimulus change. Establishing cross-modal association will lead to greater attention to the auditory stimuli. Therefore, we will be able to assess if greater attention leads to evidence of a more robust discrimination at the neural level. A second aim of this study was to establish a baseline for ERP correlates to CVC words. Previous research on infant speech perception using ERPs has focused on tones, isolated vowels or simple CV syllables. The third aim of this study was to determine the functional nature of the mismatch response seen in infants. This was accomplished by looking at how manipulating attention affects the electrophysiological responses of the infants. If the positivity in the MMR of infants increases in amplitude when the infant's attention is directed to any auditory change then at least a portion of the positive MMR may reflect an orienting response, as proposed by Kushnerenko and colleagues (2002). If the positive MMR reflects obligatory afferent input, as suggested by Shafer, et al. (2010; 2011), then attention is expected to have a minimal effect. If the negative MMR is increased in amplitude then this can indicate one of two possibilities. Either the negative MMR is directly modulated by attention, or the positive MMR is decreased (allowing the negativity to be observed) because the stimulus change is less unexpected. In addition, increased negative MMR could lead to the appearance or a reduction in the positive

MMR, if the two responses overlap.

There were two attention conditions established in this study (contingent and non-contingent). Attention was manipulated by directing the infants' attention to the auditory stimulus by pairing a picture of a face randomly to the no-change and change stimulus (non-contingent condition) in one case, and directing it only to the change stimulus by pairing the face with deviants (contingent condition). The contingent condition was expected to direct the infant's attention to the auditory condition more so than the non-contingent condition because the auditory stimuli in the contingent condition provided information concerning when a face-reward will occur. Each participant participated in both attention conditions.

2.2 Participants

Twenty infants (10 for Experiment I and 10 for Experiment II) from monolingual or predominantly English-speaking homes, aged 4-8 months were tested. This age range was chosen for several reasons: (1) the infants will be able to sit on the lap of their parents; (2) they have adequate neck control to access the visual stimuli; (3) attention is not only captured by the novelty of the stimulus but by the features of the stimulus. Only infants who were full-term with no known neuropsychological disorders or risk factors for disorders were included. Each infant received a hearing screening using Transient Evoked Otoacoustic Emission (TOAE) (500-4000 Hz at 80dB SPL). Infants who failed a battery of tests of cognitive development or the hearing screening were excluded from the study and referred to a physician.

The battery of tests included:

1. Background Information (e.g. medical history, parental concerns): the information gathered from this questionnaire was used to determine whether the participants were at risk for any type of developmental disorder.
2. Bayley Scales of Infant Development (Bayley, 2005) (Tests general cognitive development): the mental scale of the Bayley was used to give an overall cognitive level to determine whether the infants were developmentally delayed.
3. Rossetti Infant-Toddler Language Scale (Rossetti, 2006) (Tests precursors of language, e.g. babbling): the Rossetti is both a parent questionnaire and direct testing of an infant's speech and language development. This gave us information regarding whether the infants were experiencing any speech and language delays.

The battery of tests took approximately 30-60 minutes to administer. The battery of tests was administered over two sessions.

2.3 Sound Stimuli

2.3a Experiment I: Tone

Train #1 (no change – standard): Stimuli: 1000Hz –1000Hz –1000Hz – 1000Hz

Train #2 (change – deviant): Stimuli: 1000Hz –1000Hz –1000Hz – 1200Hz

Figure 1: Stimuli are presented as a sequence (train) of four. The stimulus is changed in the 4th position on 40% of the trials

Two tones, 1000-Hz and 1200- Hz, were created. The tones were 150 ms in duration with rise and fall times of 10 ms created through SoundForge. The sounds were presented in two train types: no change- standard and change– deviant (Figure 1, see above). There are four tones in each train. These tone parameters were chosen for several reasons: First, they were used in a developmental study looking at the maturation of MMRs in infants and in children (Morr, et.al., 2002, Shafer, et al., 2000) and are known to elicit the positive MMR in infants in a passive condition. Second, steady state tones often result in a larger magnitude MMR than speech. We wish to ensure that an MMR was elicited in both contingent and non-contingent conditions so that we could compare the amplitude and latency of the MMRs under these conditions for the first experiment.

2.3b Experiment II: CVC Words

*Train #1 (no change – standard): Stimuli: b*εp –*b*εp –*b*εp – *b*εp

*Train #2 (change – deviant): Stimuli: b*εp – *b*εp - *b*εp – *b*Ip

Figure 1a: CVC stimuli are presented as a train of four. The vowel in the CVC word is changed in the 4th position on 40% of the trials

Two CVC words, /bIp/ and /bεp/, were used. These words were re-synthesized from natural tokens (female voice) using Analysis by Synthesis Lab, version 3.2. F1 increased by 25 Hz while F2 decreased by 30 Hz steps. Formants 3 and 4 were kept constant at 2174 and 3175 Hz respectively. Stimulus 1 and stimulus 5, the endpoints of the continuum, were used. /Bεp/ served as the standard sound and /bIp/ as the deviant sound. The words were presented in trains of four. Both words were 160 ms in duration with rise and fall time of 5 msecs. F0 was maintained at 190 Hz. All stimuli were delivered through speakers with an onset-to-offset time of 600 ms (160 ms in duration with 440 ms inter onset interval) and inter-train-interval of 900 ms.

2.4 Visual Stimuli

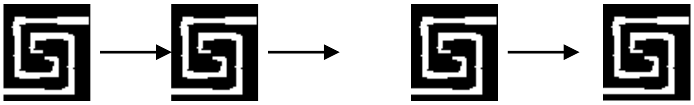
Two types of pictures were used, black and white patterns and a still shot of dynamic female faces (images of actual faces) producing child directed speech. These faces are expected to be more engaging for infants than black and white patterns (Richards, 2002). Five women were asked to produce child-directed speech towards a baby doll while being video recorded. Six different black and white patterns were used (see Figure 2). Still captures of the five different women were taken from the video. A total of one hundred and ten still shots were created. The visual stimuli were paired with the auditory stimuli. The train of four sounds was always paired with the same black and white picture. The visual stimulus (black and white pattern) began 10 ms before the first sound of the auditory train and lasted 1950 ms after the last sound in the train if it was a standard-no change train. If a change in the auditory stimulus occurred, then 450 ms after the offset of the last sound a still shot of a dynamic face producing child-directed speech appeared (replacing the black and white pattern picture) and lasted for 1500 ms. The 450 delay from the onset of the stimulus was selected so that the visually-evoked ERP components to the face will not overlap with the auditory ERP components of interest in the 100- to 450-ms time-window, particularly the positive MMR.

2.5 General Procedure

A black and white pattern is shown with the three auditory stimuli (change or no change train) throughout the train. The sounds were presented in trains of four each; with an inter-train-interval of 900 ms. In the paired-contingent condition, for the deviant train (change train), a face was presented 450 ms after the end of the last auditory stimulus of the train replacing the black and white pattern picture. For the non-contingent condition, the face occurred 100% of the time for Experiment I and randomly following 20% of the trains (that is, for 20% of deviants and 20% of standards) for Experiment II (See Figure 2, below).

Standard/ No change train:

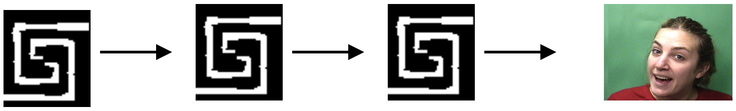
Visual Stimuli:



Tones:	1000Hz	1000Hz	1000Hz	1000Hz	
Words:	*b*ɛp	*b*ɛp	*b*ɛp	*b*ɛp	
Timing (Auditory):	600	600	600	600	1950ms
Timing (Visual):	onset 10 ms prior to 1^{st} CVC word in the train				
	610	600	600	600	1940ms

Deviant/ Change:

Visual Stimuli:



Tones:	1000Hz	1000Hz	1000Hz	1200Hz	
Words:	*b*ɛp	*b*ɛp	*b*ɛp –	*b*Ip	
Timing (Auditory):	600	600	600	600/450	1510ms

Timing (Visual): onset 10 ms prior to 1^{st} tone in the train

610 600 600 600 1500ms

Figure 2: Design of experiment showing the contingent condition.

Each experiment was comprised of eight blocks. All participants received 400 randomized trains, 50% of which included a deviant sound in the final position. Each block had 50 trains each and 3.5 minutes running time, for a total of 26 minutes of testing time. There were 200 deviant sounds, this number has been found to be more than sufficient to elicit a MMR (Dehaene-Lambertz & Dehaene, 1994). The overall percentage of standard versus deviant sound (ignoring train types) is 90% to 10%. In Experiment I, all deviant stimuli were paired with a face while in Experiment II, deviants were randomly paired with a black and white pattern or a face. All standard stimuli were paired with black and white patterns.

2.6 ERP Procedure (Experiment I and 2):

The experiments were conducted in a soundproofed and electrically shielded booth. Auditory stimuli were presented through sound field speakers (~ 1 m from infant) at 72 dB SPL. Both speakers were located midline to the participant, one in front and the other one behind and above the participant. This placement was designed to minimize potential differences in stimulus loudness to left and right ears, related to head movement of the infants.

Visual stimuli were presented through a 17” computer monitor that is one meter away from the participant. All pictures were presented using the full screen of the monitor. Infants were seated in a booster seat or their caretaker’s lap. The caretakers wore headphones and were listening to music to eliminate any bias that may occur from hearing the stimuli. A research assistant was in the room with the infant and caretaker. She was seated beside the infant and assisted in re-directing the infant's attention to the computer monitor if the infant became distracted. The experiments were designed to allow brief breaks if the infant becomes excessively active or distractible.

The caretakers were asked to shampoo their infant's scalp and hair prior to arriving to the session. This ensured better impedances and shorter time for preparation. Impedances were maintained below 40 kOhms, which is acceptable for the Geodesic system input impedance standard of 200 Mega Ohms (2003, Geodesic Sensor Net, Technical Manual).

2.7 Data Recording:

We recorded electroencephalograms (EEG) at 63 scalp sites using Net Station Software version 4.1. The electrodes were arranged as a sensor net and sheathed in sponge-encasings. The sponges were soaked in a potassium chloride solution to improve conductivity. The impedances of the electrodes were maintained below 40 kOhms. All recordings were referenced to the vertex (Cz) during data acquisition, but changed to an average reference during data analysis. The recordings were amplified with a band pass filter of 0.1 and 30 Hz and sampled at 250 Hz using a 63-channel Net Amps. The vertex served as the reference during data collection.

During data collection, all the electrodes were monitored by the experimenter for any electrical interference, lack of electrode contact to the scalp, or excessive movement. Eye movements were monitored from the frontal electrodes, #14, #10, & #2, since infants do not tolerate electrodes placed near the eyes. The state of the caretaker and infant was also observed by the experimenter to ensure that both were comfortable during testing.

2.9 Data Post-processing:

Electrophysiology data: Data were analyzed off line, the EEG recordings were segmented into epochs of 1000 ms window following the onset of a stimulus with a prestimulus baseline of 200 ms. The epochs were baseline corrected and trials greater than +/- 140 microvolts were rejected as artifacts. Further, channels with more than 15% of epochs with artifacts were replaced with data interpolated from the surrounding channels. Also, if 15% of the channels have artifacts detected in a certain epoch, that epoch was excluded from the average. The ERPs to the standard in position 1,2, and 3, standard on the 4th position, and deviant stimuli were averaged separately and baseline corrected using the 100 ms pre-stimulus interval. The average response to the standard 1, 2, and 3 stimuli was then subtracted from that of the deviant stimuli to derive difference waveforms. The average response to the standard in the 4th position was also subtracted from that of the deviant stimuli to derive a second batch of difference waveforms. This was done to see if there were any differences between internal standards (standard 1, 2, and 3) and end point standards (4th position). We wanted to eliminate the possible contribution of having a position of saliency on the average response of infants.

Statistical Analysis: There were several levels of analyses used in this study. For the first level of analysis, the averaged ERP waveform (amplitude and latency) of the deviant and standard stimuli between 0-500ms were compared at the frontal, central and mastoid sites (F3 (13), Fz (4), F4 (62), C3 (17), Cz (63), C4 (54), LM (26), RM (51)) since pMMR has typically been observed in this time range and sites. Topographical maps were also examined to identify sites of interest. ANOVAs were used to examine the presence or absence of MMRs by examining whether the standards and deviants are significantly different at these sites. The mean amplitude for eleven 30 ms intervals (161-190, 191 -220, 221-250, 251-280, 281-310, 311-340, 341-370, 371-400, 401-430, 431-460, 461-490) was calculated for analysis of variance. This time frame (161-490 ms) was chosen based on visually inspecting the data and 30 ms time window was used for statistics based on infant MMR literature (Cheour, 2002; Morr et al., 2000, 2002). Repeated measure of ANOVAs were performed in a Task (non-contingent, contingent) by Stimulus (standard, deviant) by Hemisphere (left, central, right) by time (11 intervals, from 191 – 510 ms) for frontal (F3, Fz, and F4, geodesic sites 13, 4, and 62) and central sites (C3, Cz, C4, geodesic sites 17, 63, 54) separately, to verify the presence of a significant difference (MMR) between the standard and deviant ERPs. MMRs could be seen as a negativity or positivity at the fronto-central sites (F3, Fz, F4, C3, Cz, C4) and relative positivity or negativity (opposite polarity) at the mastoids (Morr, et al., 2002; Shafer, et al., 2010).

Intervals and sites that were significant for either the contingent or non-contingent condition were then examined in an ANOVA using subtraction waveforms ((Deviant-standard=subtraction waveforms). with Site (frontal, central), Time (significant intervals), Hemisphere (left, midline and right), and Task (contingent versus non-contingent). This was done to examine whether a frontocentral negativity or positivity was consistent with this MMR topography. An average of the frontal ([f3 + Fz+ F4]/3) and central ([C3 + Cz + C4]/3) sites was calculated for the superior site and LM/RM were used for the inferior sites. These analyses included Condition as a factor to determine whether task affected the magnitude of the MMR. Post-hoc analyses were applied to significant interactions.

The data were also separated based on the polarity of the MMR (positive or negative). A negative MMR was defined as 1) a negative peak between 150-450 ms for any frontal and/or central sites and 2) inversion of the left/right mastoid or a positivity compared to the fronto-central sites in the same latency interval. A positive MMR was defined as 1) a positive peak between 150-450 ms for any frontal and/or central sites and 2) inversion of the left/right mastoid or a negativity compared to the fronto-central sites in the same latency. A fisher's exact test compared the proportion of infants showing negative versus positive MMRs in the non-contingent vs. contingent condition.

Finally, it was noted that a positivity following the negative MMR (negativity) at approximately 350-550ms was observed in both conditions (Figure 5). A positivity following a negative MMR was defined as a positive peak immediately after a negativity at the fronto-central sites. This positivity could be consistent with the P3a or an orienting response. A Fisher's exact test compared the proportion of infants showing this negative-positive pattern in the non-contingent versus contingent condition.

3.1 Visual Inspection

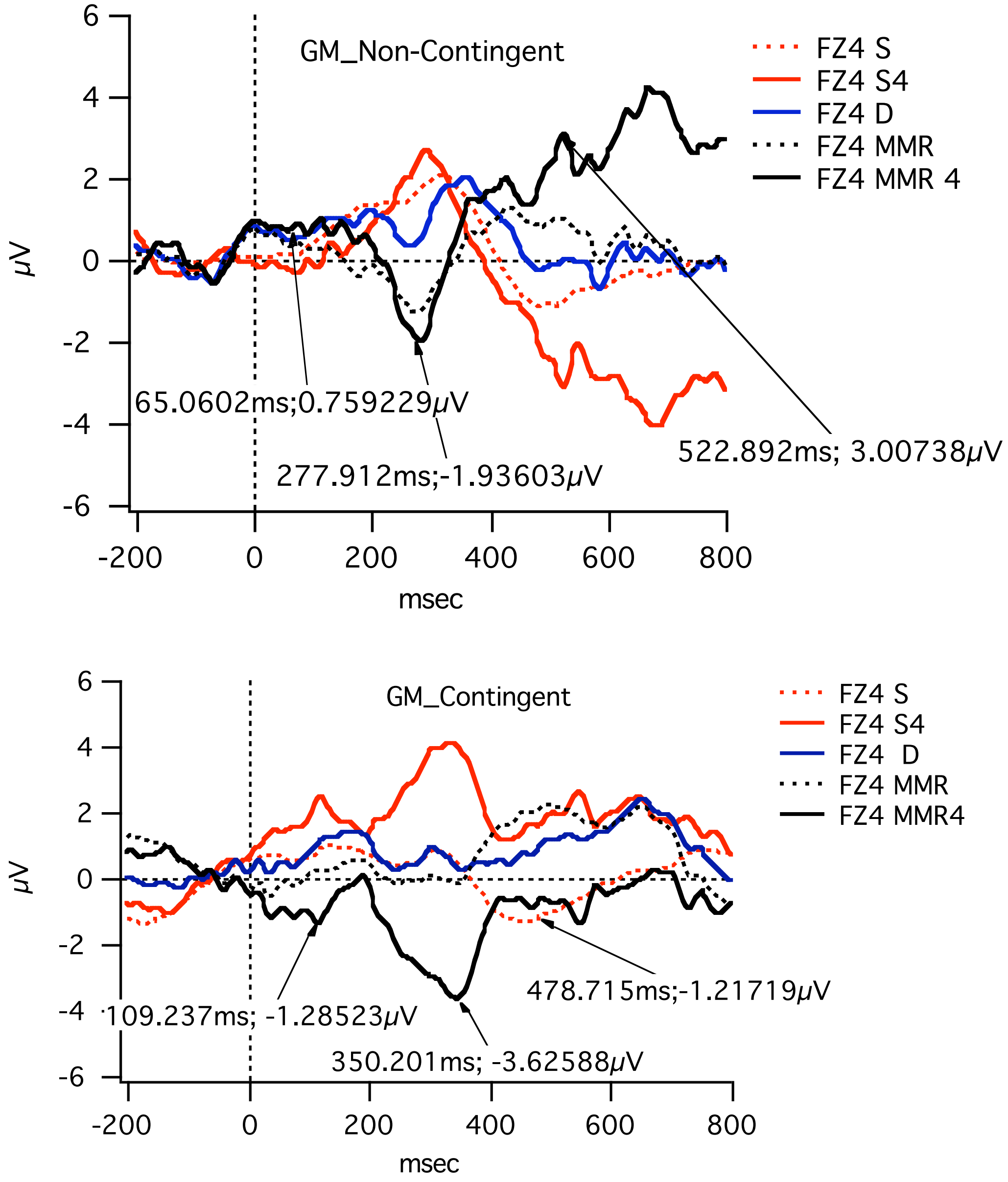
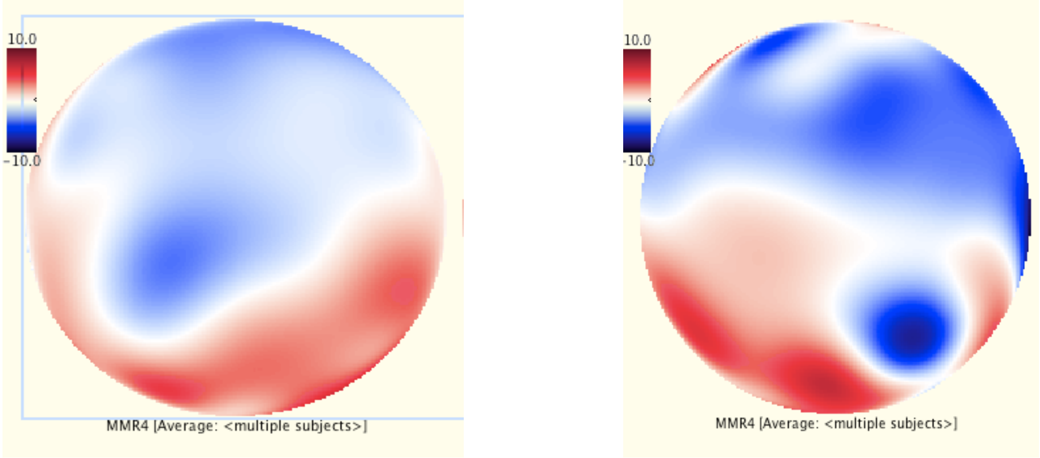


Figure 3: Grand Mean waveforms showing the standards (S) in the third and fourth positions, fourth only (S4), deviant (D), D minus S (MMR) and D minus S4 (MMR4) for the non-contingent (left) and contingent (right) conditions. Recall that a face was

presented 450 ms following the onset of the auditory stimulus for both deviant and standards in the non-contingent condition and for only the deviant in the contingent condition

A time by amplitude plot at Fz (Figure 3) revealed a broad negativity for the non-contingent condition and an even greater negativity for the contingent condition from 250-400 ms with peak amplitude of -2.2µV and -3.6 µV for the non-contingent and contingent tasks respectively. Topographical maps for both the contingent and non-contingent (Figure 4) showed that the MMR difference were greatest at the left frontal sites near F3 (site 13) and midline frontal Fz (site 4).



Non _Contingent Contingent

Figure 4: Topography maps (superior view) of the subtraction waveforms at the peak negativity of FZ -1.9µV, 270 ms for the non-contingent condition (left) and -3.6 µV, 350 ms for the contingent condition (right).

3.2 Presence of MMR

Standard vs. Deviant: Figure 3 shows the standard and deviant stimuli at Fz for the non-contingent and contingent tasks. Two-way Stimulus x Time ANOVAs at each site revealed significant interactions at all three frontal sites F3 (f(10, 90) = 2.58, p = .008), Fz (f(10, 90) = 2.76, p = .005), and F4 (f(10, 90) = 2.70, p = .006)) for the contingent condition and Fz (f(10, 90)=3.73, p=.000) for the non-contingent condition. Tukey's post-hoc analyses at the frontal sites for the contingent condition showed a significantly more negative deviant for time intervals 5, 6, and 7 (281-370 ms) at F4, and Fz for times 6 and 7 (311-370 ms). In contrast, post-hoc tests for the non-contingent condition did not reveal significant differences between the standard and deviant for any time interval. This is in contrast with the visual inspection of the non-contingent data where a clear nMMR could be seen. However, inspection of the individual data showed that not all the infants have a clear nMMR (inter-subject variation), which could have attributed to the statistical results (individual data results will be discussed further at a section below).

A three-way ANOVA (stimulus x site x time) of the average of three frontal sites (F3+Fz+F4/3) and the mastoids (LM/RM) between the standard and deviant waves for both tasks revealed an interaction of site x time (f(20, 180)= 2.32 p= .02) for the contingent condition and stimulus x time interaction (f(20, 180)= 2.7 p=.04) for the non-contingent condition.

We found that there was greater negativity for the deviant compared to the standard stimulus at left, right and midline frontal sites for the contingent task. There appears to be a greater negativity for the deviant compared to the standard stimulus at the midline frontal for the non-contingent task. However, follow-up post-hoc testing revealed no significant time bins for the non-contingent task.

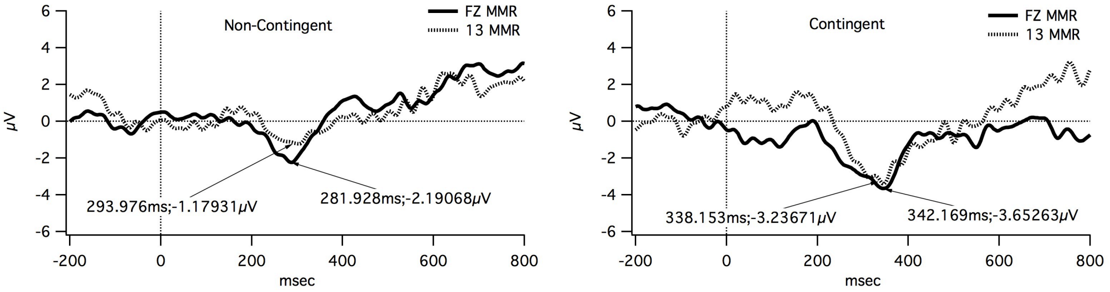


Figure 5: Grand mean subtraction waveforms showing time by amplitude at sites FZ (4) and F3 (13) for the non-contingent (left) and contingent (right) condition.

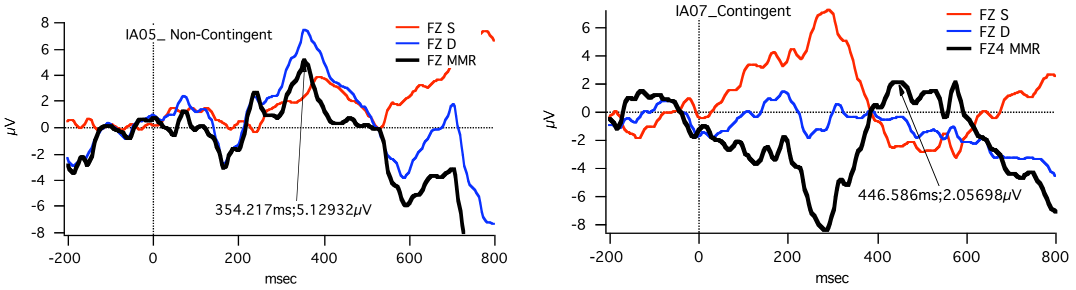


Figure 6. ERP waveforms for two infants are displayed. The positive peak following the negative MMR is shown by arrows.

3.3 Task Comparisons: Contingent versus Non-contingent differences

Subtraction Waveforms: The grand mean difference waveforms for both conditions are shown in Figures 5. These waveforms suggest that a negativity was elicited for both non-contingent and contingent tasks and this negativity inverts in polarity at the mastoid sites (Figure 7). Statistical analyses with Three-way ANOVAs, with Site, Time and Task as factors were used to examine whether there were differences in MMR amplitude as determined by task. In this analysis, we included only site/s that were significant for MMR or those that yielded a statistically significant difference between the standard and deviant waveforms in the previous analysis. The three-way ANOVA (Site x Time X Task) did not yield a significant difference between the contingent and non-contingent task at midline-frontal (FZ) (f(10, 90) = 1.45, p = 0.16), right-frontal (F4)) (f(10, 90) = 0.1.22, p = 0.28) and left-frontal (F3) (f(10, 90) = .79, p = 0.63) respectively. As follow up to the post-hoc test on the three-way ANOVA (stimulus x site x time), time bins 5, 6, and 7 (281-370 ms) were tested for difference between the contingent and non-contingent task. No significant interactions were found for the contingent and non-contingent tasks at the midline-frontal (FZ) (f(2, 18) = 2.58, p = 0.10), right-frontal (F4) (f(2, 18) = 1.44 p = 0.96) and left-frontal (F3) (f(2, 18) = 1.44, p=.96).

In summary, we did not find a statistically significant difference between the contingent and non-contingent tasks. This appears to be in contrast with the visual inspection and some of the statistical results of this experiment. Visually both tasks elicited more negative deviant waveforms than standard waveforms at frontal sites with the contingent condition considerably more negative than the non-contingent condition. Statistically, sites Fz and F4 were significant for the presence of MMR for the contingent condition (the deviant is more negative than the standard waveforms) and were not significant for the non-contingent task. This could have resulted in a difference between tasks but was not the case. Again, inter-subject variability appears to be factor in these results.

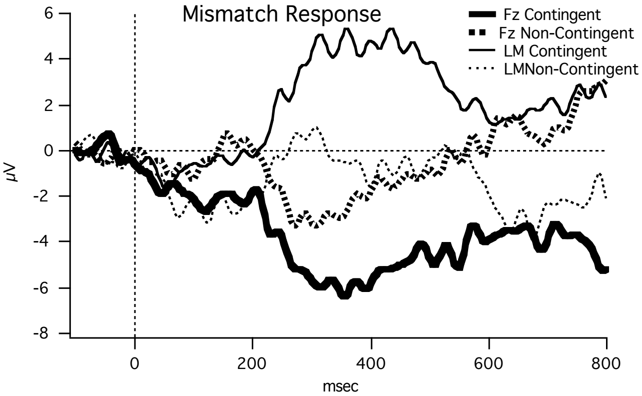


Figure 7: Grand mean subtraction waves at midline-frontal (FZ) for the contingent and non-contingent conditions and inversion at mastoid (LM).

3.4 Individual Data

Table 1. Number of infants showing negative or positive MMRs for each condition.

Task	Negative MMR	Positive MMR	Negativity followed by a Positivity
Non-contingent	6	4	3
Contingent	8	2	4

Based on the conflicting results being shown above we examined the individual data to determine whether there was a huge inter-subject variability that could have contributed to the results. We specifically wanted to see if all the infants showed a robust MMR as well as to determine whether all MMRs were negative in amplitude. A robust MMR was considered a negative or positive subtraction waveform at the fronto-central sites with inversion at the mastoid. Among the infants in the non-contingent task six showed a negative MMR and four showed a positive MMR (please see Table 1 for summary). In the contingent condition, 8 infants showed a negative MMR and two infants showed a positive MMR.

Of those infants with a negative MMR, seven had a positivity, similar to P3a, immediately after their MMR. The Fisher's Exact Test showed no difference between the non-contingent and contingent task in terms of the polarity of the MMR (p=.62)

Discussion (Experiment I):

Negative MMRs were present for both attend conditions. However, the contingent condition showed a stimulus difference at, Fz and F4, not found for the non-contingent condition. In the contingent condition, 8/10 infants showed a *negative MMR* and *4/8* infants showed a *positivity following* the negative MMR. In the non-contingent condition, 6/*10* infants showed a negative MMR and 3/6 infants showed a positivity following the negative MMR.

When attention is directed to the auditory stimulus, infants show a nMMR, similar to an adult MMN. The pMMR observed in a passive task is no longer evident in a stimulus-driven attention task. This supports one of our hypothesis that the nMMR we see in infants is in fact an immature version of the adult MMN. The infants probably needed to focus on the auditory stimuli to be able discriminate between a 1000 and 1200 Hz tone. Thus, with attention the immature nMMN could be seen. We further hypothesized that if the pMMR seen in infants is similar to an adult P3a, then with increased attention the pMMR will show increased amplitude in the contingent condition compared to non-contingent condition. What resulted is a nMMR for both conditions even though it was only significant for the contingent task. Although a few of the infants showed a positivity after the nMMR. We believe that this positivity is the P3a, or an orienting response to the infrequent deviant sounds that the infants were hearing. Adult MMN literature have shown similar results, a P3a following the MMN in discrimination tasks (Naatanen, 2007).

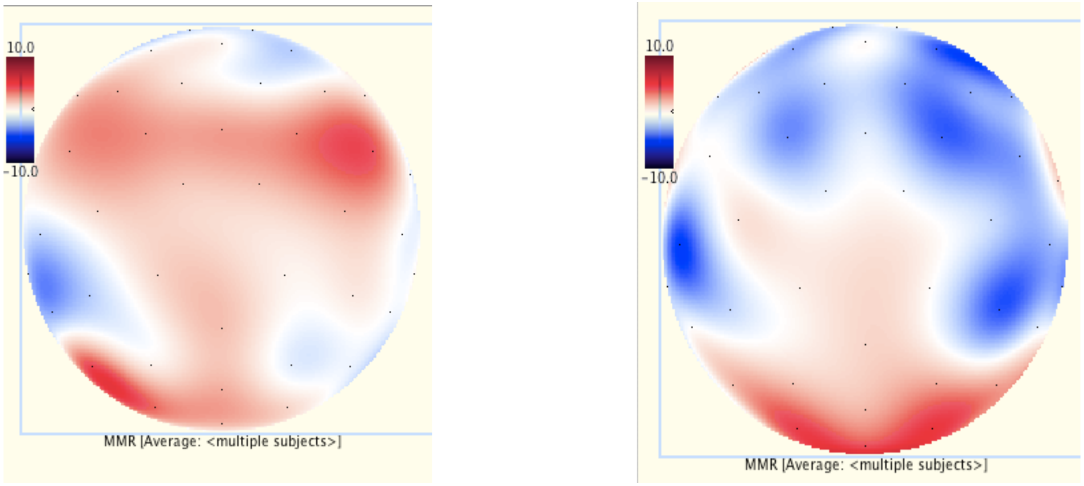
It is unlikely that the absence of a significant MMR for the non-contingent condition is due to the infants' attention not being directed to the sound change, since Morr, et al, (2002) showed a pMMR to this contrast difference of 200 HZ. Alternatively, the absence of a significant MMR to these stimuli may indicate that some of the infants were actively attending to the change (leading to a negativity), while others were not attending to the change (leading to the positivity), and as a result canceled out in the grand mean. It is also possible that the negativity is automatic and the directed attention leads to absence of the positivity and, thus, allowed for the ability to see the negative response. A major difference between this design and that of Morr and colleagues was that in the current study, in both conditions infants could develop an expectation between a stimulus in the 4th position of a train and a visual reward. In the non-contingent condition, this relationship was found for all stimuli, whereas in the contingent condition, the relationship was found for the deviant stimuli only. It is possible that in both conditions, infants attention was drawn to the auditory stimuli more strongly (or more frequently) than in in Morr, et al. (2002) where infants watched videos that had no relationship to the auditory stimuli.

Chapter 4: Method and Results: CVC Words

Overview: A second experiment was designed to test speech contrasts within a paradigm similar to that of the first experiment. A primary goal of our study was to look at how attention affects *speech* perception of infants. The paradigm, however, needed to be tested to ensure that associative learning took place. As a result, in the first study, tones rather than speech were used to validate the paradigm. We concluded from experiment I that associative learning took place and that infants were focusing their attention to the change in the auditory stimulus. In fact, it appears that they were doing this for both the contingent and non-contingent conditions as indicated by a nMMR for both conditions.

Based on the findings from experiment I, modifications to the paradigm was made to further reinforce associative learning. During the first experiment, in the non-contingent condition a visual reinforcement (female face) was shown after every train of sounds. In the second experiment, the visual reinforcement appears randomly. A picture followed only 20% of the standard trains and 20% of the deviant trains in this experiment. This change was made to enhance the contrast between the contingent and the non-contingent tasks. We expect that there would be a greater negative response in the contingent condition when the pairing of a sound change with a visual reward will draw attention to the sound change consistently compared to a randomized pairing of the visual with either change or non-change auditory stimuli in the non-contingent task. By doing this, we hope to see if there would be differences in polarity as well as magnitude of the MMR between conditions.

4.1 Visual Inspection



Non _Contingent Contingent

Figure 8: Topography maps (superior view) of the subtraction waveforms at peak amplitudes (1.6 µV, 245 ms) for the non-contingent condition (left) and 3.6 µV, 270 ms for the contingent condition (right)

Topographical distribution for both the contingent and non-contingent (Figure 8) showed the largest apparent difference at the frontal sites F3, Fz, and F4. A time by amplitude plot of these sites revealed a positivity for the non-contingent condition and negativity for the contingent condition from 250-300 ms with peak amplitude of .62 µV and 150-350ms with peak amplitude of -5.14 µV for the non-contingent and contingent tasks respectively. Visually identifying the MMR peaks for each infant showed that the mean peak amplitude for the contingent condition (please see Figure 9) was -2.81 at about 250-280 ms with a standard deviation of 4.48. The mean peak amplitude for the non-contingent condition was .49 at about 240-270 ms with a standard deviation of 2.98.

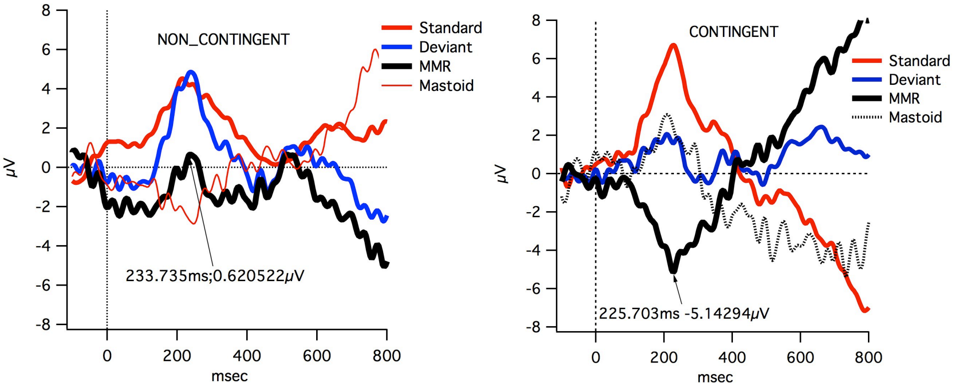
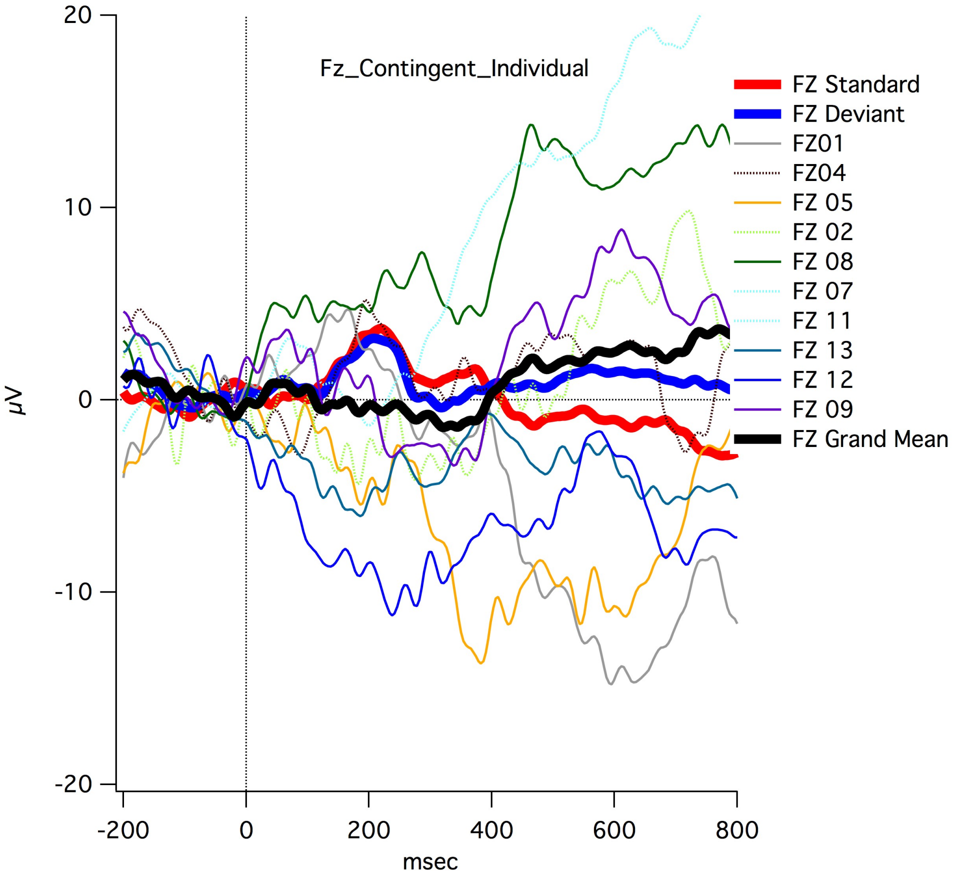


Figure 9: Displays the responses to the random pairing versus directed attention of the auditory and visual stimuli



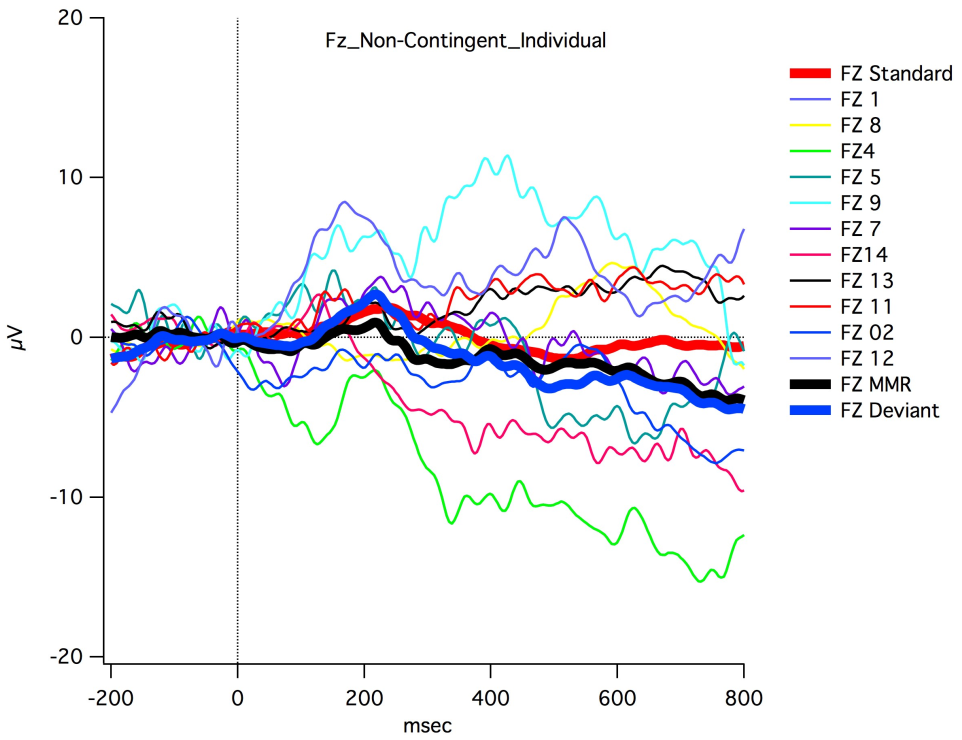


Figure 10: Peak Amplitudes for individual participants based on grand mean peak at Fz for the contingent and non-contingent tasks

4.2 Presence of MMR

Standard vs. Deviant: Figure 10 shows the standard and deviant stimuli at Fz for the non-contingent and contingent tasks. Two way Stimulus x Time ANOVAs at each frontal site revealed significant interactions at two frontal sites, left-frontal F3 (f(10,90)=3.36, p=.00), and right-frontal F4 (f(10, 90)=2.24, p=.02) for the contingent condition and right-frontal F4 (f(10, 90)=3.7, p=.000) for the non-contingent condition. Tukey's post-hoc analyses at the frontal sites for the contingent condition showed a significantly more negative deviant versus standard for time intervals 4 and 5 (251-310 ms) at F3. In contrast, post-hoc tests for the non-contingent condition did not reveal significant differences between the standard and deviant for any time interval. Again, just like in experiment I, this could be attributed to inter-subject variability.

We found that there was greater negativity for the deviant compared to the standard stimulus at the left and right frontal sites for the contingent task and the deviant was significantly more positive from the standard at the right frontal site for the non-contingent task.

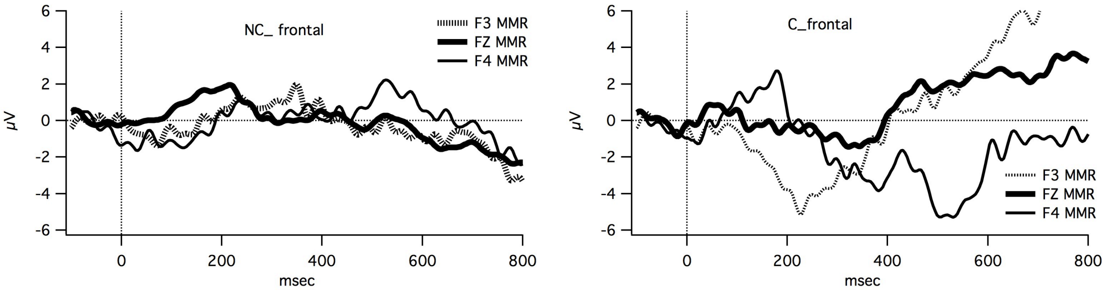


Figure 11: Grand mean subtraction waveforms showing time by amplitude at sites FZ, F3, and F4 for the non-contingent (left) and contingent (right) condition.

4.3 Task Comparisons: Contingent versus non-contingent task

Subtraction Waveforms: The grand mean difference waveforms for both conditions are shown in Figure 12. These waveforms suggest that a greater negativity was elicited for the contingent tasks and invert in polarity at the mastoid/posterior sites. Statistical analyses with Three-way ANOVAs, with Site, Time and Task as factors were used to examine whether there were differences with the MMRs as determined by task. In this analysis, we only included site/s that were significant for MMR or those that yielded a statistically significant difference between the standard and deviant waveforms, in the previous analysis. The three-way ANOVA (Site x Time X Task) at the frontals sites revealed a significant difference between the MMR for the contingent and non-contingent conditions (f(20, 180) = 2.67, p = 0.00). A follow-up two-way ANOVA (Task x Time) for each frontal site revealed a significant difference for the left-frontal site F3 (f(10, 90) = 3.02, p = 0.010), and no difference between the contingent and non-contingent condition at the midline-frontal (FZ) (f(10, 90) = 1.7, p = 0.09), right-frontal (F4) (f(df) = 1.54, p = 0.13) sites.

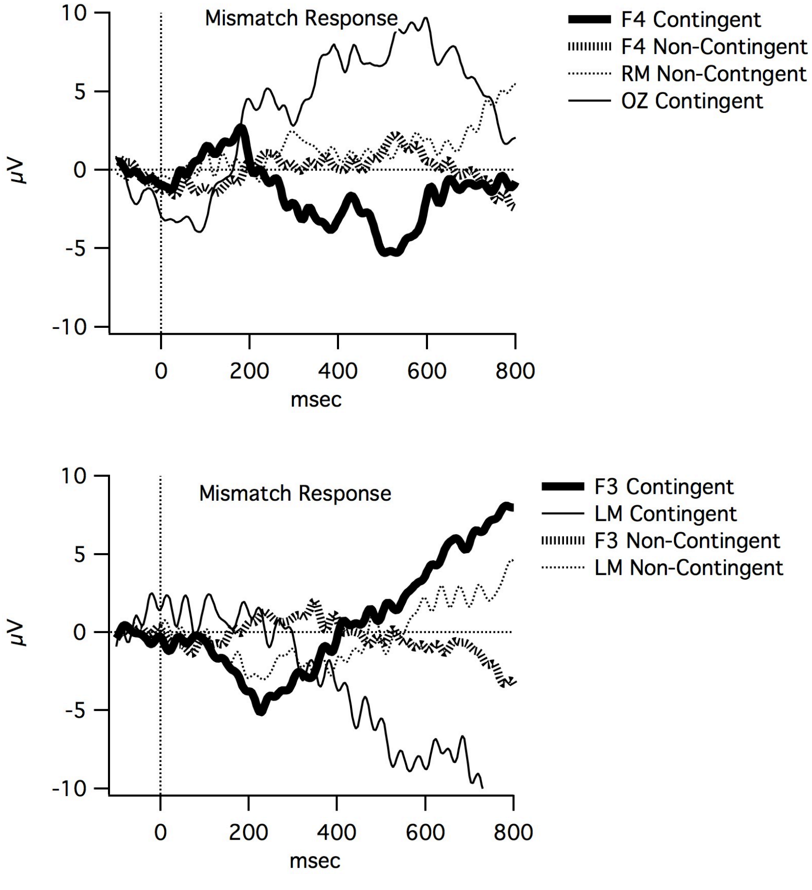


Figure 12: Grand mean subtraction waveforms at F4 (top) and F3 (bottom) and inversion at mastoid/posterior site. Note that the positivity from 500 ms to the end of the window is likely to be the response to the face.

4.4 Individual Data

Individual Data: We examined individual data to determine whether all the infants showed a robust MMR as well as to determine if all MMRs were negative in deflection for the contingent condition and positive for the non-contingent task. A robust MMR is a negative or positive subtraction wave at the fronto-central sites with inversion at the mastoid. Among the infants in the non-contingent task four showed a negative MMR at sites F3, Fz and 5 at site F4. In the contingent condition, 7 infants showed a negative MMR at site F3, Fz and 5 at site F4 (please see Table 3 for summary). The Fisher's Exact Test showed no difference between the non-contingent and contingent task in terms of the polarity of the MMR (please see Table 4). Out of the 10 infants, 8 showed a more negative MMR for the contingent conditions as compared to the non-contingent condition

Table 2: Individual data showing the polarity of MMR at sites F3, Fz, and F4

Contingent	P	F3	FZ	F4
	1	negative	negative	negative
	2	no/positive	negative	no
	3	negative	no	no
	4	negative	negative	negative
	5	positive	positive	positive
	6	negative	positive	negative

	7	negative	negative	no
	8	negative	negative	negative
	9	positive	negative	positive
	10	negative	negative	negative
Total negativity		7	7	5
Non-Contingent		F3	Fz	f4
	1	negative	positive	negative
	2	positive	negative	no
	3	negative	negative	positive
	4	positive	negative	negative
	5	positive	negative	positive
	6	positive	positive	negative
	7	negative	no	negative
	8	positive	positive	positive
	9	positive	no	negative
	10	negative	positive	positive
Total negativity		4	4	5

Table 3: Fisher's exact test for three frontal sites (F3, Fz, F4) to see if there are differences in the polarity of MMR between the contingent and non-contingent conditions. None were seen in all 3 frontal sites.

Site F3	Negative deflection	Positive deflection	
Contingent	7	3	
Non-Contingent	4	6	
			p=.15

Site F4	Negative deflection	Positive deflection	
Contingent	5	5	
Non-Contingent	5	5	
			p=.34

Site FZ	Negative deflection	Positive deflection	
Contingent	7	3	
Non-Contingent	4	6	
			p=.15

In summary nMMRs were present for the contingent condition only. A negative mismatch response was seen on left- and right- frontal sites for the contingent condition and a pMMR was seen on the right-frontal for the non-contingent condition. However, only in the left frontal site was there a significant difference between the two conditions. Individual data showed that *in the contingent condition, 7/10* infants showed a *negative MMR* and *2/10* infants showed a *positivity and 1/10 did not show a MMR.* In the *non-contingent, 5/10* infants showed a *negative MMR* and *5/10* infants showed a *positivity* MMR.

Discussion (Experiment II):

When attention is directed to the auditory stimulus, infants show a nMMR, similar to an adult MMN. When attention is randomly directed to either a change or no-change train, infants show a predominantly pMMR. The pMMR observed in a passive task is again seen in the non-contingent condition and mostly not evident in a stimulus-driven attention task. The difference in polarity of the MMR in the two conditions may indicate that focused attention does affect the MMR seen in infants. The appearance of a face after each deviant sound led the infants to actively attend to the change (leading to a negativity), while randomly focusing either on a change or no-change train resulted in a possible difficulty detecting the change in the speech stimuli (leading to a positivity). This supports our hypothesis that the nMMR is an immature version of the adult MMN. It is possible that a negativity is automatic for an obvious contrast (Experiment I) and that directed attention is necessary for difficult contrasts (Experiment II).

In this experiment, the infants could develop an expectation between a stimulus in the 4th position and a visual reward in the contingent condition alone while the infants would have a difficult time establishing such a relationship in the non-contingent condition. It is possible that the infants showed the same level of attention that Morr and colleagues were able to elicit with their passive task and thus both result in a pMMR. This positivity could reflect an orienting response as we have hypothesized. If the infants' attention is not directed towards the auditory stimuli then hearing an infrequent stimuli (deviant stimuli) could lead them to orient to this sound.

Chapter 6: General Discussion

The focus of this study was to investigate what role attention plays in the development of speech perception. Specifically, we wanted to 1) establish a method for examining attentional modulation of infant ERP correlates to sound change and 2) determine to what extent the positive and negative mismatch responses are influenced by attention. We used cross-modal processing through associative learning by creating a forward pairing of an auditory stimulus with a visual stimulus to encourage the infant to attend to a stimulus change (based on Kaplan, 1991). The infants are learning to focus their attention to one modality (auditory) by being reinforced through another modality (visual). Two conditions, contingent and non-contingent were used to be able to compare tone and speech perception under focused attention versus non-focused attention.

Previous studies using oddball paradigms with infants have identified two types of mismatch responses (MMRs), either a greater negativity to the deviant (nMMR) or a greater positivity to the deviant (pMMR) (e.g., Dehaene-Lambertz & Gigla, 2004; Morr, Shafer, Kreuzer & Kurtzberg, 2002). The difference in the polarity of the responses could be attributed to maturational or functional factors. It has been argued, that the pMMR is similar to the P3a or an orienting response (Kushnerenko, et al., 2002; Comerchero, et al., 2007), a pre-attentive discrimination response similar to an adult MMN (Friederici et al., 2002), or, more recently, a pre-attentive obligatory response that reflects afferent input and a more primitive level than the MMN (Shafer, et al., 2010; 2011; Shafer, et al., in 2012). The pMMR has been elicited using various different contrasts (i.e. tone and vowels) and in various states of alertness (i.e. sleeping or awake infants). Morr (2002) reported that a negativity following the positivity has been elicited in infants who are alert during experimentation (Morr, 2002). She concluded that the alertness level of the infants determines the presence or absence of a negativity following a pMMR. Another argument is that the difference in polarity is due to the maturational changes in the brain (Trainor, 2003). The pMMR and nMMR reflects an ability to auditorily discriminate with the polarity determined by the changes in the maturing brain. This is however, unlikely, as several studies have shown the presence of both the pMMR and nMMR (Morr, et al, 2002, Weber et al, 2004).

In these studies, however, attention of the infants was neither manipulated nor controlled. To help understand the nature of MMRs, we must determine which ERP components are automatic in nature and which can be modulated by attention. Determining the functionality of these components will help inform us on how infants process auditory and speech stimuli.

Examining how attention influences auditory and speech processing in infants is very difficult. It is not possible to instruct infants verbally, and therefore we needed to develop a task designed to manipulate infant attention without use of verbal instructions. Electrophysiological measures have made it possible to examine underlying processes in a task that does not require the use of behavioral responses. In contrast to a standard oddball paradigm where the participants are passive participants, we manipulated the level of participation of infants in these two studies. In the non-contingent, attention was either focused on the entire auditory stream (Experiment I) or randomly focused on either a change or no-change auditory train (Experiment II), and therefore never establishing a contingency between what the infants heard and saw. In the contingent condition, attention is focused to the change in the auditory stimuli (Experiment I and II) by a visual reinforcement, therefore building a contingent relationship.

In the tone study, the infants showed greater negativity at frontal sites to the deviant tone, peaking around 300 ms following the deviant onset. This nMMR was twice the magnitude (-6.4 μV vs. -3.2 μV) to the deviants in the contingent compared to non-contingent condition. In the CVC syllables study, /bEp/ and /bIp/, the infants showed greater negativity for the deviant stimulus compared to the standard stimulus at the left and right frontal sites for the contingent task. In contrast, the deviant was significantly different from the standard only at the right-frontal site for the non-contingent task. The grand mean data have shown greater positivity to the deviant than the standard in the non-contingent condition (pMMR; 1.6 μV, 246 ms). In contrast, in the contingent condition, they showed greater negativity to the deviant than the standard (-3.8 μV, 275 ms).

Based on the results of Experiment I and II, focusing attention on the auditory change trains has resulted in infants showing a nMMR, which is consistent with an adult like MMR. Random or unfocused attention to the auditory stimulus has resulted in either a pMMR or a nMMR followed by a positivity. This suggests that infants may have to actively focus their attention to be able to discriminate sound contrasts such as vowel differences. Implications of the results of both experiments will be discussed based on the following factors: (1) Effects of focused attention on speech discrimination and (2) functional nature of the pMMR or nMMR.

(1) Focused Attention and MMR

Attention or alertness level has been mentioned in different studies of infant discrimination but has never been manipulated to study its effect in the development of speech perception (Morr, et al, 2002, Friederici, 2000). To date, only the study of Shafer and colleagues (2012) has looked at saliency of stimulus and how this could lead to greater attention to the speech contrast being studied. They found increased negativity of the MMR in final position rather than internal position deviants in a design where stimuli were presented in sequences of 10, with a longer interstimluls interval between sequences than within sequences. They hypothesized that greater attention was given to the final position and therefore elicited a nMMR. However, attention has never been directly manipulated in infants to study its effect on speech discrimination. Most studies of infant speech perception employ a passive paradigm. The infants are usually sitting on a caretaker's lap watching a video or being engaged with toys while listening to sounds. Therefore, it is difficult to determine whether the infants are actively paying attention or not (Jusczyk, 1997).

In this study, the infants are encouraged to actively participate by having their level of attention manipulated through associative learning. Both experiments have shown that when attention is focused to the change in the auditory stimuli, a nMMR is elicited. It is hypothesized that this negativity could be a reflection of a developing MMN found in older children and adults. Even though the negativity occurs at a later time (200-400 ms) this appears to correspond to developmental studies of speech discrimination that have found the nMMR to increase in amplitude and shift earlier in time (Shafer, et al., 2000; 2010). The presence of a predominant pMMR when attention is inconsistently or randomly focused on the auditory stimuli may indicate that the infants are actually not perceptually discriminating the differences in the tone or speech contrasts. In fact, this pattern of results supports the hypothesis of Shafer and colleagues (2010, 2011, in 2012) that the pMMR is a recovery from refractoriness of the P100 response. The repetition of the standard stimulus led to the refractoriness of the neural response (habituation) while having a less frequent deviant stimulus resulted in greater positivity due to increased gap in time between presentations giving the set of neurons time to recover. The presence of the nMMR in the contingent condition may indicate that attention is required to discriminate harder auditory or speech contrasts.

These results are in agreement with the current theories of speech perception. Juscyk's WRAPSA model (1997) states that children learn to automatically attend to the relevant acoustic-phonetic features of the input. Strange's Automatic Selective Perception (ASP) (Strange and Shafer, 2008) states that native language learners establish selective perceptual routines (SPRs) that weight the relevant acoustic phonetic information of the native language to allow for fast and efficient perception of their native language phonemes. Kuhl (2000) also stated that infants have innate perceptual biases that automatically detect patterns in the language input and make use of statistical properties by their ambient language. What has not been addressed in these models is the time-course of development of these phonological representations. It appears that although infants may know what to automatically focus their attention on, the formation of good phonological representations may take some time. Therefore, speech discrimination at an early age may not be as automatic as believed and may require more cognitive resources.

(2) Development of speech perception and MMR

A tremendous amount of research has been devoted on demonstrating changes on how infants perceive and discriminate speech in their first year of life (Jusczyk, 1997). These changes reflect the influence of exposure to their native language. Studies have shown that children continue to develop their speech perception skills from before birth and even after 4 years of age (Kuhl, Williams, Lacerda, Stevens, & Lindblom, 1992, Werker and Curtin, 2005, Baily and Plunkett, 2002).

Infant speech perception studies using electrophysiology have used the MMR as the principle measure to assess speech discrimination. Previous research has resulted in either a positivity (Morr, Shafer, Kreuzer & Kurtzberg, 2002, Dehaene-Lambertz & Dehaene, 1994; Leppänen et al., 2002; Friederici et al., 2002; Friedrich et al., 2004) or a negativity (Cheour, Shestakova, Alku, Ceponiene, & Näätänen, 2002; Kushnerenko; Ceponiene, Bolan, Fellman & Näätänen, 2002) in the MMR. However, the functional nature of the pMMR or nMMR is still unclear. The current suggestion is that the nMMR is a reflection of a developing MMN from infants (Shafer, 2010, 2011) while a pMMR could either reflect a genuine change detection response (Leppanen, et al., 1999), an increased obligatory response (Ceponiene, et al., 2002), or a P3a (automatic detection of the novelty) response (Cheour, 1998).

Based on the results of this study, the nMMR is a precursor to an adult MMN. The nMMR is most likely an immature version of the adult MMN. In experiment I (tones), when attention was focused on either the entire auditory stream or just to the change in the auditory stream, a nMMR was elicited. However, a greater negativity was seen in the contingent condition, that is, when attention is focused specifically to the deviant sounds. This shows that the infants were able to discriminate a 200 Hz difference in tones. Morr and colleagues also showed that infants between 2-7 months could discriminate this tone difference. A negativity or nMMR was elicited preceding a pMMR (Morr, et al., 2002).

Weber, Hahne, Friedrich, & Friederici (2003) manipulated the filter setting they used for their infant data. When using a bandpass filter (1-15 Hz) they were able to show a nMMR when discriminating word stress patterns in 5 versus 4-month-old infants, effectively filtering out the slow wave activity (pMMR). When a high pass filter was used alone, a significant pMMR starting at 360 ms after change onset was observed. They concluded that the nMMR is a reflection of the five-month old infant's ability to discriminate between different stress patterns of a word. The lack of a nMMR with the four-month old infants could be explained by the fact the stress pattern discrimination might develop later in life. It appears that the positive and negative MMR overlap and with the use of appropriate filter setting, the negativity is uncovered. However, there is always the risk that using a bandpass filter near the frequencies of interest can distort the signal. Even in the case that there was an overlap, their finding suggests that the nMMR is not present at 4 months of age, begins emerging at 5 months of age, but is still small and masked by the pMMR. The results of our study indicate that the magnitude of the negativity increases with attention. It would be interesting to see whether manipulation of attention to the change in the stress pattern of a word, would lead to nMMR in four-month old infants as well as 5-month olds. It does appear that nMMR is a reflection of the infant's discrimination ability while the positivity observed may either be a recovery from refractoriness or an orienting response, as we have seen in our results.

In the study of Rivera-Gaxiola and colleagues (2007), they have shown both a positivity and a negativity in the response of infants to CV-syllables. The positivity usually occurs between 150-250s and the negativity occurs between 250-550 ms. They found that the N150-250 is sensitive to the acoustic features of the stimuli and the P250-550 to the phonetic characteristics of the stimuli. They found that the more negative the MMRs in infants, the better their language scores at later ages. They attributed this to either attentional or speech discrimination factors. Based on our current study, the negativity seen by Rivera-Gaxiola et al. may reflect a perceptual discrimination of CV syllables, resulting in a strong correlation to language score at later ages. Our findings, however, suggest that the negativity is not only a reflection of sensitivity to acoustic features, but also of selective attention to the speech. We found, both in Experiment I (tones) and II (speech), that when attention is focused to the auditory stream, a negativity is found which is not necessarily followed by a positivity. Rivera and colleagues believed that the negative-positive pattern indexed sensitivity to phonetic features. This later positivity may reflect an orienting response, similar to what Morr (2002) saw with her infants. However, we suggest that this response is related to attentional processes and not just auditory resolution.

Shafer and colleagues (2012) when looking at the effect of saliency of stimuli on the mismatch response found that having deviants (change in sound) in the final position versus internal positions of a train resulted in a nMMR. They hypothesized that there is increased attention the final position, therefore making it possible for the six-month old infants to perceptually discriminate changes in vowels. The findings of the current study are consistent with this explanation.

It appears that the nMMR is an automatic response and is present for all discriminations, but that it is masked by the pMMR. This is supported by a positivity proceeding the nMMR in the infants' responses in both the tone and CVC study. The pMMR is either eliminated and the nMMR increases in amplitude when the task requires directed attention. Attention, even when globally directed to the auditory stream, improves discrimination, as indexed by the nMMR, as seen in the Tone experiment. When attention is not focused and in fact randomized to both the no-change and change trains, the pMMR is predominantly seen in the Speech experiment. This pMMR may reflect the p100 response that has been evoked to an auditory stimulus that declines in amplitude and latency with increasing age (Ponton, et al. 2002). It is an increase in positivity around the P1 latency of the ERP to the deviant compared to that of the standard stimulus. The pMMR likely reflects a recovery from refractoriness and shows a lower level of encoding of the acoustic features of the stimulus. This explanation seems more plausible than saying that the pMMR is a perceptual discriminative response, as it could be elicited during sleep (Kushnerenko et al., 2007) and it decreases in amplitude with age (Datta, Shafer, Schwartz, Morr & Kurtzberg, 2010). The disappearance of pMMR in older children and adult is most likely to be due to the increased specificity of neural response to acoustic information, leading to a very small pMMR that is masked by other mature components (e.g., N1b and the MMN, see Shafer, et al., in 2010)

This explanation is consistent with what the literature is showing regarding the development of mismatch negativity. Children who are four- five years of age and older (6-7 years) show a negative MMR response between 300-400 ms with the latency shifting by 25 ms/yr with increasing age (Shafer, Yu & Datta., 2010). These findings suggest that the MMN is automatic for native language speech contrasts by 4 years of age and can be elicited without attention. Shafer and colleagues have examined maturational changes in the MMR from 3 months to 7 years of age and showed that developmentally, by six years of age, the pMMR is largely gone, and the nMMR can be clearly observed (Shafer, et al., 2010; Shafer, et al., 2011). By age four, the pMMR had disappeared in some children, and is replaced by a negativity, which is consistent in topography with the adult mismatch negativity (MMN). The amplitude of the pMMR decreased with age, up to 4 years of age (Shafer, Yu & Datta, 2011). In the same light, the nMMN has been found to decrease with latency by 11 ms per year from 4 to 10 year of age with no developmental change in MMN amplitude (Shafer, Morr, Kurtzberg, 2000).

If the positivity reflects a lower level of encoding (recovery from refractoriness) then infants/younger children appear to be able to encode acoustic information from what they hear. With increasing age from infancy, children seem to show maturation of their neural response to acoustic information (increased phonetic encoding), as evidenced by reduced pMMR and increased nMMR (MMN like response). This developmental pattern may indicate that 4-6-years olds have sufficient cognitive resources to automatically register phonetic information or occasional changes to the auditory stimuli. The reduction of the pMMR in early childhood may indicate increased attentional resources for processing the auditory information. It could also indicate an increased automaticity in processing this information.

Most models of speech perception have made attention a necessary part for successful learning. The results of the tone and CVC study support this role for attention. Our findings do reveal that the development of auditory and speech skills can be better understood using an ERP design because it is possible to determine auditory processing with and without focused attention. Our electrophysiological data have shown that focused attention may be necessary for infants to be able to perceptually discriminate changes in the auditory stimuli (1000 vs. 1200 Hz, bip-bep). Our data also have shown that infants can encode acoustic information as reflected in pMMR being seen in infants. Once this information is encoded then perceptual discrimination could occur, as reflected by the nMMR. Infants may invest more attention in processing this information until automaticity is established. The finding of Gomes et al. (2000) supports this claim. They found that the MMNs elicited by the hard deviant (1000 vs. 1050 Hz) were larger when the children were asked to actively discriminate the stimuli than when they were ignoring them. The MMNs elicited by the easy and medium deviants (1000 vs. 1500 and 1200 Hz) in the children and adults were not affected by attention.

We could see this in developmental speech perception literature. During the first year of life, infants become tuned in to the properties of the native language. They are able to behaviorally show sensitivity to vowels and consonant sounds of their native language, the phonotactic properties, and identify boundaries of words, phrases and sentences (Jusczyk, 2001). Electrophysiological data have also reflected the same phenomenon. However, we are realizing that automaticity of speech perception may not be established in infants and young children. If true detection of a change in stimulus is reflected in nMMM, then children continue to develop their speech perception skill until a little later in childhood.

CHAPTER 7: Summary and conclusion

Overall, the results of the two experiments, tone and speech, indicate that attention does modulate the mismatch response of infants. With focused attention, a nMMR was found in most infants in both the tone and speech studies. Reinforcing the infant's attention to the entire auditory modality also elicited a nMMR which was not found when attention was randomly focused, instead resulting in a pMMR. This investigation confirmed that the pMMR is not equivalent to an adult MMN as a nMMR was elicited to tone and speech differences when attention is focused to the auditory stimuli. The pMMR may reflect a recovery from refractoriness as suggested by Shafer and colleagues (2010). The speech perception of infants may not be as automatic as has been previously suggested. Instead infants require the use of focused attention to discriminate fine-grained differences in speech. This is in agreement with Strange (2010) and Kuhl's (2008) model of speech perception development that infants use increased cognitive resources (attention in the case of this study) to be able to discriminate speech differences until it becomes automatic.

7.1 Impact and Clinical Implications:

Neurophysiological studies of infant speech suggest that mismatch responses (MMRs) have predictive value for later language. It is therefore very important to understand the functional nature of MMR as current findings are somewhat difficult to interpret because some studies have observed increased negativity at fronto-central sites to an auditory sound change, while others show increased positivity. It is also imperative to understand the role of attention in speech perception development since most theories on speech perception indicate the crucial role of attention in the development of speech perception skills.

Knowing the functional nature of the MMR would leave us with the ability to look at how phonological properties of sounds are integrated into cortical development. With this information, we could look at different populations where phonological development is considered the underlying cause of their delays in language development.

Since attention was manipulated in this study, we found that children may not automatically develop speech perception skills but in fact require more attention, than what used to be supported. With this information, we could look at populations where attention is one of the symptoms that are suspected to cause language delay

The methodology employed in this study, using contingent and non-contingent paradigms, shows promise for understanding the relationship between attentional processes and the development of speech perception, and can help further understand speech perception deficits in language impaired populations.

7.2 Future Directions:

The current study has given us a glimpse of the functional nature of MMR by addressing an existing conflict in the literature. Results have indicated that attention does play a role in the speech discrimination and that is reflected in the polarity of the MMR seen in infants.

One limitation of this study is the relatively small groups of participants. We need to test larger number of participants. With the maturational factors involved in speech perception development, it would be an advantage to test participants longitudinally over a number of years in order to document the effects of attention on the development of speech perception. Most particularly, it would be interesting to test the notion of automaticity. If speech is encoded phonologically through experience with the ambient language then we would see that as the children get older attention should have little effect on their speech discrimination abilities. It would also be interesting to look at how the infants' performance in the MMR response task correlates to later language development. By testing a larger number of participants, we can look at other factors that have been reported in literature to cause differences in the MMRs of infants. These include factors such as a sex and age range differences.

A second limitation of this study was that it was designed to look at how attention affects speech perception with the notion that attention is necessary part of its development. Inclusion of bilingual infants would help us show how experiential factors aside from biological limitations on perception or how maturation leads to good discrimination. It is possible that with focused attention, bilingual infants could look similar to monolingual infants. Examining a bilingually-exposed population can help address this question because the amount of English experience, in the absence of a language deficit, can be observed for influences on the development of speech representations.

We have visual evoked potentials data that we can look at and correlate with the auditory evoked potentials. In the future, coupling behavioral measures such as eye tracking with electrophysiological data could be a good measure of what and how the infants are focusing their attention during speech perception tasks.

Appendix 1: Parental Informed Consent

PARENTAL INFORMED CONSENT

The purpose of this information is to help you decide whether you want your child to volunteer for a research study. Please read carefully and ask the investigator about anything that you do not understand.

Title: The Effects of Attention on the Mismatch Response in Infants

Dissertation Advisor: Valerie Shafer Ph.D.

Principal Investigator: Karen Garrido-Nag .

Study Location: The Graduate Center, CUNY

General Information

- The purpose of the study is to understand how your infant's perception of sounds is affected by their attentional state.

Experimental Procedure

- We will use a test with the electroencephalogram (EEG), to see how fast certain sounds can be told apart in the brain. The EEG is a safe test that has been used for over thirty years with children.
- The infant wears a net of sensors, and his or her brainwaves are recorded while listening to speech sounds and looking at different pictures. This will take approximately 30-40 minutes.
- We would also like you, the caregiver, to fill out a questionnaire, regarding your infant's development.
- We may also ask you to allow your child to be tested on language to produce a language sample that will be recorded. Sign here if you agree to your child being video recorded_____________________.
- We would like to test your child's hearing. Sign here if you agree to a hearing test________________.
- With your permission, in the future we would like to contact you to take part in other studies. Sign here if you agree to be contacted ____________________________.

Benefits of Volunteering

- This research will help our understanding of the development of language in infants.
- We will give referrals for further testing of his/her speech and language skills or hearing, if we identify any possible problem.
- For each visit, you will receive $25.00 for volunteering and up to $25 for travel.

Risks of Volunteering

- Your child may be uncomfortable when the sensor net is fitted to the head or while he/she wears the net during the experiment. The researcher will periodically make sure that the sensor net is appropriately fitted.
- There is no risk of personal injury and your infant should not feel any pain due to the sensors
- The researcher(s) will work to make sure your child is comfortable during the study. Please let us know if your infant seems uncomfortable, or you wish to stop taking part. You are free to stop taking part any time.

Confidentiality.

- Your child's records will be kept in a locked filing cabinet to protect your child's privacy, and will be used only for the purposes of the study.
- Only researchers directly involved with the study will have access to the research.
- Results of this study may be published, but will not include information that can identify your child.
- You are always free to request a copy of the published paper.

Volunteering

- You and your infant may stop taking part in this study at any time without negative consequence.
- As warranted by the research, your infant may be removed from this study at any time, without your consent.

Contact Information

- If you have questions about this research, contact **Valerie Shafer, Ph.D. (Advisor) at (212) 817 8833; e-mail: vshafer@gc.cuny.edu or Karen Garrido-Nag at (212) 817-8858; email: kgarrido.nag@gmail.com**
- To learn about your rights as a research volunteer, contact **Kay Powell, IRB Administrator at (212) 817 7525; e-mail: kpowell@gc.cuny.edu**

Consent – By signing this form you agree that:

- You have fully read this form, or someone has read it to you in your native language.
- You had the chance to ask questions about this research, and were given satisfactory answers.
- You understand that you are volunteering your child to take part in research
- You understand the risks and benefits in the tests described above.
- You will be given a signed copy of this form, which is yours to keep.

____________________	___________________________	__________
Signature of Parent/Guardian	Printed Name of Parent/Guardian	Date
	___________________________	
	Printed Name of Infant	

Investigator Statement

- I have fully explained to the participant the nature of this research. To the best of my knowledge, the participant signing this consent form understands the nature, risks, and benefits of this study.

_____________________	___________________	__________
Investigator's Name	Printed Name	Date

This research meets the ethical and safety standards of the Institutional Review Board of the Graduate Center, City University of New York. For information abut your rights as a volunteer, call the office of Sponsored Research at the Graduate Center at (212) 817-7525

Appendix 2: Demographics of Participants for Experiment I (Tones)

Subject Code	Sex	Race	Language/s Spoken at Home
IA04	Male	Hispanic	English/Spanish
IA05	Male	Hispanic	English/Spanish
IA07	Female	African American	English
IA08	Female	Caucasian	English
IA09	Female	Hispanic	English/Spanish
IA10	Male	African American	English
IA11	Male	African American	English
IA13	Female	Caucasian	English
IA15	Female	Asian	English
IA17	Female	African American	English

Appendix 3: Demographic Information for Experiment II (Speech)

Subject Code	Sex	Race	Language/s Spoken at HOme
SIA01	Female	Asian	Japanese/English
SIA02	Male	African American	English
SIA03	Male	Caucasian/Asian	English/Hindi
SIA04	Female	African American	English/Creole
SIA05	Female	Caucasian	English
SIA06	Female	Caucasian	English
SIA07	Male	Pacific Highlander	English
SIA10	Female	African American	English
SIA13	Male	Caucasian	English
SIA14	Female	Caucasian	English

Appendix 4: Language and Cognition Scores for Participants in Experiment I

Participant Code	Bayley Score (SS)	PLS-IV Score (SS)
IA04	93	97
IA05	101	100
IA07	99	105
IA08	98	100
IA09	102	106
IA10	106	99
IA11	108	105
IA13	101	100
IA15	100	95
IA17	100	97

Appendix 5: Language and Cognition Scores for Participants in Experiment II

Participant Code	Bayley Score (SS)	PLS-IV Score (SS)
SIA01	102	98
SIA02	95	94
SIA03	103	100
SIA04	96	100
SIA05	102	106
SIA06	100	105
SIA07	98	99
SIA10	105	102
SIA13	99	96
SIA14	103	99

Appendix 6: Accepted trials for the Standard, Standard in the 4th position and Deviant for each participant in Experiment I

Participant	Non-Contingent			Contingent		
Participant	Standard	Standard (4th position)	Deviant	Standard	Standard (4th position)	Deviant
IA04	1013/1013	75/144	91/200	2028/20208	200/200	144/144
IA05	2025/2027	143/144	200/200	1775/1775	175/175	126/126
IA06	1965/1966	138/138	194/194	2027/2027	200/200	144/144
IA07	1468/2028	108/144	158/200	2027/2027	200/200	144/144
IA08	2029/2029	144/144	200/200	1109/2028	104/200	82/144
IA09	571/2031	43/144	52/200	2025/2025	200/200	144/144
IA10	1638/1638	115/115	162/162	2028/2029	200/200	144/144
IA11	1262/2030	94/144	125/200	779/2026	68/200	58/144
IA12	1002/1967	71/137	104/195	2027/2027	200/200	144/144
IA13	585/1552	37/108	58/150	1416/1416	139/139	102/102

Appendix 7: Accepted trials for the Standard, Standard in the 4th position and Deviant for each participant in Experiment II

Participant	Non-Contingent			Contingent		
Participant	Standard	Standard (4th position)	Deviant	Standard	Standard (4th position)	Deviant
SIA01	1013/1013	75/144	91/200	2028/20208	144/144	200/200
SIA02	2025/2027	143/144	200/200	1775/1775	126/126	175/175
SIA03	1965/1966	138/138	194/194	2027/2027	144/144	200/200
SIA04	1468/2028	108/144	158/200	2027/2027	144/144	200/200
SIA05	2029/2029	144/144	200/200	1109/2028	82/144	104/200
SIA06	571/2031	43/144	52/200	2025/2025	144/144	200/200
SIA08	1638/1638	115/115	162/162	2028/2029	144/144	200/200
SIA09	1262/2030	94/144	125/200	779/2026	58/144	68/200
SIA10	1002/1967	71/137	104/195	68/200	144/144	200/200
SIA12	585/1552	37/108	58/150	200/200	102/102	139/139

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