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Effects of Stimulus Symmetry on Hierarchical Processing in Six-Month-Old Short- and Long-Looking Infants

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I am submitting herewith a dissertation written by Margaret Weinel Guy entitled "Effects of Stimulus Symmetry on Hierarchical Processing in Six-Month-Old Short- and Long-Looking Infants." I have examined the final electronic copy of this dissertation for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Doctor of Philosophy, with a major in Psychology.

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Effects of Stimulus Symmetry on Hierarchical Processing in Six-Month-Old Short- and Long-
Looking Infants

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Degree
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Margaret Weinel Guy
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Dedication

For John – My rock. I cannot describe all that your unwavering love, support, and motivation have meant to me.

For Mom and Dad – As long as I can remember, you have encouraged excellence and given me the confidence to pursue my dreams.

And for Tasha – Giving me a reason to set down my computer and take long walks, even when I didn't think I had the time.

Thank you. I love you all.

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Abstract

The current study investigated the effects of stimulus symmetry on the processing of global and local stimulus properties by 6-month-old short- and long-looking infants through the use of event-related potentials (ERPs). When compared with asymmetry, symmetry has been associated with more efficient stimulus processing and more accurate memory for stimulus configuration (Attneave, 1955; Perkins, 1932). Previous research has shown that individual differences in infant visual attention are related to hierarchical stimulus processing, such that short lookers show a precedence effect for global processing, while long lookers demonstrate a local processing precedence (Guy, Reynolds, & Zhang, 2013). Based on the Information Processing Principles proposed by Cohen and colleagues (Cohen, Chaput, & Cashon, 2002), the presence of asymmetry was expected to direct attention to the local features of stimuli, leading short lookers to regress to a local processing strategy. Analysis of the late slow wave (LSW) indicated that short lookers attended to global stimulus properties, while long lookers attended to local stimulus properties. Nc analyses revealed an interaction of familiarization condition, looker type, and stimulus type at midline central electrodes. Short lookers in the asymmetric familiarization condition showed a greater amplitude Nc response to the familiar stimulus than stimuli novel in global configuration, which indicates that these infants maintained interest in the familiar stimulus after familiarization. It is likely that interest was maintained because the familiar stimulus was not fully processed. These findings indicate that infants' ERP responses to hierarchical stimuli are impacted by individual differences in visual attention and stimulus symmetry.

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Chapter 1 Introduction

Throughout the first year of life, visual development based on brain maturation and early experience leads to rapid changes in visual attention and information processing capabilities (e.g., Cohen et al., 2002; Colombo, 2001; Reynolds, Courage, & Richards, 2013). The study of infant attention is of interest to developmental researchers because it provides a window into the nature of early cognition. Furthermore, the investigation of attention in infancy allows researchers to make predictions about cognitive outcomes in childhood (e.g., Bornstein & Sigman, 1986; Colombo & Mitchell, 1990; Fagan, 1984; Rose, Slater, & Perry, 1986). Early attention is commonly examined based on looking behavior, although measures including heart rate and brain activity can also be indicative of attention. These measures can be used to examine attention and its relation with many domains of early development including visual pattern perception, speech perception, categorization, and multimodal perception, among others.

Looking behavior in infancy that is considered to be characteristic of more efficient information processing, such as faster habituation, shorter look durations, and increased recognition of novelty, may be one of the earliest predictors of intelligence (e.g., Bornstein & Sigman, 1986; Colombo, 1993; Colombo, Shaddy, Richman, Maikranz, & Blaga, 2004; Fagan, Holland, & Wheeler, 2007; Kavšek, 2004; McCall & Carriger, 1993; Miller et al., 1977). These tasks investigating early attention are relevant to intelligence because they examine cognition based on components such as memory and speed of processing. A recent study conducted by Fagan and colleagues (2007) revealed that novelty preferences at 6 to 12 months of age were significantly and moderately correlated with IQ at 21 years of age even when controlling for parental education. Kavšek (2004) conducted a meta-analysis of 25 studies that examined infant habituation and/or dishabituation and cognitive outcomes in childhood and found that measures

of infant attention were moderately predictive of later cognition, with a mean of $r = .37$ across the studies.

Measurements of attention are also useful to the study of early intelligence, including the development of information processing capabilities in infancy. For example, measures of infant attention may be examined as indices of infants' processing strategies or processing preferences. The Information Processing Principles (IPPs), proposed by Cohen, Chaput, and Cashon (2002), provide an example of a constructivist approach to the development of information processing. According to the IPPs, information-processing skills are built upon in a hierarchic manner, with the continuous integration of higher-level units into a general knowledge system. Individuals are predisposed to use the highest level of units available to them, but when their system becomes overwhelmed they will regress to more basic information processing strategies, based on lower-level units. An example of the integration of lower-level units into higher-level units of processing may include a transition from the inspection of a stimulus based on its individual features, or details, to a focus on its overall configuration. Stimulus symmetry is associated with more efficient processing when compared with asymmetry (e.g., Attneave, 1955; Perkins, 1932) and may encourage higher-level, configural (global) processing. Furthermore, based on the IPPs, the presence of asymmetry may overwhelm the information processing system and lead infants that are processing at the global level to regress to a lower-level, local processing strategy.

Individual differences in infant looking behavior may moderate relations between processing strategy and stimulus symmetry. Short-looking infants display looking behavior characterized by brief, sweeping fixations of a stimulus (Colombo & Mitchell, 1990; Colombo, Mitchell, Coldren, & Freeseman, 1991; Colombo, Mitchell, & Horowitz, 1988; Freeseman, Colombo, & Coldren, 1993). They are more likely to demonstrate recognition memory for a

familiarized stimulus than long-looking infants, who display lengthy, narrowly focused fixations. Furthermore, research has indicated that short lookers may be more advanced in information processing abilities, evidenced by a more mature global-to-local processing strategy (Colombo, 1995; Colombo, Frick, Ryther, & Gifford, 1996; Freeseman et al., 1993; Guy et al., 2013). In contrast, long lookers may use a local-to-global, or just a local, processing strategy (Colombo, Freeseman, Coldren, & Frick, 1995; Guy et al., 2013). Short-looking infants may adapt their processing strategy based on the increased complexity seen in asymmetric stimuli, which would be seen in a regression to stimulus processing at the local level. Long lookers may utilize a local processing strategy whether processing a symmetric or an asymmetric stimulus.

Examination of behavioral and electrophysiological correlates of attention provides insight into the functioning of preverbal infants. The current study utilized event-related potentials (ERPs) to examine the impact of stimulus symmetry on the processing of global and local stimulus properties by 6-month-old short- and long-looking infants. ERPs were measured in response to Navon-type stimuli, which consisted of a local feature arranged to form a global configuration, and that were manipulated based on symmetry (symmetric or asymmetric) and familiarity (familiar, novel-global, or novel-local). The Negative central (Nc) and late slow wave (LSW) ERP components were analyzed to examine attentional engagement and recognition memory. Based on these measures, long lookers were expected to demonstrate greater sensitivity to local stimulus elements despite stimulus symmetry, whereas short lookers were expected to demonstrate sensitivity to either global or local stimulus components, depending on stimulus symmetry. This study is the first to examine the effect of stimulus symmetry on hierarchical processing, and provides insight into the relationship between symmetry and global or local processing. It also aims to provide a deeper understanding of processing advantages in short- and

long-looking infants. Finally, it allowed for the examination of the impact of increasing task demands on information processing in infancy and the relationship between task demands and looker type on information processing.

1.1 Infant Attention

Historically, research on infant attention has been conducted by examining variations in looking behavior to an assortment of stimuli with age. Developmental changes have been well documented and have been tied to the emergence of attention systems thought to reflect increased eye movement control and visual attention (see Reynolds et al., 2013). Three attention systems have been identified that are believed to be functional in infancy, including the reflexive system, the posterior orienting system, and the anterior attention system (Bronson, 1974; Colombo, 1995; Hood, 1995; Johnson, 1990, 1995; Johnson, Posner, & Rothbart, 1991; Maurer & Lewis, 1979; Posner, 1995; Posner & Peterson, 1990; Richards & Hunter, 1998; Schiller, 1985, 1998). Richards (2001) proposed that these attention systems are influenced by a general arousal/attention system. Examination of the timing of changes in visual behavior provides insight into the development and functionality or the attention systems.

The reflexive system is operative during the newborn period, from birth through about 3 months of age. Throughout this stage, infants display selective attention during brief periods of inactive alertness, which increase in duration with development (Colombo, 2001). At this time, young infants display preferences based on stimulus familiarity, size, and contrast (e.g., Fantz, 1963, 1964; Fantz & Fagan, 1975; Lewis, Kagan, & Kalafat, 1966). The reflexive system is believed to be under the control of brain areas including the lateral geniculate nucleus, the primary visual cortex, and the superior colliculus, which are immature in structure and function, restricting young infants' control over eye movements (Atkinson, 2000; Banks & Salapatek,

1983; Hickey & Peduzzi, 1987). From 2 to 3 months of age, rapid neurological development takes place in the retina and visual cortical pathways, which is reflected by increased visual functioning, an expansion of the visual field, and the ability to control inhibitory mechanisms that restrict eye movements (see Colombo, 2001; Haith, 1980; Reynolds et al., 2013). This marks a shift from reflexive to more voluntary control of visual orienting as the posterior orienting system reaches functional maturity.

The posterior orienting system becomes functional and dominates infants' attention from about 3 to 6 months of age (Posner & Petersen, 1990). Major transitions in neural structure and function are seen, including rapid visual system maturation, increased periods of arousal and alertness, more flexible deployment and shifting of attention, and more efficient information processing. These developments are tied to maturation of the pulvinar nucleus of the thalamus, posterior parietal lobe, and the superior colliculus (Johnson, 1990; Johnson et al., 1991; Posner & Petersen, 1990). Johnson and colleagues (1991) found that infants were 4 months old before being able to consistently disengage, switch, and reengage attention from a central stimulus to a more attractive peripheral stimulus, possibly indicating the onset of posterior orienting. With development of the posterior orienting system, infants are able to effectively scan and focus on features within stimuli. During this period of time, the duration of looking to stimuli decreases across a broad range of stimulus types (Courage, Reynolds, & Richards, 2006).

The anterior attention system shows early functioning beginning at 6 months of age and is marked by the emergence of higher level, volitional control of sustained attention. Infants continue to demonstrate brief looking to static stimuli, but look duration to complex and dynamic stimuli increases (Courage et al., 2006). Infants also begin to demonstrate more social looking behavior, in areas such as social referencing (Bertenthal & Campos, 1990) and joint attention

(Bakeman & Adamson, 1984). The emergence of anticipatory looking behavior around 6 to 7 months of age may indicate the development of voluntary control over attention and the emergence of the anterior attention system (Sheese, Rothbart, Posner, White, & Fraundorf, 2008). These advances in attention are tied to improved executive function, thought to reflect increased frontal brain activity (Bell & Fox, 1994; Chugani, 1994; Posner, 1995).

Based on the attention systems, changes in early development of attention occur between 2 and 3 months of age, with a transition from reflexive system to posterior orienting system dominance, and again at about 6 months of age, with the emerging functionality of the anterior attention system. Posner and colleagues have proposed a final transition from posterior orienting system dominance to anterior attention system dominance by 3 to 4 years of age (Posner, Rothbart, Sheese, & Voelker, 2012; Rothbart, Sheese, Rueda, & Posner, 2011). These transitions have been incorporated into a triphasic theory of infant looking behavior (Colombo, 2001). Colombo (2001) proposed that there are predictable changes in look duration characterized by an increase in looking from birth to 3 months of age, a decrease in looking between 3 and 6 months of age, and a slow, but continual increase in looking from 6 months through 2 to 3 years of age. The decrease in looking from 3 to 6 months of age is hypothesized to reflect development of the posterior orienting system, while the transition at 6 months is proposed to reflect the onset of the anterior attention system (Colombo, 2001).

Colombo's (2001) triphasic model of attention was largely based on research that employed only static stimuli, and has since been investigated with a more diverse range of stimuli (Colombo et al., 2004; Courage et al., 2006; Reynolds Zhang, & Guy, 2012). Courage, Reynolds, and Richards (2006) examined look duration to a variety of static and dynamic stimuli in 3- to 12-month-old infants. A decline in look duration was reported between 3 and 6 months

of age across all stimulus types, however beyond 6 months of age an increase in looking was

shown to more complex and dynamic stimuli. These results were extended in a second study

through a comparison of look duration to dynamic visual stimuli with dynamic audiovisual

stimuli in 3-, 6-, and 9-month-old infants (Reynolds et al., 2012). Stimuli included segments of

Sesame Street and dynamic geometric patterns. At all ages, longer look durations were seen to

Sesame Street stimuli versus geometric stimuli and to multimodal audiovisual conditions

compared with the unimodal visual condition. These results indicate that patterns of look

duration change with development based on stimulus complexity and modality.

The theoretical models of the attention systems along with behavioral findings indicate

that relevant changes in attention occur around 6 months of age, when the posterior attention

system has developed and the anterior attention system shows early functionality. With the

development of the posterior orienting system, infants demonstrate the ability to voluntarily shift

their attention in a controlled manner. This development may lead to utilization of more efficient

and mature information processing strategies, distinguished by configural, rather than featural,

stimulus processing. However, as these capabilities may be relatively new or immature in 6-

month-old infants more complex stimuli may overload the information processing system,

resulting in use of less efficient processing strategies, consistent with Cohen and colleagues'

(2002) IPPs.

1.2 Cohen's Information Processing Principles

The Information Processing Principles (IPPs) proposed by Cohen, Chaput, and Cashon

(2002) are proposed to be domain-general learning mechanisms that support a constructivist

view of infant cognitive development, beginning with an innate information processing system

that guides all learning. Cohen and colleagues (2002) hypothesized that information is processed

hierarchically, as more complex, higher-level information is built upon previously processed, lower-level units of information. According to the IPPs, there is a bias to use the highest-level units of information available, but lower-level units are utilized when higher-level units are not available, such as when the information processing system is overloaded. The authors argued that this system could be applied throughout development and across multiple cognitive domains.

Cohen and colleagues' (2002) IPPs are supported by earlier research conducted by Cohen and Younger (Cohen & Younger, 1984; Younger & Cohen, 1983, 1986). The results of these studies provide evidence for transitions from lower- to higher-level units of processing with development. For example, Cohen and Younger (1984) habituated 6- and 14-week-old infants to an angle and then presented them with variations of the angle based on the lines' orientation or the degree of the angle created by the lines. Only the older infants demonstrated a novelty preference based on changes to the angle's degree. Cohen and Younger (1984) concluded that they had processed the habituated stimulus as a whole, higher-level unit, unlike the younger infants who processed the lines as separate, lower-level units. This can be viewed in support of the IPPs, which propose the presence of hierarchical lower- and higher-level units that are built upon with development.

A similar set of experiments utilized more complex visual stimuli, specifically drawings of imaginary animals (Younger & Cohen, 1983, 1986). The question of interest was whether 4-, 7-, or 10-month-old infants would process the animal holistically or as individual, independent features. When features perfectly correlated with one another, 7-month-olds, but not 4-month-olds, were able to process the animal as a whole. However, when some features correlated with one another and others varied independently, as in a categorization task, only 10-month-olds

were able to process the features based on their configuration. These findings are consistent with the IPPs because they illustrate hierarchical learning and indicate that higher-level units are processed when available, and that an increase in task demands can lead to the utilization of lower-level units (Cohen et al., 2002). With increasing functionality of the various attention systems, higher-level units would be utilized, reflected by the recruitment of infant attention to different stimulus characteristics and by more efficient stimulus processing. However, when the system is overloaded, less mature processing strategies may be utilized, characterized by the use of lower-level units.

1.3 Individual Differences in Infant Attention

Individual differences in infant looking behavior may interact with the IPPs to influence what information within a stimulus an infant will attend to. Research in infant visual attention has revealed stable individual differences in look duration (Colombo, Mitchell, O'Brien, & Horowitz, 1987) and has found that infants who display shorter look durations are more likely to demonstrate recognition memory for a previously viewed stimulus than long-looking infants (Colombo & Mitchell, 1990; Colombo et al., 1991; Colombo et al., 1988; Freeseman et al., 1993). Look duration in infancy has important implications, as it has been negatively associated with: responsiveness to novelty, advanced motor development, and intelligence test performance at up to eight years of age (Bornstein & Sigman, 1986; Colombo, 1993; Colombo & Mitchell, 1990; Colombo et al., 2004; Fagan, 1984; Miller et al., 1977; Rose, Slater, & Perry, 1986). A recent study found that looker type assessed at 5 months of age was correlated with executive function at 24, 36, and 48 months of age (Cuevas & Bell, 2013). Infants categorized as short lookers demonstrated higher executive function scores as toddlers than infants categorized as long lookers.

In clinical populations, at-risk infants, including those diagnosed with Down Syndrome and those born preterm, show longer look durations and require extended time for stimulus familiarization compared with non-risk infants (Cohen, 1981; Fantz & Fagan, 1975). Among preterm individuals, look durations in infancy have been negatively correlated with intelligence test performance at 18 years of age (Sigman, Cohen, & Beckwith, 1997). This relationship was most pronounced when comparing short lookers with highly responsive caregivers to long lookers with less responsive caregivers. For the most complete understanding of the relationship between infant look duration and cognitive outcomes in childhood, Colombo and colleagues (2004) recommend utilizing a developmental systems approach and considering environmental influence, as well.

Colombo (1995) proposed that individual differences in look duration reflect individual differences in speed of processing, possibly due to variations in neural speed or in processing strategies utilized during stimulus encoding. In support of differences in encoding speed, past research has suggested that long-looking infants are able to discriminate some of the same stimuli as short-looking infants, but require an extended period of stimulus exposure during familiarization (e.g., Colombo et al., 1991; Freeseman et al., 1993; Frick & Colombo, 1996; Stoecker, Colombo, Frick, & Allen, 1998). Differences in neural speed could be due to developmental differences in the structure or function of the central nervous system (Colombo, 1995). A recent study conducted by Diaz and Bell (2011) found that 5-month-old short lookers showed an increase in EEG power from baseline to an attention task, but long lookers did not. EEG power reflects neuronal excitability and increased EEG power values seen developmentally across infancy are thought to reflect brain maturation (Bell & Fox, 1994).

Another possibility is that the differences are driven by use of distinct processing strategies (Colombo, 1995). Short lookers may utilize a more efficient processing strategy, resulting in faster and more thorough stimulus processing. Specifically, they may use a global processing strategy, reflected in a "global precedence effect," where processing progresses from global to local features (Colombo et al., 1991). It is possible that long lookers employ a local-to-global, or just a local processing strategy, described by a more tedious feature-by-feature analysis that may never reach the global level (Frick & Colombo, 1996). Degree of eye movement control may operate as a mechanism for differences in processing speed and strategy, which is impacted by the development of the posterior orienting system (Colombo, 1995). Long lookers may be delayed in development of the posterior orienting system, reflected in deficits in disengaging and switching attention in comparison to short lookers. These mechanisms have been further investigated through use of infant ERPs (Guy et al., 2013; Reynolds, Guy, & Zhang, 2011).

1.4 Infant ERPs

ERPs allow for the examination of cognitive processing in infancy, and can provide insight into the role of individual differences and stimulus symmetry in the processing of higher- and lower-level stimulus units by 6-month-old infants. Voltage-oscillations in the electroencephalogram (EEG) that are time-locked with an event of interest, such as stimulus onset (Fabiani, Gratton, & Coles, 2000; Picton et al., 2000), are averaged together to form ERPs. ERP components associated with different stages of stimulus processing can be identified in the averaged ERP waveform and reflect perceptual or cognitive processing. Two components that are particularly interesting to research on infant visual processing, and that were examined in the current study, include the Negative central (Nc) component, associated with attention and

stimulus orienting, and the late slow wave (LSW), associated with stimulus processing and recognition memory (de Haan & Nelson, 1997, 1999; Reynolds, Courage, & Richards, 2010; Reynolds & Richards, 2005; Snyder, 2010).

The Nc is a negatively polarized deflection in the waveform that is seen across midline frontal and central electrodes occurring approximately 350-750 ms after stimulus onset. A higher amplitude Nc response has been seen to salient and novel stimuli and is thought to reflect attentional engagement, novelty detection, or a general orienting response (Carver, Bauer, & Nelson, 2000; Courchesne, Ganz, & Norcia, 1981; de Haan & Nelson, 1997, 1999; Guy et al., 2013; Nikkel & Karrer, 1994; Reynolds et al., 2010; Reynolds & Richards, 2005; Richards, 2003; Webb, Long, & Nelson, 2005). Research incorporating ERPs with heart rate measures has provided support for the proposal that Nc reflects attentional engagement (Reynolds et al., 2010; Richards, 2003). These studies have shown greater amplitude of Nc during heart rate periods that are indicative of attention, compared with periods indicative of inattention in 4.5- to 7.5-month-old infants. Supporting the role of stimulus salience, Nc is greater in amplitude towards a mother's face versus a dissimilar looking stranger's face (de Haan & Nelson, 1997, 1999), and Nc is greater in amplitude toward an infant's preferred stimulus, regardless of familiarity, based on behavioral measures of attention (Reynolds et al., 2010). Thus, Nc amplitude most likely reflects the magnitude of the attentional response (Reynolds et al., 2010, 2013).

The LSW may be observed at frontal, central, temporal, and parietal electrodes and is examined from 1000-2000 ms after stimulus onset (de Haan, 2007). The LSW may be positive or negative in polarity and researchers have proposed that positivity and negativity may reflect different levels of stimulus processing; specifically, a positive LSW may indicate ongoing stimulus processing, a negative LSW may indicate novelty detection, and a LSW at baseline

amplitudes may indicate that stimulus processing is complete (e.g., de Haan, 2007; de Haan &

Nelson, 1997). However, this pattern of results has not been consistently supported. LSWs both

negative (Nelson & Collins, 1991, 1992; Quinn, Westerlund, & Nelson, 2006; Reynolds &

Richards, 2005; Richards, 2003) and positive (de Haan & Nelson, 1997, 1999; Snyder, 2010;

Snyder, Garza, Zolot, & Kresse, 2010; Snyder, Webb, & Nelson, 2002; Webb et al., 2005; Wiebe

et al., 2006) in polarity have been seen in response to infrequent or novel stimuli. While not

necessarily reflected by a LSW at baseline, a consistent finding across studies is that there is a

change in the amplitude of the LSW with repeated stimulus exposure, which may reflect

stimulus processing and recognition (de Haan & Nelson, 1997, 1999; Guy et al., 2013; Reynolds

et al., 2011; Richards, 2003; Snyder, 2010). LSW analyses are most informative in paradigms

utilizing varying amounts of stimulus exposure, as the results may indicate differences in the

degree of stimulus processing or recognition memory.

 Reynolds, Guy, and Zhang (2011) integrated measures of looking behavior with ERPs to

examine individual differences in attention. Colombo (1995) hypothesized that individual

differences in look duration are caused by variation in processing speed either due to general

differences in neural function or structure, or due to differences in processing strategy during

stimulus encoding. We utilized ERPs to examine possible neural mechanisms associated with

these differences. Six- and 7.5-month-old infants accumulated 20 s of looking to a photograph of

an unfamiliar female face and peak look length to the face was measured to determine looker

type. This was followed by a second familiarization phase, including 20 s of accumulated

looking to a photograph of an unfamiliar household object. An ERP phase then measured

electrophysiological responses to the familiar stimulus and several novel object photographs. It

was hypothesized that Nc results would support a greater attentional response by short lookers;

however, no significant differences were seen in Nc based on looker-type. LSW results showed significantly different responses to familiar and novel stimuli for short lookers, but not long lookers.

These findings indicate that short lookers discriminated the familiar stimulus from the novel stimuli, while long lookers did not (Reynolds et al., 2011). Because these differences were detected in the LSW, thought to reflect recognition memory, but not in Nc, a measure of attentional arousal or engagement, the results support variations in recognition of the familiar stimulus by short versus long lookers, but not in their magnitude of attention. Differences in short and long lookers recognition of the familiar stimulus could be due to the use of distinct processing strategies. Short lookers would be expected to have been more successful than long lookers at processing the familiar stimulus if they were utilizing a more efficient processing strategy. Research conducted by Colombo and colleagues (1995) has indicated that short lookers might use a more mature, global processing strategy, while long lookers may focus on stimulus details led to the investigation of individual differences in hierarchical stimulus processing.

1.5 Hierarchical Processing

It has long been debated whether processing of the stimulus whole comes before its parts or if processing of the parts is necessary for comprehension of the whole. For example, are faces recognized based on the configuration of their features, including the eyes, nose, and mouth, or based on identification of these features? Structuralists, including Titchener (1909) and Wundt (1874), hypothesized that objects were recognized based on the collective firing of several nerves, all responding to a specific stimulus feature. Gestaltists, however, believed that perception of the whole was not dependent on its parts and that the brain responds to a stimulus based on its overall configuration rather than as a summation of responses to its parts (e.g.,

Koffka, 1963; Kohler, 1929, 1971; Wagemans et al., 2012; Wertheimer, 1967). Specifically, the Gestalt law of Prägnanz hypothesized that early perception is in response to the simplest possible organization of a stimulus (see Wagemans et al., 2012).

More recently, the terms "top-down" and "bottom-up" have been employed in the debate of stimulus processing (Kimchi, 1992; Kinchla & Wolfe, 1979). "Top-down" refers to a more configural or conceptual processing approach, in which the stimulus is broken down as necessary during processing. "Bottom-up" processing refers to a more featural approach based on the integration of sensory information into a holistic perception later in the processing stream. Visual stimuli consist of both configural and featural information, where the configuration is dependent on the arrangement of the stimulus features. Infants may display a configural top-down approach to stimulus processing, evidenced by a global to local level processing strategy, or they may demonstrate a structural bottom-up approach, evidenced by a local to global processing strategy. E. J. and J. J. Gibson (E. Gibson, 1988; J. Gibson, 1979) proposed that knowledge develops in a top-down manner based on the early recognition of constants, or invariants, within one's environment and action possibilities that the environment offers an individual, also known as affordances. With increased attentional capabilities and through detection of invariants during perception, this information becomes further differentiated. According to J. J. Gibson (1979), it is recognition of invariants that most accurately reflects how individuals perceive their environment.

It is possible that development of attention may reflect transitions in processing strategy, which are traditionally investigated through use of hierarchical stimuli. Hierarchical stimuli are compound patterns that consist of multiple levels. There is a global level, based on the overall configuration of the stimulus, and a local level, which consists of smaller components that are

arranged to form the global pattern. Research conducted with adult participants has formed the foundation of our knowledge on the processing of hierarchical patterns.

In his classic study, Navon (1977) utilized compound stimuli consisting of alphabetic letters arranged to compose a larger letter. Participants were asked to respond to the presence of a specific letter at one level of the stimulus. Navon hypothesized the presence of a Stroop-like effect, where one level may interfere with the processing of the letter at another level. He found that while the small letters did not affect recognition of the larger, global letter, the larger letter did interfere with recognition of the smaller letter. Based on these results, Navon (1977) proposed a global precedence effect characterized by processing at the global level followed by a more detailed, local analysis and a global interference effect, indicating that automatic processing at the global level may interfere with attention to the local level. Navon's hypothesis of a global precedence effect supports the Gestalt view of holistic processing and has been well documented in follow-up behavioral (e.g., Hughes, Layton, Baird, & Lester, 1984; Kimchi, 1988; Navon, 1981) and electrophysiological (e.g., Han, Yund, & Woods, 2003) research.

However, further research has provided evidence that these effects are only seen under certain circumstances, such as when the perception of the local level is degraded (Grice, Canham, & Boroughs, 1983). For example, a significant difference in reaction time to the global or local level of a compound letter stimulus has only been seen when stimulus location was uncertain (Grice et al., 1983; Pomerantz, 1983). If participants were asked to fixate on a cross that was replaced by the center of a hierarchical stimulus, no differences in reaction time were seen (Grice et al., 1983). When switching attention between global and local levels to a target letter, level repetition played a role by drawing participants' attention to the previously attended level, whether global or local, despite the presence of a large global processing advantage

(Hübner, 2000). Other factors that have been found to affect global precedence, include stimulus

size (Kinchla & Wolfe, 1979; Lamb & Robertson, 1990; Luna & Montoro, 2008; McLean,

1979), local element density (Martin, 1979b; Navon, 1983), global or local level distortion

(Hoffman, 1980; Luna & Montoro, 2008; Sebrechts & Fragala, 1985), pattern exposure duration

(Hughes et al., 1984; Kimchi, 1988; Paquet & Merikle, 1984, 1988), background color

(Michimata, Okubo, & Mugishima, 1999), attention allocation (Förster & Denzler, 2012;

Hoffman, 1980; Ward, 1982), priming (Schwarzkopf & Rees, 2011), and stimulus

meaningfulness (Poirel, Pineau, & Mellet, 2006, 2008).

Global precedence and interference effects in hierarchical processing have been

replicated in research employing pictorial stimuli (Antes & Mann, 1984; Poirel et al., 2006,

2008), as well as in auditory research (Bouvet, Rousset, Valdois, & Donnadieu, 2011; List,

Justus, Robertson, & Bentin, 2007; Sanders & Poeppel, 2007), suggesting use of common

processing strategies across modalities. Poirel and colleagues (2006) replaced the letters common

to hierarchical stimuli with objects, which were recognizable and had meaning, and non-objects,

which were unrecognizable and had no meaning. Participants viewed two hierarchical

object/non-object stimuli side-by-side, which could be identical or dissimilar within a level, and

were asked to make same/not same judgments. In a dissimilar pair, the global precedence effect

was overcome when the irrelevant local level was composed of objects, but the global level was

not. The presence of the objects was thought to draw attention away from the global level,

suggesting that the automatic identification of familiar objects interfered with automatic

preferences in structural analysis.

Reliable hemispheric differences in global and local processing have been found in adult

(Blanca, Zalabardo, García-Criado, & Siles, 1994; Fink, Halligan, et al., 1997; Fink, Marshall, et

al., 1997; Han et al., 2002; Martin, 1979a; Van Kleeck, 1989; Volberg & Hubner, 2004) and developmental samples (Mondloch, Geldart, Maurer, & de Schonen, 2003; Moses et al., 2002). Adults often show right hemisphere advantages in processing compound letter stimuli at the global level and left hemisphere advantages for processing information at the local level (Blanca et al., 1994; Fink, Halligan, et al., 1997; Fink, Marshall, et al., 1997; Martin, 1979a; Van Kleeck, 1989). Developmental studies have observed adult-like lateralization in adolescents as well (e.g., Mondloch et al., 2003; Moses et al., 2002). Mondloch and colleagues (2003) found evidence of hemispheric specialization in children as young as 10 years old. Although 10-year-olds, 14-year-olds, and adults showed a global precedence effect for processing stimuli presented in either visual field, participants responded more quickly on local trials when stimuli were presented in the right visual field, reflecting left hemisphere activation. These results led the authors to hypothesize that local level processing becomes more laterally specialized earlier than global processing.

Neurological research has indicated that activity in the prestriate cortex and temporal-parietal cortex is relevant to hemispheric differences in processing advantages (Fink, Halligan, et al., 1997; Fink, Marshall, et al., 1997). Studies employing EEG and PET, which are procedures with high temporal resolution, have found no hemispheric asymmetries in early stimulus recognition, leading researchers to propose that asymmetries emerge later in higher levels of the processing stream (Heinze, Hinrichs, Scholz, Burchert, & Mangun, 1998). In support of this hypothesis, Volberg and Hübner (2004) detected hemispheric asymmetries in the amplitudes of N2 and P3, later the occurring adult ERP components.

Investigation of hierarchical processing in developmental populations provides insight into the emergence of mature processing strategies. Although results have been contradictory at

times, most research indicates an increase in global processing capabilities with age that may be coupled with a transition from a local to a global processing bias (Dukette & Stiles, 1996; 2001; Mondloch et al., 2003). In a forced choice paradigm, participants, ranging from 6 years old to adult, were asked whether a pair of stimuli were the same or different at either the global or local level, a global precedence effect was observed in all participants (Mondloch et al., 2003). Surprisingly, 6- and 10-year-olds showed an even greater global bias than adults, evidenced by longer latencies to make decisions and more mistakes at the local level.

A series of studies conducted by Dukette and Stiles (1996, 2001) tested 4- through 8-year-olds and adults in multiple paradigms examining hierarchical processing. In a forced choice paradigm employing hierarchical stimuli, participants were presented with a target stimulus and then shown two non-matching stimuli and were asked to identify the stimulus more similar to the target (Dukette & Stiles, 1996). The forced choice pairs were designed to encourage decisions based on global properties, local properties, or to put global and local properties in competition with one another. All ages demonstrated a bias towards making judgments based on global stimulus elements. However, when stimulus density was made sparser, by removing some of the local components, and potentially interfering with the global configuration, 4-year-olds no longer showed a global processing bias.

Another study asked participants to copy a hierarchical pattern or recreate it from memory after 5 s of stimulus exposure (Dukette & Stiles, 2001). Overall performance increased with age, as well as when participants were allowed to copy the pattern while it was being presented to them. When recreating forms based on memory, 4-year-olds did a significantly better job of reproducing the local level than the global level. When local element density was decreased, 6- and 8-year-olds showed an advantage for reproducing the local compared with the

global stimulus level. In contrast, increasing the local element density within the stimulus led to an equivalent ability to reproduce local and global levels at all ages. These findings suggest that global and local level processing can be manipulated based on local element density, and that this manipulation affects individuals differently based on age. Although, a global bias was observed at most ages, the youngest children showed a local level bias and overall global processing was not as developed in children as in adults.

Poirel, Mellet, Houdé, and Pineau (2008) investigated the impact of stimulus meaningfulness on global and local processing in children through the use of object and non-object stimuli. Four-, 5-, 6-, and 9-year-old participants were exposed to pairs of hierarchical stimuli and had to make judgments of same or not same based on either the global or local level. Four-year-olds showed a local processing advantage, which matured to a global processing advantage by 9 years of age. The meaningfulness of object stimuli played a large role in pattern processing. Object differences at either the global or local level were detected more quickly and with fewer errors than non-object differences, suggesting that stimulus meaningfulness facilitated discrimination.

In line with Dukette and Stiles' (1996, 2001) results, Poirel and colleagues (2008) found an increase in the use of global processing strategies and a decrease in errors with age. Additionally, Bialystok (2010) found that bilingualism, often associated with advanced cognitive development, was related to enhanced performance on a hierarchical task. Six-year-old monolingual and bilingual children completed Navon-like hierarchical processing tasks utilizing letter and object stimuli. Overall, the participants made more errors in global identification than local identification, but bilingual children showed an advantage for global identification in comparison with their monolingual counterparts.

These trends in the development of adult-like processing strategies appear to be unique to humans, as comparative research involving nonhuman primates does not indicate a transition from a local to global processing strategy. Adult humans have been found to out-perform monkeys in tasks requiring global stimulus property processing, while monkeys have demonstrated greater accuracy and faster processing of local stimulus elements compared with global stimulus characteristics (Fagot & Tomonaga, 1999; Hopkins & Washburn, 2002). Developmental research has shown that preschool children perform equally well at matching hierarchical visual stimuli based on global and local properties, but monkeys did not perform as well when matching visual stimuli on global properties in comparison to matching based on local elements. (De Lillo, Spinozzi, Truppa, & Naylor, 2005). The preschool children were significantly better at matching based on global elements than monkeys.

1.6 Hierarchical Processing: Infancy

Research on hierarchical processing in infancy has revealed many developmental changes in relation to looking behavior and stimulus processing in the first year of life. From birth, newborns show looking behavior characterized by a focus on the outer contours of a stimulus (Fantz, Fagan, & Miranda, 1975; Haith, Bergman, & Moore, 1977; Milewski, 1976; Salapatek, 1975). When stimulus size is increased, they also show a preference for looking at stimuli possessing internal complexity, for example a checkerboard pattern with a high number of squares (Fantz & Fagan, 1975). These results among others (e.g., Farroni, Valenza, Simion, & Umilta, 2000; Macchi Cassia, Simion, Milani, & Umiltà, 2002) indicate sensitivity towards global and local stimulus properties from birth. Preferences for outer contours and stimuli with large local elements may be due to low contrast sensitivity of infants at this age.

Milewski (1978) used compound visual patterns composed of an external and an internal shape to assess 1-month-olds' preferences for external contours. Similar to newborns, it was hypothesized that these young infants may have an attentional bias based on size, leading the larger external contours to recruit their attention. Milewski utilized an operant sucking technique to assess whether 1-month-olds were demonstrating a global preference or simply a size bias. Compound stimuli were divided so that the larger and smaller components were presented side-by-side. No evidence of recognition memory for the smaller stimulus was seen. Based on these results, it does not appear that very young infants display a global or local processing preference, but that they do display a size preference and larger stimuli recruit their attention.

At 3 to 4 months of age, infants maintain sensitivity to both global and local levels, but a global bias appears to emerge (e.g., Frick, Colombo, & Allen, 2000; Ghim & Eimas, 1988; Quinn, Burke, & Rush, 1993; Quinn & Eimas, 1986). For example, in a series of experiments, Ghim and Eimas (1988) tested 3- and 4-month-olds' ability to discriminate compound stimuli, which consisted of global squares and diamonds composed of local squares and diamonds, as well as global Xs and crosses that were made up of local Xs and crosses. Each participant was familiarized to a single stimulus for 15 s of accumulated looking and then completed two 10 s paired-comparison trials that included the familiar stimulus and a novel stimulus that differed from the familiar stimulus in either global or local components. Results showed novelty preferences in the paired comparison task, regardless of whether the stimulus was novel in global or local characteristics. These results indicate that 3- to 4-month-old infants are capable of acquiring global and local stimulus information.

The development of global processing in infancy has also been investigated through use of subjective contour stimuli. Subjective contours are formed by arranging small elements to

create the illusion of edges. Bertenthal, Campos, and Haith (1980) tested 5- and 7-month-old infants with stimuli that were arranged using four circles with one quadrant removed to either create the illusion of a square or in a non-illusion, where the circles did not create subjective contours. An infant-controlled habituation procedure was used to find that 7-month-olds, but not 5-month-olds, could discriminate between a subjective-contour array and a non-subjective-contour array. These results indicate that 7-month-olds perceived the figure formed by the subjective contours and had processed the stimulus globally. A later study found evidence for the perception of subjective contours in infants as young as 3 months old (Ghim, 1990). This study utilized a paired comparison procedure and found that 3- and 4-month-olds discriminated a pattern with subjective contours from patterns without subjective contours, although they did not discriminate two patterns without subjective contours.

Results of behavioral and electrophysiological research infancy have shown that individual differences in visual attention are correlated with hierarchical processing preferences (Colombo et al., 1995; Colombo et al., 1996; Colombo & Mitchell, 1990; Colombo et al., 1991; Freeseman et al., 1993; Frick & Colombo, 1996; Frick et al., 2000; Guy et al., 2013; Macchi Cassia & Simion, 2002). Colombo (1995) proposed that short lookers might utilize a more efficient visual processing strategy than long lookers, resulting in faster and more thorough processing of stimulus properties, possibly reflecting greater maturation of the posterior orienting system. Specifically, short lookers may utilize a global processing strategy and long lookers may utilize a local processing strategy (Colombo et al., 1991). Freeseman, Colombo, and Coldren (1993) tested 4-month-olds using a paired-comparison procedure with hierarchical patterns. The stimuli were similar to those employed by Navon (1977) and consisted of geometric shaped configurations (diamond or hourglass patterns) composed of 13 upper-case letters ("N" or "Z").

Short lookers were successful in discriminating stimuli based on changes in global and local stimulus properties. After 10 s of familiarization, discrimination was shown based on novel global properties and after 20 s of familiarization, based on changes in local features. Long lookers required 40 s of familiarization to show evidence of discrimination based on global properties, but they never demonstrated discrimination based on local features. These results suggest that short and long lookers utilize the same global to local processing sequence, yet short lookers process information more efficiently.

However, a follow-up study yielded contradictory results (Colombo et al., 1995). Once again, 4-month-old infants were familiarized with the hierarchical stimuli described above and completed a paired-comparison task that included two novel stimuli (Freeseman et al., 1993). One of the stimuli contained familiar global properties and novel local features; the other stimulus contained a novel global pattern composed of the familiar local features, putting preferences for global and local stimulus properties in competition with one another. The results were consistent with previous findings (Freeseman et al., 1993) for short lookers, who demonstrated a novelty preference based on global properties after 20 s of familiarization and local elements after 30 s of familiarization. However, this was not the case for long lookers. Long lookers did not show a preference on the paired comparison after 20, 30, or 40 s of familiarization. Upon 50 s of familiarization, they showed a preference based on novel local stimulus properties. Even after habituation, long lookers did not show a preference based on global stimulus properties.

These findings demonstrate that while short lookers consistently show preferences indicative of a global-to-local processing strategy (Colombo et al., 1995; Colombo et al., 1996; Colombo et al., 1991; Freeseman et al., 1993; Frick & Colombo, 1996), long lookers' selective

attention may be biased towards the local level, evidenced by local precedence effects (Colombo et al., 1995; Frick & Colombo, 1996). This hypothesis is further supported by research conducted by Macchi Cassia and Simion (2002) that analyzed visual and manual object examination in 8-month-old infants. While short lookers spent more time looking at objects with novel global properties, long lookers spent more time looking at objects with novel local features. In contrast, an additional study by Frick, Colombo, and Allen (2000) indicated that both short and long lookers process global stimulus properties prior to local features. Three-month-old long-looking infants showed sensitivity to global, but not local, stimulus properties after just 30 s of familiarization. The results were more in line with the findings of Freeseman et al. (1993), but in competition with those of Colombo et al. (1995).

These inconsistencies led Guy, Reynolds, and Zhang (2013) to further investigate individual differences in attention and processing strategy use in a study that measured ERPs, which may be a more sensitive index of stimulus encoding than look duration. Six-month-old infants were divided into short and long lookers based on peak look length to an unfamiliar female face. We then familiarized infants with a Navon-type hierarchical pattern, consisting of uppercase letters arranged in a geometric configuration, and measured ERP responses to brief presentations of the familiar pattern, patterns novel in their overall configuration (i.e. novel-global), and patterns novel in their individual features (i.e. novel-local). It was hypothesized that short lookers would demonstrate differential responding to novel-global versus familiar stimuli, indicating processing of the overall stimulus configuration. They were not expected to discriminate novel-local stimuli. Long lookers were not anticipated to respond differentially based on stimulus type, but if any effects were shown, it was expected that they would indicate detection of novelty based on local stimulus features.

The results showed that infants demonstrated processing advantages for global or local stimulus properties, which varied based on individual differences in look duration. Short-looking infants responded differently based on stimulus type at Nc and the LSW, indicating greater attention to and discrimination of changes in global properties. At midline frontal and central electrodes, short lookers displayed a significantly greater amplitude response to novel-global versus familiar and novel-local stimuli. Long lookers did not show differences in Nc responses based on stimulus type. Analysis of the LSW at parietal electrodes revealed that long-looking infants discriminated changes in local features from the familiar stimulus, but did not discriminate changes in global properties of the stimuli. Short lookers showed significant differences in their LSW responses between familiar and novel-global stimuli at frontal and central electrodes. These results suggest that short- and long-looking infants utilize different approaches when processing hierarchical patterns. Short lookers showed evidence of a global processing preference, supporting a global-to-local processing strategy, while long lookers showed evidence of a local processing preference, supporting a local-to-global or local processing strategy. The research on hierarchical stimulus processing indicates that both global and local precedence effects are based on a dominant tendency to direct attention to and process one level of a stimulus over the other under certain conditions (e.g., Pomerantz, 1983) as opposed to being based on an obligatory sequence of perceptual processing (e.g., Navon, 1977). Therefore short and long lookers would not be expected to demonstrate the same processing preferences under all circumstances; based on increasing or decreasing task difficulty, it may be possible to manipulate the processing strategies that they employ. Specifically, increasing task demands may lead short-looking infants to regress to a local processing strategy.

1.7 Symmetry

The presence of symmetry within a stimulus could foster the use of a global processing strategy. Based on the Gestalt approach to stimulus encoding, it has been proposed that "goodness of form" may impact global precedence effects (e.g., Hoffman, 1980). Goodness of form is dependent on various properties based on features' configuration within a stimulus, including symmetry, which is defined by redundancy across an axis (Garner, 1970, 1974, 1978). Bilateral symmetry, achieved when two halves of a stimulus are mirror images of one another, is especially prolific. As illustrated by Hargittai and Hargittai (1994), there are numerous examples of bilateral symmetry in our environment including human bodies, animals, insects, architecture, artwork, body movement, city planning, automobiles, plants, and music. Symmetry is not only attractive to humans, comparative research provides evidence of a preference for symmetry in other species as well, providing support for the evolutionary hypothesis that symmetry is indicative of genetic health (e.g., Moller, 1992; Thornhill, 1992; Wignall, Heiling, Cheng, & Herberstein, 2006).

Symmetry has been thoroughly investigated in judgments of facial attractiveness (Fink, Manning, Neave, & Grammer, 2004; Grammer & Thornhill, 1994; Mealey, Bridgstock, & Townsend, 1999; Rhodes, Geddes, Jeffery, Dziurawiec, & Clark, 2002; Rhodes et al., 2001; Scheib, Gangestad, & Thornhill, 1999; Zaidel & Cohen, 2005). Grammer and Thornhill (1994) first found an effect of symmetry on men and women's ratings of facial attractiveness. Their results indicated that when predicting ratings of facial attractiveness, the role of facial symmetry is more important than facial averageness. Support for the relationship between symmetry and form attractiveness has been shown in areas beyond the face literature. Szilagyi and Baird (1977) conducted a study in which they asked participants to arrange components within one, two, and

three dimensional arrays in a manner "visually pleasing;" they found that at least one form of symmetry was consistently present in these patterns.

Beyond preferences for symmetry, symmetric patterns are more easily identified, discriminated, and remembered than asymmetric patterns (Attneave, 1955; Ballesteros, Millar, & Reales, 1998; Baylis & Driver, 1994, 2001; Locher & Nodine, 1973; Perkins, 1932). Perkins (1932) investigated recall of asymmetric forms over an extended period of time and replicated the results of earlier studies (J. J. Gibson, 1929; Kuhlmann, 1906; Wulf, 1922), indicating that participants' reproduction became more symmetric in nature with time. Researchers have proposed that because symmetric patterns are redundant, they contain less information than asymmetric patterns (e.g., Attneave, 1957). Symmetric shapes have repeatedly been judged as less complex than asymmetric ones, despite controlling for complexity by equating the number of sides of the shapes (Attneave, 1957; Day, 1968). Locher and Nodine (1973) examined looking behavior to symmetric and asymmetric patterns. They found that structural complexity was positively correlated with look duration and number of fixations for both types of patterns, but that the fixations were focused on one side of the stimulus for symmetric patterns and not asymmetric patterns.

As previously suggested, vertical symmetry may be especially salient. Results of behavioral research indicate that vertical symmetry is detected more quickly and more accurately than symmetry in other orientations (Corballis & Roldan, 1975; Cornelis, van Doorn, & Wagemans, 2009; Evans, Wenderoth, & Cheng, 2000; Palmer & Hemenway, 1978; Wenderoth, 1994) and electrophysiological research demonstrates a possible perceptual advantage for vertical symmetry (Beh & Latimer, 1997). For example, Wenderoth (1994) presented participants with a variety of symmetric and asymmetric dot arrays while measuring reaction

times and instructed participants to quickly and accurately indicate whether the stimulus was symmetric or asymmetric. Responses were more accurate and were provided more quickly for vertically symmetric than horizontally symmetric arrays and for horizontally symmetric arrays than all remaining arrays. Beh and Latimer (1997) measured visual evoked potentials to symmetric and asymmetric stimuli of different orientations. Examination of early waveform components, up to 300 ms after stimulus onset, revealed that vertical symmetry produced a greater amplitude response that was shorter in latency than other symmetric and asymmetric patterns. Furthermore, studies utilizing behavioral and electrophysiological measures have found a greater magnitude of response and faster response times to vertical, followed by horizontal, followed by oblique symmetry (Beh, 1990; Beh & Latimer, 1997; Fisher & Bornstein, 1982; Latimer, Joung, & Stevens, 1994).

Developmental research has indicated an increased sensitivity to stimulus symmetry with age (e.g., Boswell, 1976; Chipman & Mendelson, 1979; Mendelson, 1984; Mendelson & Lee, 1981). Chipman and Mendelson (1979) tested kindergartners, second graders, fourth graders, sixth graders, and college students with symmetric and asymmetric dot arrays in addition to stimuli possessing oblique symmetry, checkerboard organization, and rotational organization that varied in the amount of contour. Participants were presented with pairs of stimuli and were instructed to select the simpler pattern in the pair. This method revealed developmental changes in sensitivity to structure. Kindergartners only appeared to be sensitive to double and vertical symmetry in their judgments, whereas older participants appeared to be sensitive to all forms of organized structure. The authors hypothesized that sensitivity to double and vertical symmetry develops earlier than sensitivity to other forms of pattern structure. They also predicted that a

general increase in the perception of structured patterns occurs between fourth and sixth grades, evident from the uniform increase in simplicity judgments across stimulus types at this age.

Mendelson and Lee (1981) extended these findings (Chipman & Mendelson, 1979) by testing sensitivity to asymmetry and various types of symmetry (vertical, horizontal, and oblique) in even younger children. Participants were exposed to a pattern for 1.5 s and asked to match it to one of two patterns in front of them. Overall performance increased significantly with age and children were more accurate in matching symmetric than asymmetric patterns. Vertical and horizontal symmetry facilitated pre-kindergarteners' performance, while all types of symmetry facilitated kindergarteners' performance. These results extend earlier findings and suggest increases in sensitivity to symmetry are present across early childhood.

Another series of experiments provided support for a gradual progression of symmetry perception with development (Bornstein & Stiles-Davis, 1984). Four-year-olds, who were the youngest group tested, were able to discriminate vertically symmetric patterns from asymmetric ones. Four- to 5-year-olds were able to differentiate stimuli based on vertical and horizontal symmetry, and children over 5 years of age successfully discriminated vertical, horizontal, and oblique symmetry from asymmetry. After employing more complex stimuli in a study testing only the oldest children, a difference in performance emerged and only vertical symmetry was easily discriminated. This developmental trend was once again replicated in a reproduction task utilizing symmetric and asymmetric arrays composed of 4, 5, or 6 elements. Performance increased with age and varied based on the number of elements and the orientation of the pattern. Vertical symmetry was reproduced most accurately, followed by horizontal symmetry, oblique symmetry, and asymmetry. The authors concluded that salience of and memory for symmetric patterns varies based on the orientation of the axis of symmetry.

1.8 Symmetry: Infancy

Bornstein and colleagues expanded their investigation of the perception of symmetry to include infants (Bornstein, Ferdinandsen, & Gross, 1981; Bornstein, Gross, & Wolf, 1978; Bornstein & Krinsky, 1985; Fisher, Ferdinandsen, & Bornstein, 1981). They found that 4-month-old infants habituated more quickly to vertically symmetric than horizontally symmetric or asymmetric patterns and that 12-month-olds, but not 4-month-olds, exhibited a looking preference for vertically symmetric patterns compared with horizontally symmetric and asymmetric patterns (Bornstein et al., 1981). These results indicate that even young infants are sensitive to vertical symmetry, but that preferences for symmetry develop sometime between 4 and 12 months of age. In a discrimination task, Fisher, Ferdinandsen, and Bornstein (1981) found that 4-month-olds were able to distinguish vertically symmetric patterns from horizontally symmetric and asymmetric patterns, but were unable to differentiate horizontally symmetric from asymmetric patterns.

Bornstein and Krinsky (1985) further examined the salience of vertical symmetry in infancy by comparing responses to vertically symmetric patterns with vertically repetitive but asymmetric patterns. Replicating the results of previous studies, 4-month-old infants did not show a looking preference based on stimulus type. However, they did habituate more quickly to the vertically symmetric patterns. In this study, Bornstein and Krinsky (1985) also examined the impact of local element density on processing speed of vertically symmetric stimuli. Similar to findings in the adult literature, they found that increases in local element sparsity were correlated with deficits in processing speed. Together, these findings indicate that young infants view vertically symmetric patterns, as wholes rather than as parts, and may possess a preference for processing these stimuli globally.

Other researchers have investigated the relationship between infants' perception of symmetry and related stimulus properties. Inspired by Garner's (1974) description of form goodness, Humphrey, Humphrey, Muir, and Dodwell (1986) manipulated stimulus goodness based on the number of axes around which their stimuli were symmetric. Results demonstrated that 4-month-olds' speed of habituation was influenced by the amount of symmetry the stimulus possessed, and that stimuli possessing a greater degree of symmetry were habituated to more quickly than less symmetric stimuli. Symmetry also affected discrimination; infants recovered looking to a rotated image, which had possessed vertical symmetry during habituation. Humphrey and Humphrey (1989) hypothesized that patterns possessing structure infants are sensitive to, will be more quickly habituated than patterns lacking it. In accord with this hypothesis, Strauss and Curtiss (1981) found that 3-month-old infants were able to discriminate between good patterns that were symmetric based on several axes, 5-month-olds discriminated intermediate patterns that were symmetric although not necessarily symmetric around several axes, and 7-month-olds discriminated poor patterns that did not possess symmetry.

While Bornstein and colleagues did not find a looking preference for symmetric patterns in young infants, Humphrey and Humphrey (1989) revisited looking preference related to symmetry using a paired comparison task. Four- to 5-month-old infants were presented with patterns possessing vertical symmetry, horizontal symmetry, double symmetry, or fourfold symmetry beside an asymmetric pattern. The greatest look duration was seen to stimuli possessing fourfold symmetry. Looking time to double and fourfold symmetric patterns was significantly greater than chance.

Early preferences for symmetry can be seen in literature examining the development of face processing. Morton and Johnson (1991) have hypothesized that an innate mechanism called

CONSPEC serves as a face detector by driving attention to a face template composed of an inverted triangle, representing the eyes and mouth. CONSPEC relies on vertical symmetry, which is a key component of other models of early face preferences and face processing as well (e.g., Viola & Jones, 2001). However, Balas (2010) conducted research utilizing computational models and found that preferences for symmetry, top heaviness, and texture more accurately predicted the presence of faces in naturalistic scenes than a model demonstrating a preference for a 3-dot pattern and texture, as CONSPEC would support. Even if CONSPEC is an inaccurate model of face perception, these results indicate that symmetry plays a significant role in face recognition.

Advances in infants' ability to process hierarchical symmetric and asymmetric stimuli may be tied to progress in category formation. Past research has shown an increase in the ability to form categories across the first year of life (e.g., Quinn, Doran, Reiss, & Hoffman, 2009; Younger, 1985), leading researchers to propose significant developmental change is taking place during this time (Mareschal & Quinn, 2001). Althaus and Mareschal (2012) recently conducted an eye tracking study indicating that during a categorization task, 4-month-olds utilize a bottom-up approach to processing novel stimuli, drawing their attention towards the stimulus body, whereas 12-month-olds are more information-driven evidenced by increased attention towards high variability features.

Quinn (2000) proposed that infants form categories based on the equivalence of stimuli within a category and deviations between those stimuli and stimuli outside of the category. A reference point may be seen in a stimulus that encompasses category ideals, serving as a magnet. This is potentially relevant because these references are proposed to possess perceptual properties that recruit attention and that lead to rapid encoding. Past research has indicated that

form goodness plays a role in infants' discrimination and categorization (Bomba & Siqueland, 1983; Humphrey & Humphrey, 1989; Humphrey et al., 1986; Quinn, 1987; Younger & Gotlieb, 1988). Quinn (2000) manipulated form goodness to investigate whether properties of good forms serve as reference points during stimulus processing. Based on Gestalt principles including preferences for symmetry, dots arranged in perfect triangles, diamonds, and squares were considered good forms, while random arrangements of the dots were considered poor forms. Distortions of each form were created by shifting the dots a predetermined distance from their previous placement. This yielded six stimulus pairs of good and poor forms and their distortions. Three- and 4-month-old infants were assigned to one stimulus and familiarized with it during six 15 s trials, followed by two 10 s paired comparisons of the familiar stimulus and its distortion. Novelty preferences indicated that infants discriminated good forms from their distortions, however infants were unable to discriminate poor forms from their distortions. Based on these findings, Quinn (2000) proposed that good forms act as anchors, by promoting discrimination based on reference points.

Colombo's investigation of individual differences in infant look duration led to an examination of the role of symmetry (Stoecker et al., 1998). It was hypothesized that short lookers would process symmetric stimuli more quickly than asymmetric stimuli, but that long lookers would not. Four-month-old infants were familiarized with an abstract shape that was either symmetric or asymmetric and was later presented in a paired comparison with a novel asymmetric stimulus. Short lookers were able to discriminate a familiar symmetric form from a novel asymmetric form after 10 s of familiarization and a familiar asymmetric form from a novel asymmetric form after 20 s of familiarization. Surprisingly, the long lookers required 50 s of familiarization to demonstrate discrimination, and at this point it was between a familiarized

asymmetric form and a novel asymmetric form. It was proposed that short lookers employed a global-to-local processing strategy, while long lookers relied on arbitrary, but distinguishing features to discriminate asymmetric forms.

1.9 Focus of the Current Study

In the current study, I utilized the IPPs (Cohen et al., 2002) as a framework for examining the role of symmetry in hierarchical processing by 6-month-old short- and long-looking infants. Six-month-olds were recruited for consistency with previous research investigating individual differences in infant attention (Guy et al., 2013; Reynolds et al., 2011) and infant ERPs (Ackles & Cook, 1998; de Haan & Nelson, 1997, 1999; Reynolds et al., 2010; Reynolds & Richards, 2005; Snyder, 2010). By 6 months of age, the posterior orienting system is believed to be functionally mature and any delays in its development should become apparent based on the ability to voluntarily disengage and shift attention in a controlled manner (Posner & Petersen, 1990). Differences in short and long lookers' visual behavior could be due to varying levels of development of the posterior orienting system and more advanced development of the posterior orienting system may lead to short lookers to utilize more efficient information processing strategies.

Participants were familiarized with either a symmetric or an asymmetric hierarchical stimulus and were then presented with ERP trials including presentations of the familiar pattern, patterns novel in local elements, and patterns novel in global configuration. Previous research has indicated that infants at this age detect changes in stimuli at the global level, but that this varies with individual differences (Guy et al., 2013). When compared based on looker type, short lookers detected changes in the stimuli at the global level and long lookers detected changes in the stimuli at the local level. Following the logic of Cohen and colleagues (2002), global

stimulus processing, based on holistic processing of individual elements, would be a higher-level unit of processing and local stimulus details would be lower-level units. Cognitive overload of the system should lead infants to revert to lower-level units for stimulus processing. In the current study, this would be reflected by a regression in short-looking infants' hierarchical processing from recognition of changes in the global configuration to recognition of changes in the local level.

In the most recent study examining hierarchical processing, ten of the twelve global configurations employed possessed at least bilateral, vertical symmetry (Guy et al., 2013). In the current study, the familiarization stimulus was manipulated based on symmetry and half of the participants were familiarized with a symmetric pattern, while the other half were exposed to an asymmetric pattern. This isolated the role of symmetry in early hierarchical processing. Six-month-old infants may be able to process a symmetric hierarchical stimulus by utilizing a global processing strategy, but may regress to a local processing strategy when processing an asymmetric stimulus. Furthermore, when considering the impact of symmetry and looker type, short lookers were expected to show a global processing advantage for symmetric stimuli and a local processing advantage for asymmetric stimuli. Long-looking infants were expected to demonstrate a local processing advantage for both symmetric and asymmetric stimuli. An ERP phase was included to allow for examination of attentional engagement (Nc) and recognition memory (LSW) in response to familiar, novel-global, and novel-local symmetric and asymmetric stimulus properties. Nc was examined at midline frontal and central electrode clusters. The LSW was analyzed at frontal, central, parietal, and temporal electrode clusters. In sum, the current study sought to determine if global asymmetry interacts with looker-type and leads short lookers to utilize a lower-level processing strategy based on local features.

Based on previous research (Guy et al., 2013; Reynolds et al., 2011), short lookers were expected to display more advanced development of attention compared with long lookers. Specifically, after familiarization with a symmetric stimulus, short lookers should differentiate stimuli based on global properties, whereas long lookers were expected to show differentiation of stimuli based on local elements, which is evidence of a less mature processing strategy. These results would replicate the previous findings of Guy, Reynolds, and Zhang (2013). The current study concurrently examined stimulus symmetry and hierarchical processing. To my knowledge, this is the first study to investigate the role of symmetry in hierarchical processing and I predicted that the presence of symmetry would dictate the processing strategy used by short-looking, but not long-looking, infants. After familiarization with a symmetric hierarchical stimulus, short lookers were expected to demonstrate a higher-level, global, processing advantage, evidenced by discrimination of global stimulus properties. Upon familiarization with an asymmetric stimulus, short lookers were expected to regress to a lower-level, local, processing advantage, evidenced by discrimination of novel-local elements. Long lookers were not expected to be affected by asymmetry and were expected to continue to discriminate stimuli based on changes in local features regardless of familiarization condition. Because nearly all of the stimuli utilized in the earlier study (Guy et al., 2013) possessed symmetry and long lookers utilized a local processing strategy, they were expected to continue to display this processing preference when faced with the more complex, asymmetrical stimuli.

I hypothesized that symmetric stimuli would be processed globally, while stimulus asymmetry would overload the 6-month-olds' information-processing system, encouraging stimulus processing at the local level. These effects were expected to interact with looker type. Short-lookers were expected to discriminate stimuli based on changes in global configuration

after familiarization with a symmetric stimulus. Significant differences in Nc and LSW amplitude should be seen at frontal and central electrodes to familiar versus novel-global stimuli. A greater amplitude Nc to novel-global stimuli versus the familiar stimulus would indicate a greater attentional response to changes in the global configuration of the stimulus. Differences in LSW amplitude between the familiar stimulus and novel-global stimuli would reflect processing of the familiar stimulus and recognition of novelty based on global configuration. After familiarization with an asymmetric stimulus, short lookers were expected to regress to a local processing strategy, evidenced by discrimination based on local features. Significant differences in Nc and the LSW should be seen at frontal and central electrodes to familiar versus novel-local stimuli, indicating a greater attentional response to novel-local stimuli and recognition of the familiar stimulus based on its local features. Long lookers were hypothesized to process stimuli at the local level after familiarization with symmetric or asymmetric stimuli. Based on previous findings (Guy et al., 2013; Reynolds et al., 2011), differences in Nc amplitude were not anticipated. However, recognition of familiar local stimulus components were anticipated based on differential LSW responses to the familiar versus novel local stimuli.

Although all of my predictions were based on discrimination of novel global and local pattern characteristics, stimuli were designed to allow comparisons based on novel symmetric and asymmetric pattern characteristics as well. After familiarization with a symmetric or an asymmetric hierarchical pattern, infants were presented with brief presentations of familiar, novel-global-symmetric (novel global configuration that was symmetric), novel-global-asymmetric (novel global configuration that was asymmetric), novel-local-symmetric (novel local element that was symmetric), and novel-local-asymmetric (novel local element that was asymmetric) stimuli. Fifty trials (i.e. 10 per condition) of clean EEG data would be required in

order to compare ERP responses from all five stimulus types, which is unlikely in an infant sample. Designing the stimuli as described above allowed for comparisons between familiar, novel-global, and novel-local stimulus types, as well as comparisons between familiar, novel-symmetric, and novel-asymmetric stimulus types, while only requiring 30 good trials.

I did not have specific predictions regarding the symmetry analysis, but broadly hypothesized that symmetric changes to the global and local properties of the stimuli may be easier to recognize than asymmetric changes. This could be reflected in a greater Nc amplitude response to novel-symmetric stimuli in comparison with the familiar stimulus, indicating increased attention to novel symmetric stimulus properties. Differences in LSW responses to the familiar stimulus versus novel-symmetric stimuli, but not novel-asymmetric stimuli, would indicate recognition of the familiar stimulus and discrimination of novel stimuli based on novel symmetric stimulus properties. Based on Stoecker et al.'s (1998) behavioral research, short lookers may be more sensitive to stimulus symmetry than long lookers. This would be evidenced by differences in the Nc and LSW based on symmetric changes to the familiar stimulus for short lookers, but not for long lookers.

Chapter 2 Method

2.1 Participants

A sample of forty infants (17 females, 23 males) was recruited for this experiment. All infants were tested within two weeks of their 6-month (26-week) birthdates. All participants were recruited from the Knoxville, Tennessee area, which is characterized by a predominantly Caucasian, middle class population. Participants were recruited from a predominantly Caucasian, middle class population. The racial distribution of the infants was: 31 Caucasian (not Hispanic), 4 biracial, 1 Asian, 2 African American, and 2 Caucasian (Hispanic). Participants were born full-term and without complications. An additional 65 infants participated in the experiment, but were not included in the final sample due to fussiness ($N = 19$), an insufficient number of artifact free trials ($N = 40$), and technical problems ($N = 6$).

2.2 Apparatus

Participants were positioned on their parent's lap in a sound-attenuated room. Infants were seated 55 cm away from a 27" color LCD monitor (Dell 2707 WFP). To limit distraction during testing, black curtains were set up on the front, left, and right walls surrounding the participant and room lighting was turned off. A digital camcorder (Sony DCR-HC28) located just above the monitor recorded infant visual fixations. Fixations were judged online using a video feed to a computer in an experimental control room, adjacent to the testing room. The video was recorded through the use of Net Station software produced by Electrical Geodesics Incorporated (EGI; Eugene, Oregon). The Net Station was used to record EEG data and to synchronize this data with the video. The experimental procedure was controlled on a PC using E-Prime 2.0 software (Psychology Software Tools, Inc.; Sharpsburg, PA). The E-Prime program

sent experimental events to the Net Station and utilized a single-clock system to time lock these experimental events with the EEG and video data.

2.3 Visual Stimuli

Female face: In order to measure peak look duration and to determine looker type, a digital photograph of an adult female's face was presented in a 20° square on the center of the computer monitor (see Figure 1). **Geometric patterns:** Test stimuli consisted of 196 black and white Navon-type hierarchical patterns (Navon, 1977), composed of 24 white, upper case letters arranged against a black background. Five different stimulus types were used: familiar, novel-global-symmetric, novel-global-asymmetric, novel-local-symmetric, and novel-local-asymmetric. Novel-global stimuli differed from the familiar stimulus in overall configuration or global pattern, but were composed of the same local features (i.e., upper-case letters) as the familiar pattern. Novel-global-symmetric stimuli were configured to possess global, bilateral, vertical symmetry. Novel-global-asymmetric stimuli did not possess any symmetry at the global level. Novel-local stimuli were composed of different local elements than the familiar stimulus, yet were configured in the same global pattern as the familiar stimulus. The local elements of novel-local-symmetric stimuli possessed bilateral, vertical symmetry, while the local elements that formed novel-local-asymmetric stimuli did not possess any symmetry. The stimuli consisted of 14 different patterns, seven symmetric and seven asymmetric. There were 14 exemplars of all patterns, seven composed of symmetric upper-case letters and seven composed of asymmetric upper-case letters for the local features. Each participant was exposed to 27 of these stimuli during testing: 1 familiar, 13 novel-global, and 13 novel-local. Figures 2 and 3 provide examples of stimuli utilized in symmetric and asymmetric familiarization conditions. The patterns were presented in a 20° square centered on the computer monitor. **Sesame Street characters:** Videos

of Sesame Street characters were used to regain infants' interest and fixation on the monitor after becoming distracted. The Sesame Street video covered a 15° square area centered on the monitor.

2.4 Procedure

Following the informed consent process, infants were held on a parent's lap approximately 55 cm from the center of the computer monitor. The experiment was then completed in two phases. The first phase was used to determine looker type. The photograph of the female face was displayed on the monitor until the infant had acquired 20 s of accumulated looking. Upon completion of the first phase, participants were fitted with an EGI sensor net and impedances were measured.

The second phase of the experiment included familiarization with one of the patterns and ERP trials. One of the geometric patterns was displayed on the monitor until the infant attained 20 s of accumulated looking. This pattern was designated as the familiar stimulus for the remainder of the experiment. The pattern used for the familiar stimulus was randomly determined and varied between participants; familiarization with a symmetric stimulus or an asymmetric stimulus was counterbalanced across infants. After familiarization, ERP test trials were recorded, during which the familiar, novel-global-symmetric, novel-local-symmetric, and novel-local-asymmetric stimuli were briefly presented to each infant. The stimuli were presented for 500 ms, followed by a blank, black screen for a random duration of 2000 to 2500 ms, which allowed for the analysis of the LSW, which occurs 1000 to 2000 ms following stimulus onset, and for a pre-stimulus interval prior to the subsequent stimulus onset. Familiar, novel-global, and novel-local stimulus presentations were equally distributed across trials. Within the novel-global and novel-local trials, half of the stimulus changes were symmetric and half were asymmetric.

Stimuli were presented in pseudorandom order in blocks of 30 stimulus presentations. Trials were initiated only when the infant was judged to be looking at the monitor. During periods of distraction, the Sesame Street videos were presented as an attractor stimulus. In cases in which the attractor stimulus was used, there was a blank screen for a minimum of 500 ms prior to the subsequent stimulus onset. Stimulus presentations continued for as long as the infant did not become tired or fussy.

2.5 EEG Recording and Analyses

The EGI Geodesic EEG System 300 (GES 300) 128-channel system was used. The system consisted of the HydroCel Geodesic Sensor net, the NetAmps hardware, and the Net Station recording program. The 128 channel net used consisted of 124 electrodes mounted in a geodesic configuration of pedestals held in place with elastic connections. There were an additional 4 channels available for recording EOG and/or heart rate, which were not used in this experiment. Electrolytic sponges were located within the pedestals and the entire net was soaked in an electrolytic (saline-based) solution prior to use. Pedestals corresponding to the vertex, mastoids, and nasion locations were marked on the net and used to position the sensor net in relationship to these anatomical landmarks while the elasticity of the net connections served to maintain the correct position of the pedestals corresponding to the remaining 120 electrodes. The average interelectrode distance of the scalp electrodes was 21 mm.

The proper placement of the sensor net resulted in electrode impedances of about 10 to 50 kΩ. The EGI system utilized high-impedance amplifiers containing 128 channels connected to a computer A/D card in a PowerPC-based computer system. The Net Station program was used for the A/D sampling, storing the data, the zero and gain calibration for each channel, and measuring impedances. The Net Station program also received serial communication from a Dell

Workstation used to control the experimental protocol with the use of E-Prime 2.0 software. Communication between the two computers was temporally synchronized based on the sending of experimental information (e.g., trial type, trial onsets) from the experimental computer to the Net Station program using the E-Prime single-clock system. The sampling rate of the EEG was 250 Hz with 20K amplification. Band-pass filters were set from 0.3 to 100 Hz during recording. EEG recordings were referenced to the vertex. Following testing, EEG recordings were run through a 30 Hz low-pass filter and algebraically re-referenced to the average reference. The application and adjustment of the net typically required 5 to 10 minutes, during this time a second experimenter distracted the infant with rattles and infant-directed speech to keep the infant in a positive state prior to testing.

The EEG recordings were inspected for artifacts (i.e., blinks, saccades, movement artifact, and drift) and poor recordings using the Netstation review system. Individual channels were marked bad within trials as necessary. Segments in which more than 10% of the channels were marked bad were eliminated from the analysis. For trials that were retained for the ERP analysis, individual channels marked bad were replaced using a spherical spline interpolation (Perrin, Pernier, Bertrand, & Echallier, 1989; Srinivasan, Tucker, & Murias, 1998). Only participants who contributed enough ERP trials per condition (i.e., at least 10 trials; DeBoer, Scott, & Nelson, 2007) for stable ERP averages following EEG editing were included in the final dataset.

ERP averages were calculated from 100 ms before stimulus onset through 2 s after onset. This segment length allowed for analysis of the Nc and LSW components. The Nc component is typically located at midline frontal and central electrodes (i.e., Fz, Cz). The LSW has been observed at frontal, central, parietal, and temporal electrodes. Mean data from clusters of

electrodes of the EGI sensor net that correspond to these regions were analyzed. As is standard practice in the field, the specific electrodes used in each cluster were determined based on past research and visual inspection of the grand average ERP waveforms (DeBoer et al., 2007). Nc peak (i.e., minimum) amplitude was analyzed from 350 – 750 ms following stimulus onset at midline frontal and central electrode clusters. For the late slow wave, mean amplitude from 1 – 2 s following stimulus onset was analyzed separately at frontal, central, parietal, and temporal electrode clusters.

2.6 Design for Statistical Analysis

Full factorial analyses were carried out using mixed ANOVAs with familiarization condition (2: symmetric, asymmetric) and looker-type (2: short, long) as between-subjects factors, and stimulus type (3: familiar, novel-global, novel-local or 3: familiar, novel-symmetric, novel-asymmetric or 3: familiar, novel-symmetric, novel-asymmetric) as a within-subjects factor. I also analyzed electrode location as a within-subjects factor; the level for this factor varied by component and region. The Greenhouse-Geisser correction was used in cases of violations of the assumption of sphericity. For significant effects, follow-up analyses were carried out using one-way ANOVAs or paired-samples t-tests (two-tailed). Effect sizes (η_p^2) are reported on all significant effects, and all significant tests are reported based on an alpha level of $p < .05$.

Chapter 3 Results

3.1 Looker Type Analysis

The forty infants that participated in this study were split into short and long lookers using a median split based on their peak look length to the photograph of a female face ($Mdn =$ 14.077 s). The median split yielded 20 short lookers (peak look: $M = 8.188$ s) and 20 long lookers (peak look: $M = 20.037$ s) infants. Peak look lengths to the face ($M = 14.112$ s) and to the pattern ($M = 9.019$ s) were positively correlated, $r = .273$, $p = .044$, indicating that infants demonstrating a longer peak look fixation to the photograph of a female face were likely to demonstrate a long peak look to the geometric pattern, as well. This result supports past research correlating infants' look lengths across multiple stimulus types (e.g., Courage et al., 2006; Reynolds et al., 2012). Figures 4 and 5 depict frequency distributions of the participants' peak looks to the face and to the geometric patterns plotted against the normal distribution curve.

3.2 ERP Grand Averages

Grand averages were calculated based on stimulus type across electrodes of interest. Figure 6 depicts grand averages based on the comparison of familiar, novel-global, and novel-local stimuli. Figure 7 depicts grand averages based on the comparison of familiar, novel-symmetric, and novel-asymmetric stimuli. The Nc can be seen as a negative deflection occurring from 350 to 750 ms after stimulus onset at midline frontal and central electrodes. The LSW can be seen at frontal, central, parietal, and temporal electrodes from 1 to 2 s after stimulus onset.

3.3 Nc Analysis

Nc peak (minimum) amplitude was analyzed using mixed ANOVAs including midline electrodes (3: frontal, frontocentral, central) and stimulus type (3: familiar, novel-global, novel-local or 3: familiar, novel-symmetric, novel-asymmetric) as within-subjects factors and looker

type (2: short and long) and familiarization condition (2: symmetric and asymmetric) as between-subjects factors.

3.3.1 Nc Analysis: Global/Local Comparison

There were no significant Nc effects at midline frontal or frontocentral electrodes (all ps were greater than .05). At midline central electrodes, there was a significant interaction of familiarization condition by looker type and stimulus type, $F(2,72) = 5.155$, $p = .008$, $n_p^2 = .125$ (see Figure 8). For infants in the symmetric familiarization condition, there was no main effect of stimulus type, $F(2, 36) = 0.298$, $p = .744$, $n_p^2 = .016$, and there was no effect of looker type on stimulus type response, $F(2, 36) = 1.476$, $p = .242$, $n_p^2 = .076$. For infants in the asymmetric familiarization, there was a significant looker type by stimulus type interaction, $F(2, 36) = 4.016$, $p = .027$, $n_p^2 = .182$. Short lookers in the asymmetric familiarization condition showed a significantly greater Nc to the familiar stimulus ($M = -11.473$ μV, $SD = 6.456$ μV) than novel-global stimuli ($M = -7.587$ μV, 6.728 μV), $t(9) = 2.382$, $p = .041$. There were no differences in their Nc responses to the familiar stimulus versus novel-local stimuli ($M = -11.163$ μV, $SD = 8.127$ μV), $t(9) = 0.173$, $p = .866$, or to novel-global versus novel-local stimuli, $t(9) = 1.847$, $p = .098$. Long lookers in the asymmetric familiarization condition did not respond differently based on stimulus type: familiar ($M = -7.776$ μV, $SD = 6.366$ μV), novel-global ($M = -10.837$ μV, $SD = 5.912$ μV), and novel-local ($M = -10.576$ μV, $SD = 5.189$ μV).

3.3.2 Nc Analysis: Symmetric/Asymmetric Comparison

There were no significant Nc effects at midline frontal, frontocentral, or central electrodes based on the comparison of familiar, symmetric-novel, and asymmetric-novel stimuli (all ps were greater than .05).

3.4 LSW Analysis

LSW effects were analyzed using mixed ANOVAs examining mean amplitude from 1 to 2 s after stimulus onset at frontal, frontocentral, central, parietal, and temporal electrodes. ANOVAs included looker type (2: short and long) and familiarization (2: symmetric and asymmetric) as between-subjects factors and stimulus type (3: familiar, novel-global, novel-local or 3: familiar, novel-symmetric, novel-asymmetric) as within-subjects factors.

3.4.1 LSW Analysis: Global/Local Comparison

At frontocentral electrodes, there was a significant looker type by stimulus type interaction, $F(2, 72) = 3.402$, $p = .039$, $n_p^2 = .086$ (see figure 9). Short lookers responded significantly differently to the familiar stimulus ($M = 0.335$ µV, $SD = 6.895$ µV) versus novel-global stimuli ($M = 3.349$ µV, $SD = 7.708$ µV), $t(19) = 2.299$, $p = .033$. They did not show differences in their responses to the familiar stimulus versus novel-local stimuli ($M = 2.246$ µV, $SD = 6.637$ µV), $t(19) = 1.107$, $p = .282$, or to novel-global versus novel-local stimuli, $t(19) = 0.706$, $p = .489$. At the same electrode location, long lookers responded significantly differently to the familiar stimulus ($M = 3.596$ µV, $SD = 5.239$ µV) versus novel-local stimuli ($M = 0.429$ µV, $SD = 4.774$ µV), $t(19) = 2.360$, $p = .029$, and to novel-local versus novel-global ($M = 3.124$ µV, $SD = 5.513$ µV) stimuli, $t(19) = 2.175$, $p = .042$. Long lookers did not show differences in their responses to the familiar stimulus versus novel-global stimuli, $t(19) = 0.465$, $p = .647$.

These effects were also seen at midline central electrodes, where there was a significant looker type by stimulus type interaction, $F(2, 72) = 3.175$, $p = .048$, $n_p^2 = .081$ (see figure 10). Short lookers showed marginally significant differences in their responses to the familiar stimulus ($M = 2.632$ µV, $SD = 8.334$ µV) versus novel-global stimuli ($M = 5.641$ µV, $SD = 8.610$ µV), $t(19) = 1.852$, $p = .080$, but did not demonstrate differences in responses to the familiar

stimulus versus novel-local stimuli ($M = 5.350$ μV, $SD = 8.171$ μV), $t(19) = 1.290$, $p = .213$, or

novel-global versus novel-local stimuli, $t(19) = 0.148$, $p = .884$. Long lookers showed marginally

significant differences in their responses to the familiar stimulus ($M = 5.610$ μV, $SD = 5.417$ μV)

versus novel-local stimuli ($M = 2.039$ μV, $SD = 7.101$ μV), $t(19) = 1.904$, $p = .072$. They did not

show differences in responses to the familiar stimulus versus novel-global stimuli ($M = 4.886$

μV, $SD = 5.417$ μV), $t(19) = 0.634$, $p = .534$, or to novel-global versus novel-local stimuli, $t(19)$

$= 1.629$, $p = .120$.

At left temporal electrodes, there was a marginally significant stimulus type main effect,

$F(2, 72) = 2.586$, $p = .082$, $n_p^2 = .067$ (see figure 11). Infants responded significantly differently

to novel-global ($M = 3.125$ μV, $SD = 6.020$ μV) versus novel-local stimuli ($M = 0.242$ μV, $SD =$

6.665 μV), $t(39) = 2.195$, $p = .034$, but showed no differences in their responses to the familiar

stimulus ($M = 1.723$ μV, $SD = 6.319$ μV) versus novel-global stimuli, $t(39) = 1.136$, $p = .263$, or

to the familiar stimulus versus novel-local stimuli, $t(39) = 1.139$, $p = .262$. There was also a

marginally significant familiarization condition by stimulus type interaction at left temporal

electrodes, $F(2, 72) = 2.807$, $p = .067$, $n_p^2 = .072$ (see figure 12). Infants familiarized with a

symmetric stimulus responded significantly differently to the familiar stimulus ($M = -0.353$ μV,

$SD = 5.934$ μV) versus novel-global stimuli ($M = 4.024$ μV, $SD = 6.455$ μV), $t(19) = 2.581$, $p =$

.018. They also showed marginally significant differences in their response to novel-global

versus novel-local ($M = -0.708$ μV, $SD = 7.408$ μV) stimuli, $t(19) = 2.039$, $p = .056$. There were

no differences in their responses to the familiar stimulus versus novel-local stimuli, $t(19) =$

0.178, $p = .860$. Within the symmetric familiarization condition, these effects were seen for

short lookers, but not long lookers. Short lookers in the symmetric familiarization condition

responded significantly differently to the familiar stimulus ($M = 0.044$ μV, $SD = 7.153$ μV)

versus novel-global stimuli ($M = 6.253$ µV, $SD = 7.012$ µV), $t(9) = 2.529$, $p = .032$. They also

showed marginally significant differences in their responses to novel-global versus novel-local

($M = -1.076$ µV, $SD = 9.348$ µV) stimuli, $t(9) = 2.015$, $p = .075$. There were no differences in

their responses to the familiar stimulus versus novel-local stimuli, $t(9) = 0.311$, $p = .763$. Long

lookers in the symmetric familiarization condition, did not respond differentially based on

stimulus at left temporal electrodes: familiar ($M = -0.750$ µV, $SD = 4.777$ µV), novel-global ($M =$

1.796 µV, $SD = 5.268$ µV), and novel-local ($M = -0.341$ µV, $SD = 5.308$ µV). Infants

familiarized with an asymmetric stimulus did not respond differently based on stimulus type:

familiar ($M = 3.800$ µV, $SD = 6.138$ µV), novel-global ($M = 2.226$ µV, $SD = 5.570$ µV), novel-

local ($M = 1.193$ µV, $SD = 5.864$ µV).

3.4.2 LSW Analysis: Symmetric/Asymmetric Comparison

At frontal electrodes, there was a significant stimulus type main effect, $F(2, 72) = 3.174$,

$p = .048$, $n_p^2 = .081$ (see figure 13). Responses to novel-symmetric stimuli ($M = -7.893$ µV, $SD =$

10.479 µV) were significantly different than those to novel-asymmetric stimuli ($M = -4.080$ µV,

$SD = 10.692$ µV), $t(39) = 2.390$, $p = .022$. There were no differences in responses to the familiar

stimulus ($M = -5.406$ µV, $SD = 9.953$ µV) versus novel-symmetric stimuli, $t(39) = 1.640$, $p =$

$.109$, or in responses to the familiar stimulus versus novel-asymmetric stimuli, $t(39) = 0.952$, $p =$

$.347$.

At midline central electrodes, there was a marginally significant looker type by stimulus

type interaction, $F(2, 72) = 2.816$, $p = .066$, $n_p^2 = .073$ (see figure 14). Short lookers showed

marginally significant differences in responses to the familiar stimulus ($M = 2.628$ µV, $SD =$

8.332 µV) versus novel-symmetric stimuli ($M = 6.532$ µV, $SD = 10.166$ µV), $t(19) = 1.851$, $p =$

$.080$. They did not respond differently to the familiar stimulus versus novel-asymmetric stimuli

(M = 4.774 μV, SD = 7.900 μV), $t(19)$ = 1.182, p = .252, or to novel-symmetric stimuli versus novel-asymmetric stimuli, $t(19)$ = 0.805, p = .431. Long lookers showed no differences in their LSW response at midline central electrodes based on stimulus type: familiar (M = 5.610 μV, SD = 5.417 μV), novel-symmetric (M = 3.630 μV, SD = 5.137 μV), and novel-asymmetric (M = 3.724 μV, SD = 6.691 μV).

At right temporal electrodes, there was a significant familiarization condition by stimulus type interaction, $F(2, 72)$ = 3.789, p = .027, n_p^2 = .095 (see figure 15). Infants familiarized with a symmetric stimulus showed significant differences in their responses to the familiar stimulus (M = -0.952 μV, SD = 5.712 μV) versus novel-symmetric stimuli (M = 4.026 μV, SD = 7.023 μV), $t(19)$ = 2.656, p = .016, and to novel-symmetric versus novel-asymmetric (M = 0.782 μV, SD = 6.946 μV) stimuli, $t(19)$ = 2.690, p = .015. They did not respond differently to the familiar stimulus in comparison with novel-asymmetric stimuli, $t(19)$ = 0.921, p = .369. These effects were significant for short lookers in the symmetric familiarization condition, but not long lookers. Short lookers familiarized with a symmetric stimulus responded significantly differently to the familiar stimulus (M = -1.025 μV, SD = 6.537 μV) versus novel-symmetric stimuli (M = 4.283 μV, SD = 7.387 μV), $t(9)$ = -2.282, p = .048. There were marginally significant differences in their responses to novel-symmetric versus novel-asymmetric (M = 0.026 μV, SD = 6.341 μV), $t(9)$ = 2.003, p = .076. They did not respond differentially to the familiar stimulus versus novel-asymmetric stimuli, $t(9)$ = 0.581, p = .576. Long lookers familiarized with a symmetric stimulus did not show differences in their LSW responses based on stimulus type: familiar (M = -0.880 μV, SD = 5.113 μV), novel-symmetric (M = 3.769 μV, SD = 7.030 μV), and novel-asymmetric (M = 1.539 μV, SD = 7.770 μV). Infants familiarized with an asymmetric stimulus did not show differences in their LSW responses based on stimulus type at right temporal electrodes: familiar

(M = 2.052 µV, SD = 7.826 µV), novel-symmetric (M = 0.601 µV, SD = 6.472 µV), and novel-asymmetric (M = 1.677 µV, SD = 7.506 µV).

Infants familiarized with an asymmetric stimulus did show differences in their LSW responses based on stimulus type at right parietal electrodes (see figure 16), although the familiarization condition by stimulus type interaction did not reach significance, $F(2, 72)$ = 2.388, p = .099, n_p^2 = .062. Based on visual review of the waveforms and to follow up on this marginal interaction, which indicated differences based on familiarization condition, t-tests were run. Infants in the symmetric familiarization condition did not show differences in their responses based on stimulus type: familiar (M = 2.785 µV, SD = 7.748 µV), novel-symmetric (M = 1.583 µV, SD = 7.591 µV), and novel-asymmetric (M = 0.092 µV, SD = 8.522 µV). Infants familiarized with an asymmetric stimulus showed significant differences in their responses to the familiar stimulus (M = 3.406 µV, SD = 8.098 µV) versus novel-symmetric stimuli (M = 9.317 µV, SD = 11.276 µV), $t(19)$ = 2.739, p = .013, and in their responses to novel-symmetric versus novel-asymmetric (M = 3.871 µV, SD = 8.319 µV) stimuli, $t(19)$ = 2.155, p = .044. They did not respond differently to the familiar stimulus versus novel-asymmetric stimuli, $t(19)$ = 0.264, p = .795. Long lookers, but not short lookers, in the asymmetric familiarization condition showed significant differences in their responses based on stimulus type. Long-looking infants responded significantly differently to the familiar stimulus (M = 0.853 µV, SD = 6.048 µV) versus novel-symmetric stimuli (M = 6.813 µV, SD = 4.482), $t(9)$ = 2.924, p = .017. They did not respond differentially to the familiar stimulus versus novel-asymmetric stimuli (M = 4.040 µV, SD = 7.913 µV), $t(9)$ = 1.362, p = .206, or to novel-symmetric versus novel-asymmetric stimuli, $t(9)$ = 1.416, p = .191. Short lookers familiarized with an asymmetric stimulus did not demonstrate differences in their LSW responses based on stimulus type: familiar (M = 5.960 µV, SD = 9.348

µV), novel-symmetric (M = 11.822 µV, SD = 15.310 µV), and novel-asymmetric (M = 3.702 µV,

SD = 9.133 µV).

3.5 Results Summary

Significant interactions indicated that looker type and familiarization condition impacted

stimulus processing (see Table 1 for a summary). Replicating previous findings (Guy et al.,

2013), short-lookers demonstrated evidence of recognition memory and novelty detection based

on global level changes to the familiar stimulus, while long lookers showed evidence of

recognition memory and novelty detection based on local level changes to the familiar stimulus.

At the level attentional engagement, looker type and familiarization condition interacted with

stimulus type responses. Short lookers familiarized with an asymmetric stimulus showed a

greater amplitude Nc to the familiar stimulus in comparison with novel-global stimuli, indicating

a preference for the familiar stimulus. In the analysis comparing responses to the familiar

stimulus with responses to novel-symmetric and novel-asymmetric stimuli, infants familiarized

with a symmetric hierarchical stimulus showed evidence of recognition of novel-symmetric

stimulus properties.

Chapter 4 Discussion

The current study utilized Cohen and colleagues' (2002) IPPs as a framework to investigate the effect of stimulus symmetry on hierarchical processing by short and long lookers. Participants were familiarized with either a symmetric or an asymmetric hierarchical stimulus and were then presented with ERP trials including presentations of the familiar pattern, patterns novel in local elements, and patterns novel in global configuration. Novel stimulus properties were either symmetric or asymmetric. Based on previous research (Guy et al., 2013; Reynolds et al., 2011), short lookers were expected to display more advanced development of attention compared with long lookers.

The current study concurrently examined individual differences in infant visual attention and stimulus symmetry and their effects on hierarchical processing. After familiarization with a symmetric hierarchical stimulus, short lookers were expected to demonstrate a higher-level, global processing advantage, evidenced by discrimination of global stimulus properties. Upon familiarization with an asymmetric stimulus, short lookers were expected to regress to a lower-level, local processing advantage, evidenced by discrimination of novel-local elements. Long lookers were not expected to be affected by symmetry or asymmetry and were expected to continue to discriminate stimuli based on changes in local features regardless of familiarization condition.

ERP averages were analyzed to examine attentional engagement (Nc) and recognition memory (LSW) in response to familiar, novel-global-symmetric, novel-global-asymmetric, novel-local-symmetric, and novel-local-asymmetric stimuli. Nc was examined at midline frontal and central electrode clusters. In the hypotheses, predictions were made that short lookers familiarized with a symmetric stimulus would show evidence of greater attention to and

recognition of novel-global stimulus properties based on differences in Nc and LSW amplitude to the familiar stimulus versus novel-global stimuli. Short lookers familiarized with an asymmetric stimulus were expected to show greater attention to and recognition of novel-local stimulus properties, based on differences in Nc and LSW amplitude to the familiar stimulus compared with novel-local stimuli. Long lookers in both the symmetric and asymmetric familiarization conditions were predicted to discriminate novel-local stimulus properties based on differences in LSW amplitude to the familiar stimulus versus novel-local stimuli. In replication of previous studies (Guy et al., 2013; Reynolds et al., 2011), long lookers were not expected to respond differently based on stimulus type at the Nc component. The results of the analyses did not support all of the hypotheses, but they did indicate that both looker type and stimulus characteristics influence hierarchical processing biases.

4.1 Analysis of the Processing of Global and Local Stimulus Properties

Nc analyses revealed a significant familiarization condition by looker type by stimulus type interaction at midline central electrodes. Follow-up tests revealed differences in stimulus type responses only for short lookers in the asymmetric familiarization condition, who demonstrated a significantly greater Nc to the familiar stimulus in comparison with novel-global stimuli. Short lookers in the symmetric familiarization condition did not show a greater Nc to novel-global stimuli and the short lookers in the asymmetric familiarization did not show a greater Nc to novel-local stimuli, as hypothesized. Still, the results for short-looking infants familiarized with an asymmetric stimulus suggest that stimulus asymmetry may have increased processing demands. The greater Nc to the asymmetric familiar stimulus indicates short lookers retained interest in it. This could be due to less complete processing of the familiar stimulus by

short lookers in the asymmetric familiarization condition in comparison with short lookers in the symmetric familiarization condition.

LSW results of the current study replicated those of Guy, Reynolds, and Zhang (2013). Short lookers responded significantly differently to novel-global stimuli versus the familiar stimulus at frontocentral electrodes, indicating recognition memory for the familiar stimulus and discrimination of novel-global stimuli. This result supports a global processing advantage for short lookers. At frontocentral electrodes, long lookers showed a significantly different LSW response to novel-local stimuli, in comparison with the familiar stimulus and novel-global stimuli. This indicates that long lookers showed recognition for the familiar stimulus and discriminated it from novel-local stimuli. Long lookers therefore demonstrated a local processing advantage.

4.2 Analysis of the Processing of Symmetric and Asymmetric Stimulus Properties

Nc and LSW analyses were conducted to examine the effects of looker type and familiarization condition on the discrimination of novel symmetric and asymmetric stimulus properties. There were no significant Nc effects, but there was a significant familiarization condition by stimulus type interaction at right temporal electrodes. Infants familiarized with a symmetric stimulus demonstrated discrimination of the familiar stimulus from stimuli possessing novel-symmetric properties, but infants familiarized with an asymmetric stimulus did not respond differentially based on stimulus type. For infants familiarized with a symmetric stimulus, symmetric changes to the stimuli were likely easier to detect, leading to discrimination. LSW results at right temporal electrodes indicate that novel symmetry is more easily detected than novel asymmetry when infants were familiarized with a symmetric hierarchical stimulus whether they were short lookers or long lookers.

4.3 Summary

The results of this study provide evidence that both individual differences in infant visual attention and stimulus symmetry impact global and local stimulus responses. Short lookers showed an advantage for recognizing novel stimuli based on global changes to the familiarized stimulus. Long lookers demonstrated evidence of a local processing advantage, based on discrimination of local changes to a familiarized stimulus. The results indicate that short lookers exhibited a more mature stimulus processing strategy than long lookers and show support for varying levels of development of the posterior orienting system based on looker type. Long lookers' local processing bias may be due to developmental delays in the ability to voluntarily disengage and shift visual attention in a controlled manner.

A familiarization condition by looker type by stimulus type interaction was seen at the Nc, but not the LSW ERP component. Results did not support the hypothesis that short lookers familiarized with a symmetric stimulus would demonstrate a greater amplitude Nc to novel-global stimuli compared with the familiar stimulus and that short lookers familiarized with an asymmetric stimulus would demonstrate a greater amplitude Nc to novel-local stimuli compared with the familiar stimulus. However, results did support the hypothesis that short lookers in the symmetric familiarization condition would respond differently to the stimuli than short lookers in the asymmetric familiarization condition. Short-looking infants familiarized with an asymmetric stimulus showed a greater amplitude Nc to the familiar stimulus compared with novel-global stimuli, which indicates that they retained interest in the familiar stimulus and showed an increased attentional response to it in comparison with the novel-global stimuli. This could have been due to incomplete processing of the familiar stimulus.

My hypothesis that short-looking infants familiarized with an asymmetric stimulus would regress to a local processing strategy was not supported. LSW responses indicated that across both familiarization conditions, short lookers recognized the familiar stimulus and discriminated it from novel-global stimuli, however it was predicted that short lookers in the asymmetric familiarization would show of evidence of discrimination based on novel local stimulus properties. The lack of significant results in support of this hypothesis may indicate that the IPPs are incorrect and that cognitive overload is not associated with a regression in processing strategy. To reach this conclusion, more research supporting the stability of processing strategy use across multiple tasks and levels of cognitive demand would be necessary. There are alternative, more parsimonious explanations: a local processing strategy may not be a lower-level form of information processing in comparison with a global processing strategy, or the manipulation of stimulus symmetry may have not been strong enough to lead to cognitive overload and a regression in processing strategy. Based on the abundance of research indicating that the use of global processing strategies is more mature and more efficient than the use of local processing strategies, local processing does reflect the use of lower-level units of information in comparison with global processing. Therefore, it is most likely that the manipulation of stimulus symmetry was not strong enough to impact processing strategy use. Although results examining attentional engagement showed that short lookers' responses based on stimulus type were impacted by the symmetry of the familiar stimulus, this did not carry over to the examination of recognition memory. Even if the asymmetric stimulus was more difficult for short lookers to process than the symmetric stimulus during the 20 s familiarization period, it did not increase the difficulty of the task enough to lead to a regression in processing strategy.

Although my primary hypotheses were based on discrimination of novel global and novel local pattern characteristics, the stimuli allowed for comparisons based on novel symmetric and novel asymmetric stimulus characteristics, as well. Symmetric changes at both the global and local level were compared with responses to the familiar stimulus and asymmetric changes at the global and local level. The additional analyses, which examined discrimination of novel symmetric and asymmetric stimulus properties, indicated that infants in the symmetric familiarization condition were sensitive to stimulus symmetry. At right temporal electrodes, infants familiarized with a symmetric stimulus responded differently to the familiar stimulus versus novel-symmetric stimuli. These results are in line with findings from behavioral research examining the perception of symmetry in infancy, which indicate that infants process symmetry more quickly than asymmetry (Bornstein et al., 1981; Bornstein & Krinsky, 1985; Humphrey et al., 1986) and show an advantage for discriminating symmetric stimuli over asymmetric stimuli (Fisher et al., 1981; Strauss & Curtiss, 1981), and support the broad hypothesis that symmetric stimulus changes would be easier to detect than asymmetric stimulus changes. It is possible that the short lookers were most sensitive to symmetric global changes and that the long lookers were most sensitive to symmetric local changes, however that could not be examined with the current dataset.

The results of the current study provided support for the IPPs (Cohen et al., 2002). Cohen, Chaput, and Cashon (2002) proposed that infants' information processing capabilities develop hierarchically and that smaller units of processing develop into larger units of processing. According to this framework, local processing of a hierarchical stimulus would be a lower level of processing in comparison with global processing of a hierarchical stimulus. Long lookers may be delayed in the development of the posterior orienting system and may be less

efficient processors than short lookers. It appears that they are attending to local stimulus

properties, thus utilizing lower level processing units than short lookers, who are attentive to the

global level. Cohen and colleagues also predicted that infants are biased to using the highest-

level units available to them, but that cognitive overload (e.g., due to increased task demands)

leads to a regression to lower-level unit processing. The results of the current study do indicate

that task demands, specifically processing a symmetric versus an asymmetric stimulus, affect

processing strategies utilized. Infants familiarized with a symmetric stimulus showed evidence of

processing stimuli at the global level, but infants familiarized with an asymmetric stimulus did

not show evidence of a global or local processing bias. In concordance with the results of

previous research, novel symmetric stimulus changes were easier to recognize than asymmetric

stimulus changes. Infants were better at discriminating novel symmetry regardless of

familiarization condition and looker type.

4.4. Limitations and Future Directions

In order to more clearly understand the relationships between individual differences in

infant visual attention, stimulus properties, and stimulus processing biases, it would be ideal to

compare all five stimulus types (i.e. familiar, novel-global-symmetric, novel-global-asymmetric,

novel-local-symmetric, and novel-local-asymmetric) across all participants in a single analysis.

Unfortunately, this analysis would require an unrealistic amount of data to be collected from

each infant. Ten trials per stimulus type within a single participant and 10 participants per

condition are required for reliable ERP results. This ERP study conducted with five stimulus

types would require a minimum of 50 trials of clean EEG data from 40 infants. Because this is an

impractical amount of data to collect, it may be interesting to simplify the procedure by focusing

infants' responses to fewer stimulus types in the future.

There are numerous adjustments that could be made to the current procedure to increase understanding of the relationships between the various factors examined. This would be necessary to expand the implications of the study. At the level of the participant, multiple age groups during infancy should be tested. This would be necessary to establish a transition in infancy from a local to a global processing strategy. Testing infants at multiple ages would also help to confirm the importance of the development of the posterior orienting system to global processing. Furthermore, it would allow for the confirmation that short lookers younger than 4 to 6 months of age use local processing strategies and establish that long lookers older than 6 months of age use global processing strategies.

There are countless possible manipulations of the hierarchical stimuli that would be expected to impact the results. The stimulus types could be more limited to allow for the collection of sufficient data to examine infants' responses in more detail. For example, a single study could examine short and long lookers' processing of hierarchical asymmetric stimuli. Other studies could limit symmetric or asymmetric changes to either the global or the local level (e.g., compare familiar, novel-global-symmetric, and novel-global-asymmetric stimulus responses). I would expect that these analyses would help to elucidate the relationship between processing biases based on individual differences in infant visual attention and processing biases due to stimulus characteristics. As previously indicated, a stronger manipulation than stimulus symmetry may be necessary to impact short and long lookers' use of processing strategies. Manipulating the number of local elements within the global patterns may lead long lookers to process globally (e.g., in the case of a hierarchical stimulus with many dense local elements) or may lead short lookers to processing locally (e.g., in the case of a hierarchical stimulus with few sparse local elements). Overall, changes that increase the stimulus complexity would be expected

to increase the task demands, while changes that decrease stimulus complexity would be expected to decrease task demands.

An additional way to alter task demands would be through the manipulation of the familiarization condition. Jankowski, Rose, and Feldman (2001) familiarized 5-month-old short and long looking infants with black and white geometric designs. Short lookers showed evidence of recognition of the familiar pattern based on higher rates of looking to a novel pattern during a paired comparison phase, but long lookers did not. A follow-up study utilized a dynamic, transparent red box to illuminate various regions of the patterns during familiarization. It was hypothesized that this would encourage long lookers to shift their attention across the stimulus at higher rates, similar to short lookers. The results of the successive illumination confirmed the authors' hypothesis and long lookers showed novelty scores above chance levels. A similar manipulation of hierarchical could examine whether an intervention that encouraged high rates of shifting would encourage long lookers, like short lookers, to utilize a global processing strategy. Highlighting could also be altered to focus on single local elements, rather than larger stimulus regions, as in the study by Jankowski and colleagues (2001). It would be interesting to examine whether single element highlighting would draw attention in to a single detail, encouraging local processing, or whether shifting of the highlighted area would be enough to encourage global processing.

Finally, it may be informative to utilize additional measurements of infant attention and information processing. Based on the current study as well as previous research, ERPs show increased sensitivity to short and long lookers' processing biases than measurements of look duration and novelty scores alone. However, it would be interesting to incorporate eye-tracking analyses. This would allow for the examination of rates of disengagement and switching across

short and long lookers. Short lookers would be expected to shift at higher rates and across a greater area of the stimulus than long lookers. This could help to shed light onto why short lookers attend to the global stimulus configuration while long lookers attend to local stimulus details.

4.5 Conclusion

The results of the current study replicated previous research demonstrating differences in processing strategy based on looker type. Short lookers exhibited a global processing advantage based on differences in LSW responses to the familiar stimulus versus novel-global stimuli, while long lookers exhibited a local processing advantage based on differences in LSW responses to the familiar stimulus versus novel-local stimuli. These results support the proposal that short and long lookers utilize different processing strategies (Colombo, 1995). It is likely that differences in processing strategy are driven by overall more efficient processing capabilities in short lookers.

Familiarization with a symmetric or an asymmetric stimulus interacted with looker type to impact Nc responses based on stimulus type. Short lookers familiarized with an asymmetric stimulus showed a greater Nc response to the familiar stimulus compared with stimuli possessing novel global properties, but short lookers familiarized with a symmetric stimulus did not respond differentially based on stimulus type. A greater Nc for short lookers in the asymmetric familiarization condition indicates that they retained interest in the familiar stimulus in comparison with other stimulus types and could be due to its increased complexity relative to the symmetric familiarization stimulus. Although the results of the current study did not provide evidence of the regression to a local processing by short lookers in the asymmetric familiarization condition, the findings indicate that the manipulation of stimulus symmetry

impacted task demands. Because short lookers familiarized with an asymmetric stimulus were still interested in it during the ERP phase, it is likely that the asymmetric stimuli were more difficult to process than the symmetric stimuli.

Results of the analyses examining attention to and recognition of novel symmetric and asymmetric stimulus properties support easier detection of novel symmetric stimulus properties. Regardless of familiarization with a symmetric or an asymmetric hierarchical stimulus, infants showed increased sensitivity for novel symmetric stimulus characteristics. These results suggest that novelty was easier to recognize at the global and local level when it was symmetric, rather than asymmetric. Further studies will be necessary to increase understanding of the relationship between task demands and stimulus asymmetry.

The examination of individual differences in infant visual attention can provide insight into individual differences in early intelligence based on the examination of information processing capabilities. In the current study, infants displaying short look durations, associated with more advanced development, showed evidence of the use of a global processing strategy. This is considered a more efficient and mature processing strategy than a local processing strategy, which was employed by infants displaying longer looker durations. These differences in processing strategy may help to explain differences in other areas of development, as well, because individual differences in attention have been shown to have moderate predictive value for intelligence scores into adulthood (e.g., Colombo et al., 2004; Fagan et al., 2007; Kavšek, 2004; McCall & Carriger, 1993). The relationship between look duration and cognitive outcomes may be especially strong for at-risk infants (Kavšek, 2004; Sigman et al., 1997). Kavšek (2004) found stronger correlations between behavioral measures of infant attention and later intelligence for at-risk infants than typically developing infants. Studies examining the relationships between

looking behavior and early information processing may help to determine interventions that would be most effective for these infants, and when, developmentally, interventions should be applied. In the context of typically developing infants, research investigating the relationship between looking behavior and performance on information processing tasks in infancy is important because it provides further insight into the development of visual attention and recognition memory and the normal range of variability in these tasks for typically developing infants.

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Appendix

Table 1. Description of significant results

Global/Local Comparison			
Effect	**Significance**	**Electrode cluster**	**Sig. follow-up comparisons**
Nc: familiarization condition X looker type X stimulus type interaction	$p = .008$, $n_p{}^2 = .125$	Midline central	Asymmetric familiarization: looker type X stimulus type interaction, $p = .027$, $n_p{}^2 = .182$ Short lookers in the asymmetric familiarization: greater Nc to familiar than novel-global, $p = .041$
LSW: looker type X stimulus type interaction	$p = .039$, $n_p{}^2 = .086$	Frontocentral	Short lookers: differences in response to familiar versus novel-global, $p = .033$ Long lookers: differences in response to novel-local versus familiar, $p = .029$, and novel-global, $p = .042$
LSW: looker type X stimulus type interaction	$p = .048$, $n_p{}^2 = .081$	Midline central	The same pattern of results was seen as at frontocentral electrodes, but comparisons did not reach significance.
Symmetric/Asymmetric Comparison			
Effect	**Significance**	**Electrode cluster**	**Sig. follow-up comparisons**
LSW: stimulus type main effect	$p = .048$, $n_p{}^2 = .081$	Frontal	Differences in response to novel-symmetric versus novel-asymmetric, $p = .022$
LSW: familiarization condition X stimulus type interaction	$p = .027$, $n_p{}^2 = .095$	Right temporal	Symmetric familiarization: differences in responses to novel-symmetric versus familiar, $p = .016$, and novel-asymmetric, $p = .015$

Figure 1. The photograph of a female face utilized to determine looker type
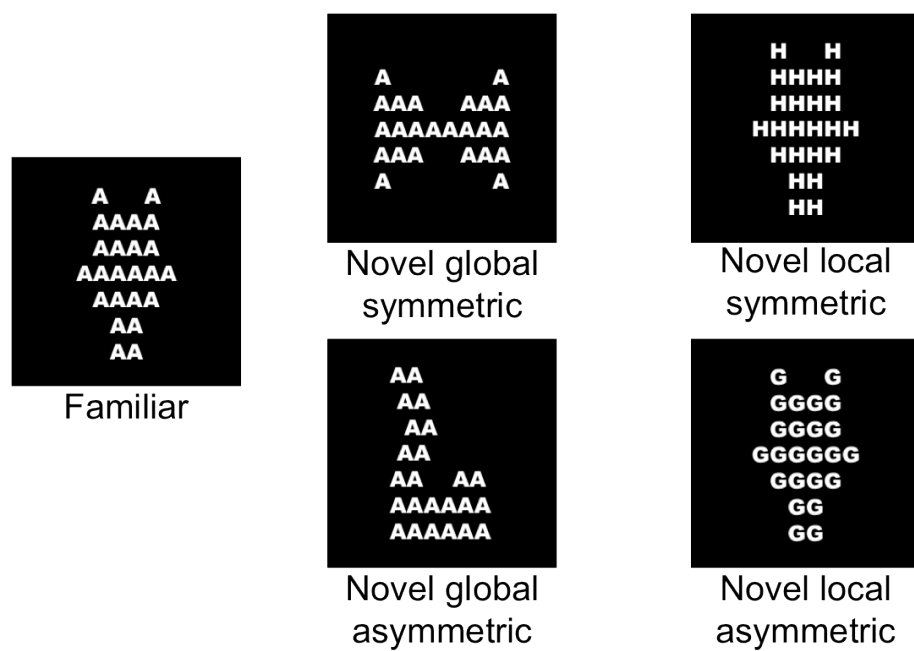
Figure 2: Sample stimuli in the symmetric familiarization condition
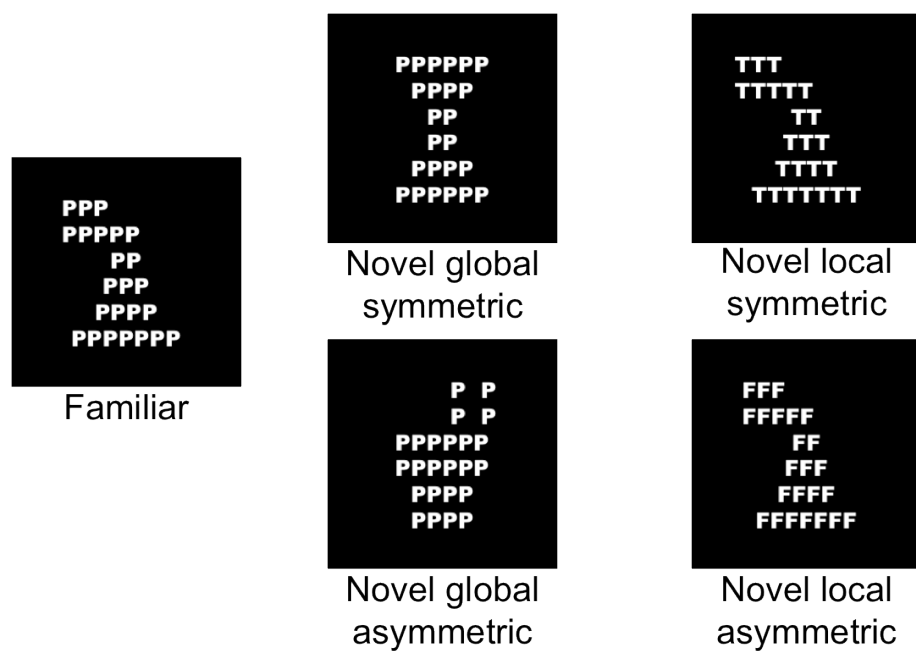
Figure 3: Sample stimuli in the asymmetric familiarization condition
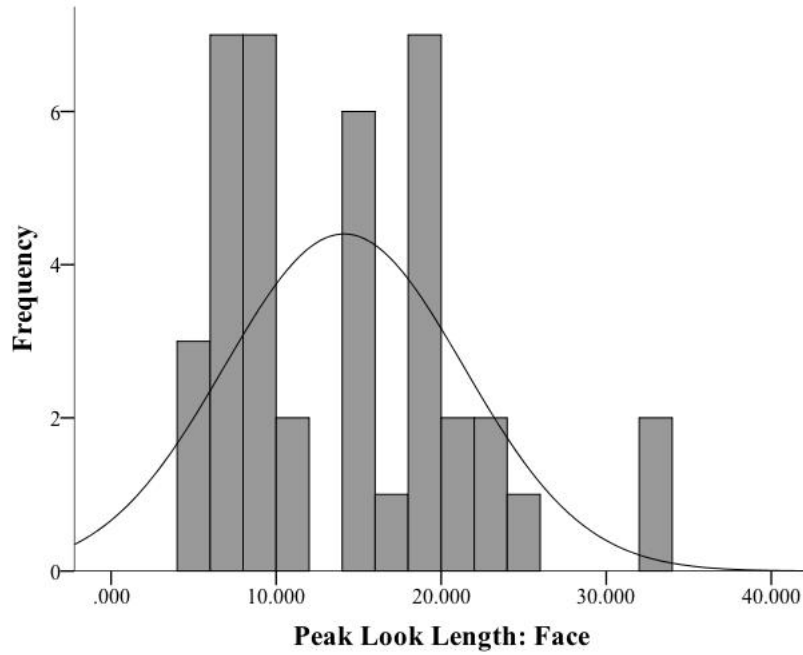
Figure 4. Frequency distribution of peak look lengths during familiarization with the photograph of a female face plotted against the normal curve
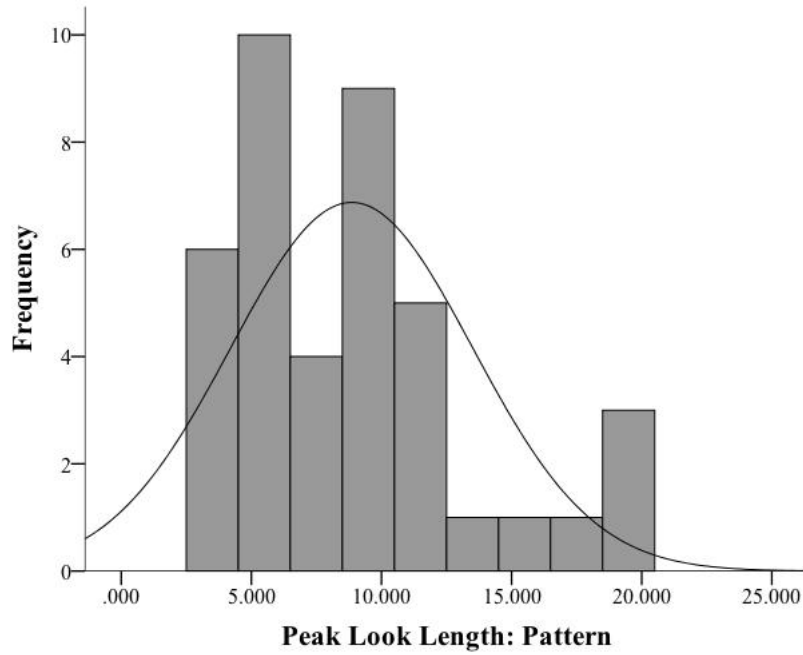
Figure 5. Frequency distribution of peak look lengths during familiarization with a geometric

pattern plotted against the normal curve
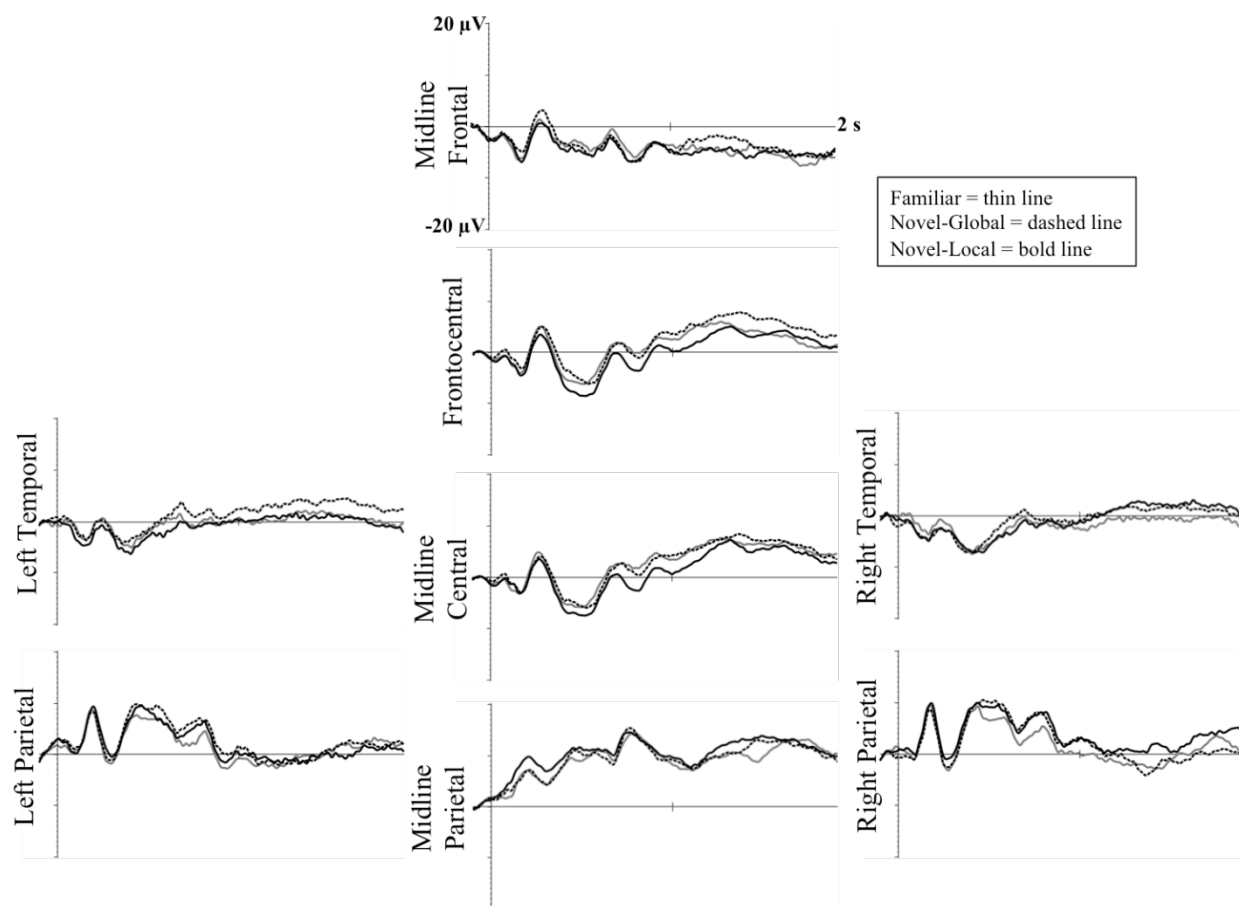
Figure 6: ERP grand average waveforms comparing responses to familiar, novel global, and novel local stimuli
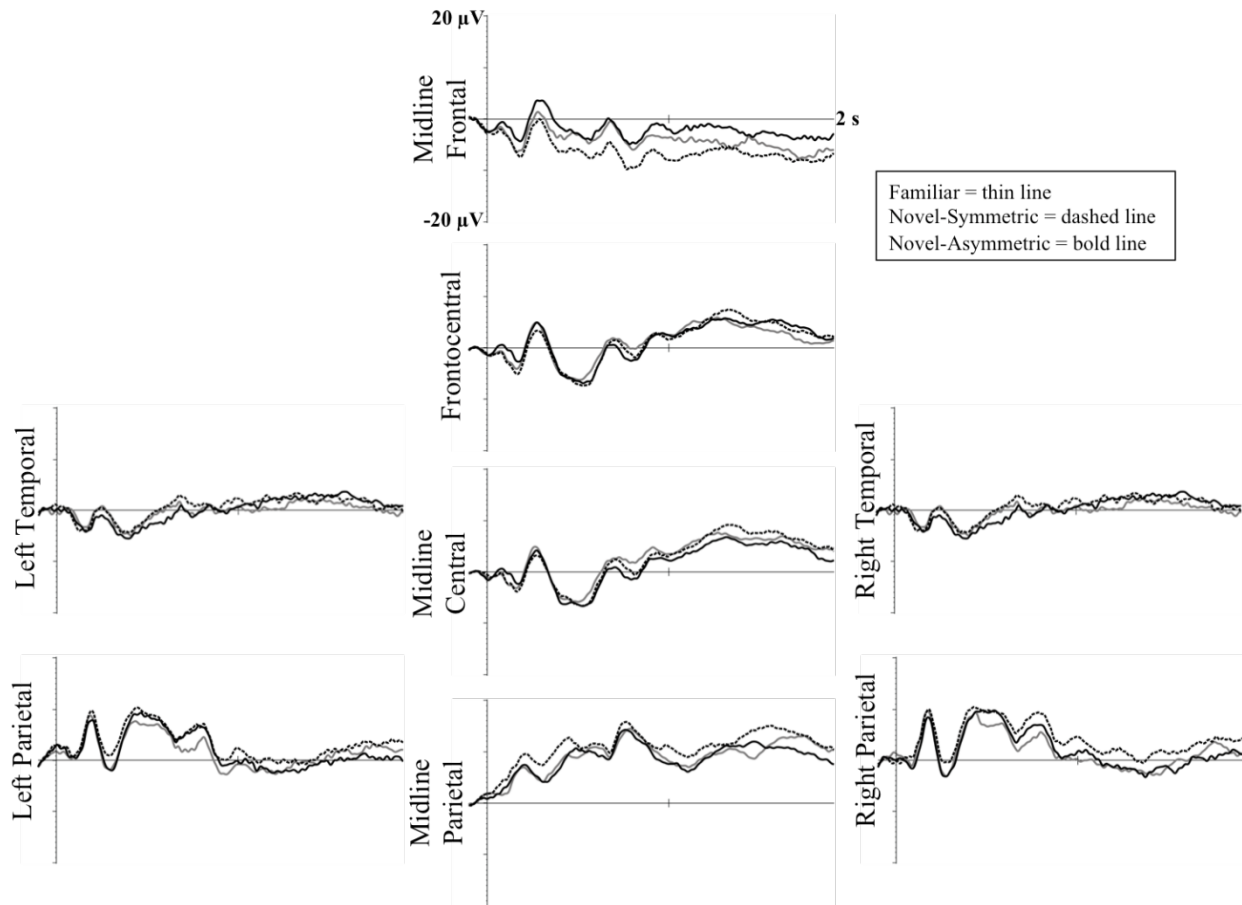
Figure 7: ERP grand average waveforms comparing responses to familiar, novel symmetric, and novel asymmetric stimuli
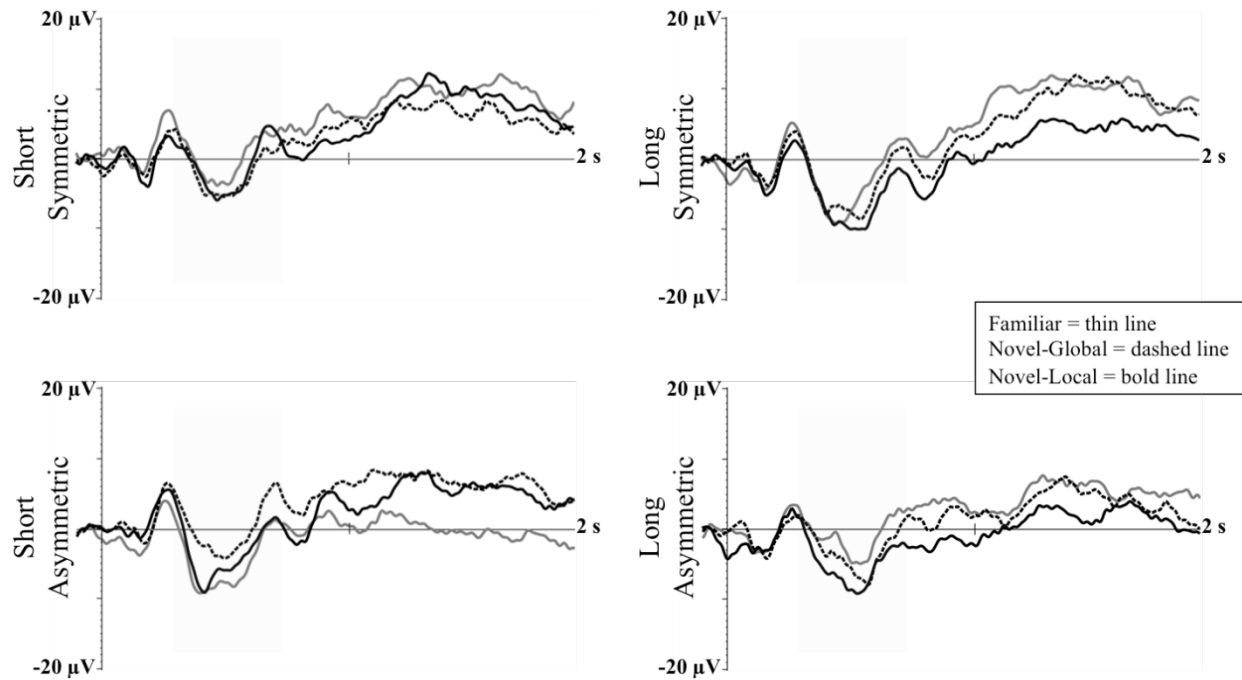
Figure 8: Nc familiarization condition by looker type by stimulus type interaction at midline

central electrodes comparing responses to familiar, novel global, and novel local stimuli
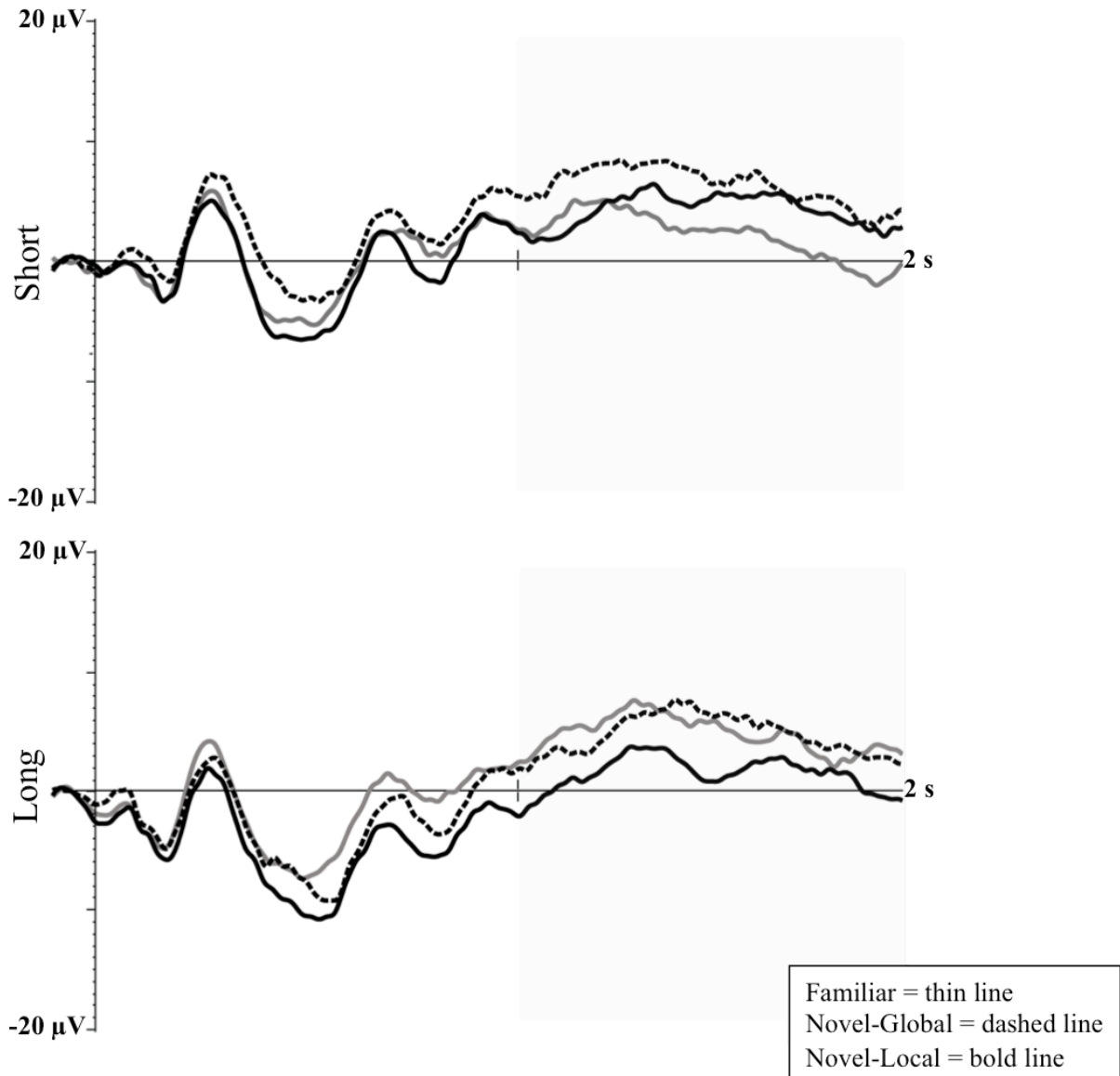
Figure 9: LSW looker type by stimulus type interaction at frontal-central electrodes comparing responses to familiar, novel global, and novel local stimuli
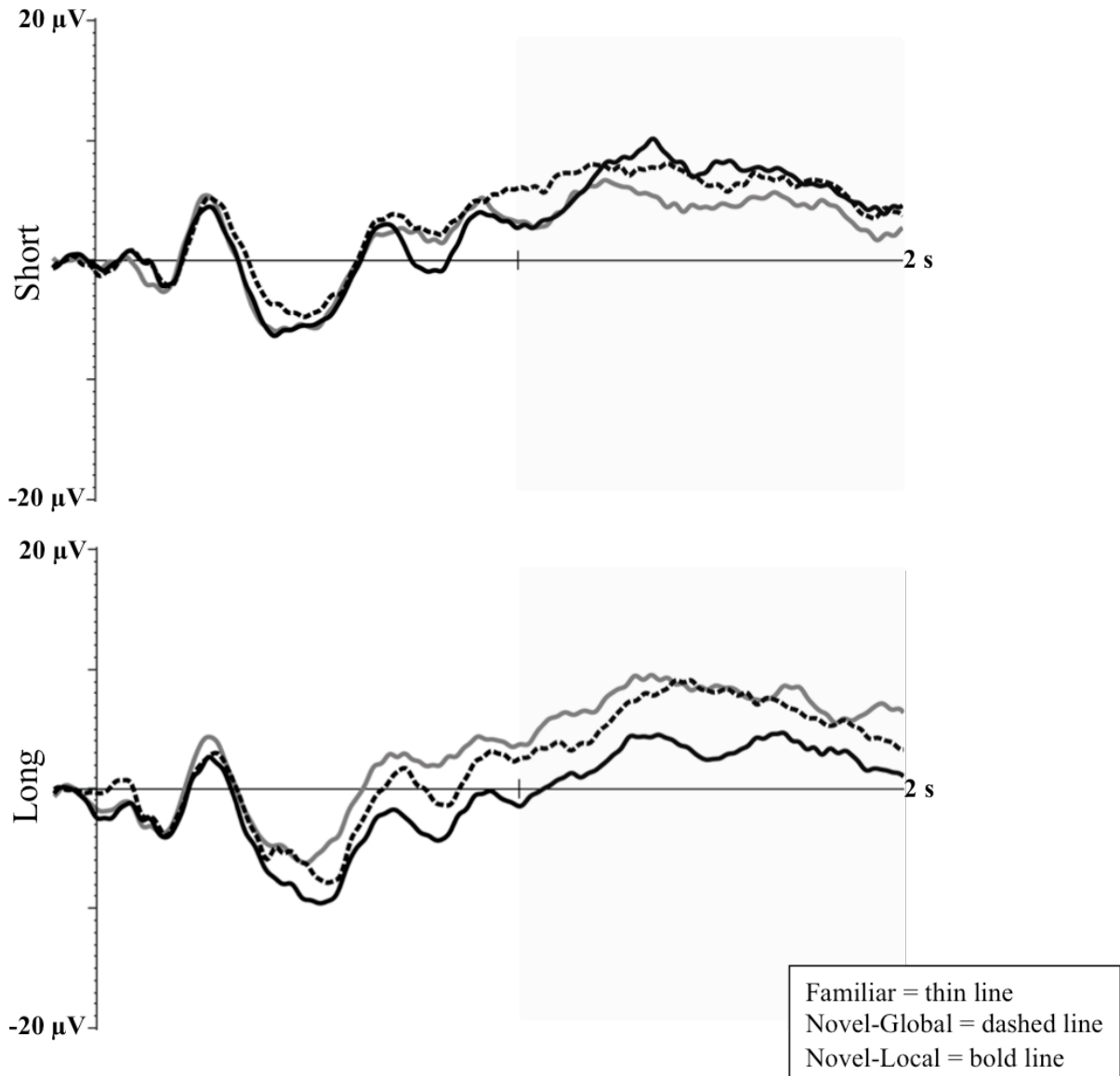
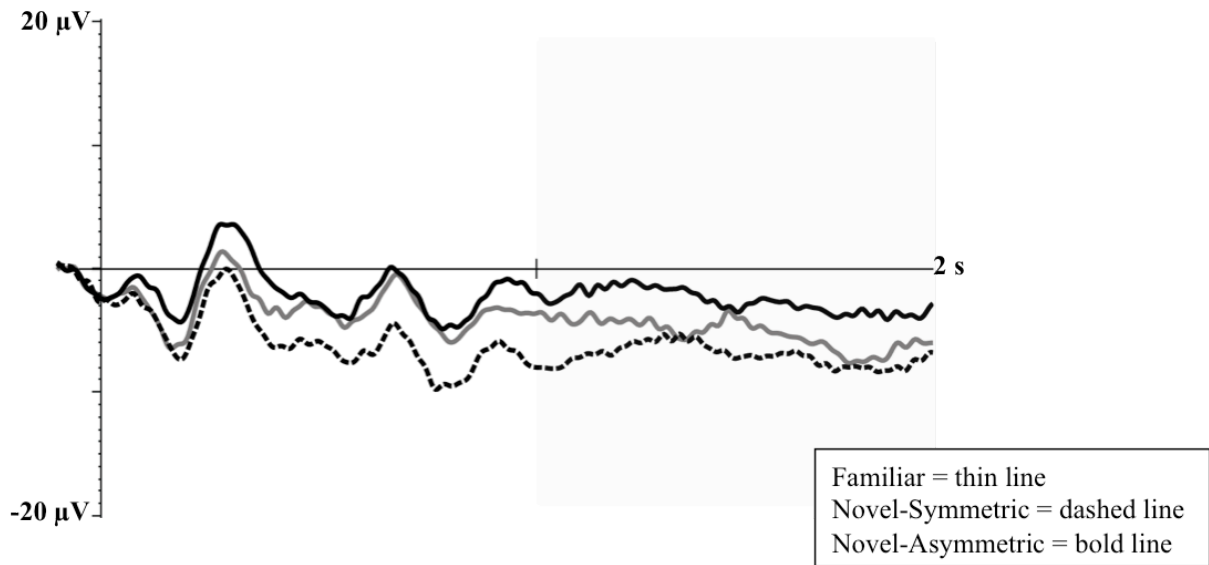Figure 10: LSW looker type by stimulus type interaction at midline central electrodes comparing responses to familiar, novel global, and novel local stimuli
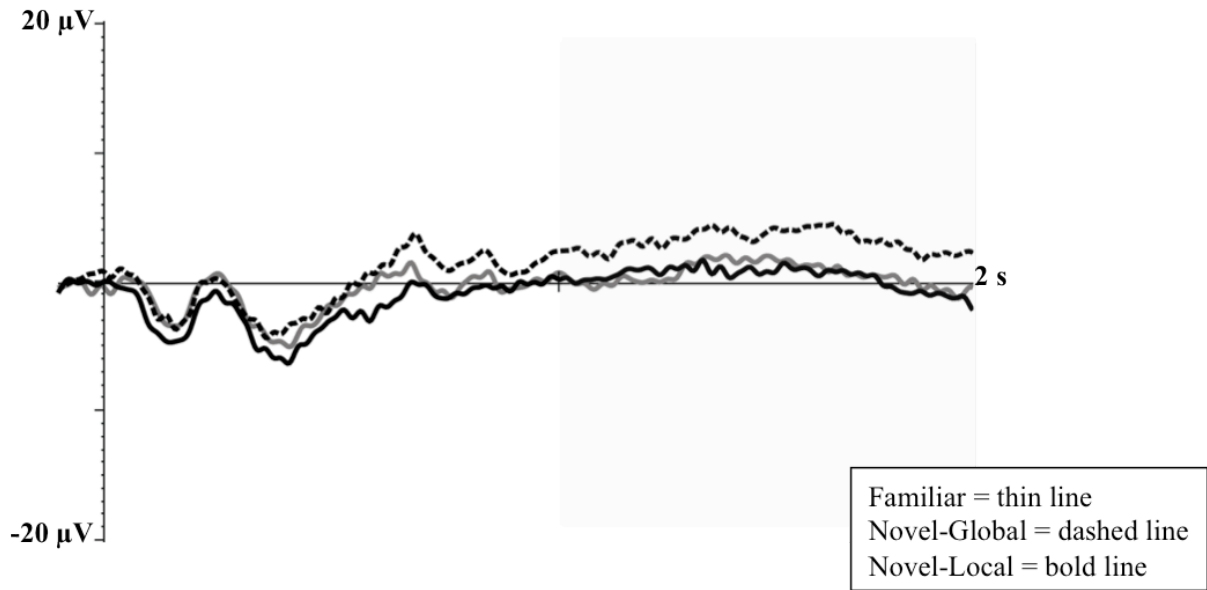
Figure 11: LSW stimulus type main effect at left temporal electrodes comparing responses to familiar, novel global, and novel local stimuli
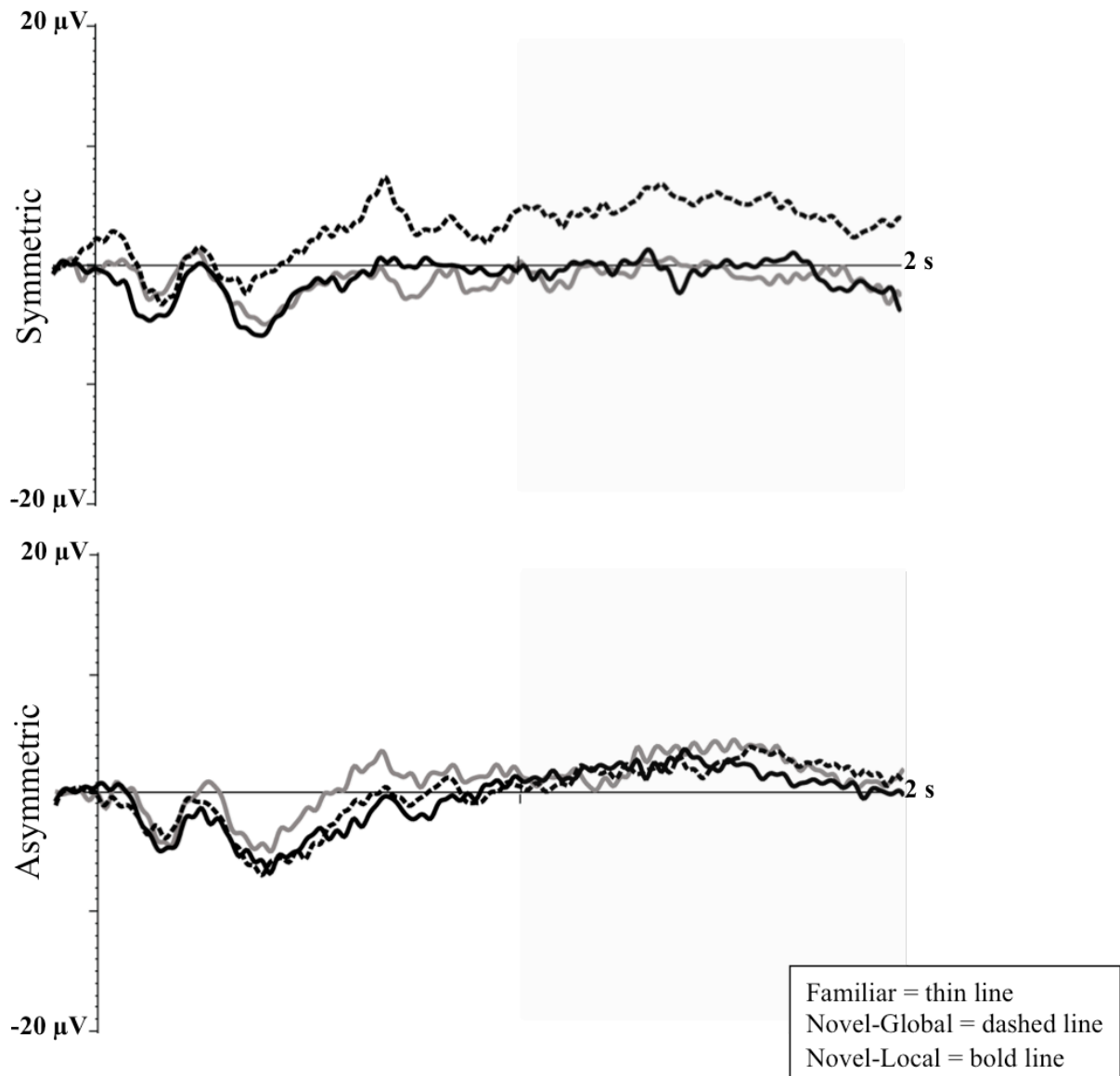
Figure 12: Marginally significant familiarization condition by stimulus type LSW interaction at

left temporal electrodes comparing responses to familiar, novel global, and novel local stimuli

Figure 13: LSW stimulus type main effect at midline frontal electrodes comparing responses to familiar, novel symmetric, and novel asymmetric stimuli
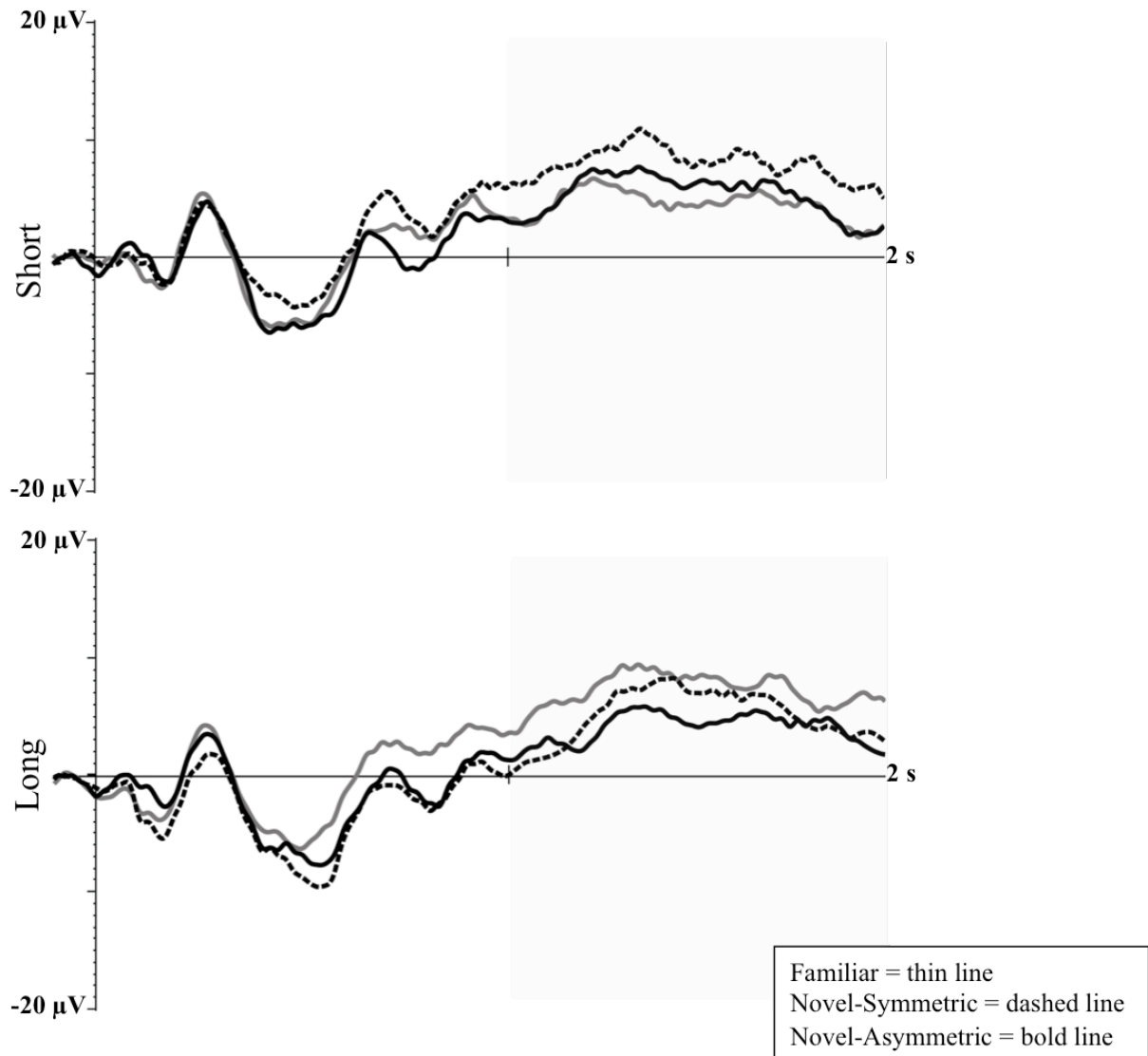
Figure 14: Marginal looker type by stimulus type LSW interaction at midline central electrodes comparing responses to familiar, novel symmetric, and novel asymmetric stimuli
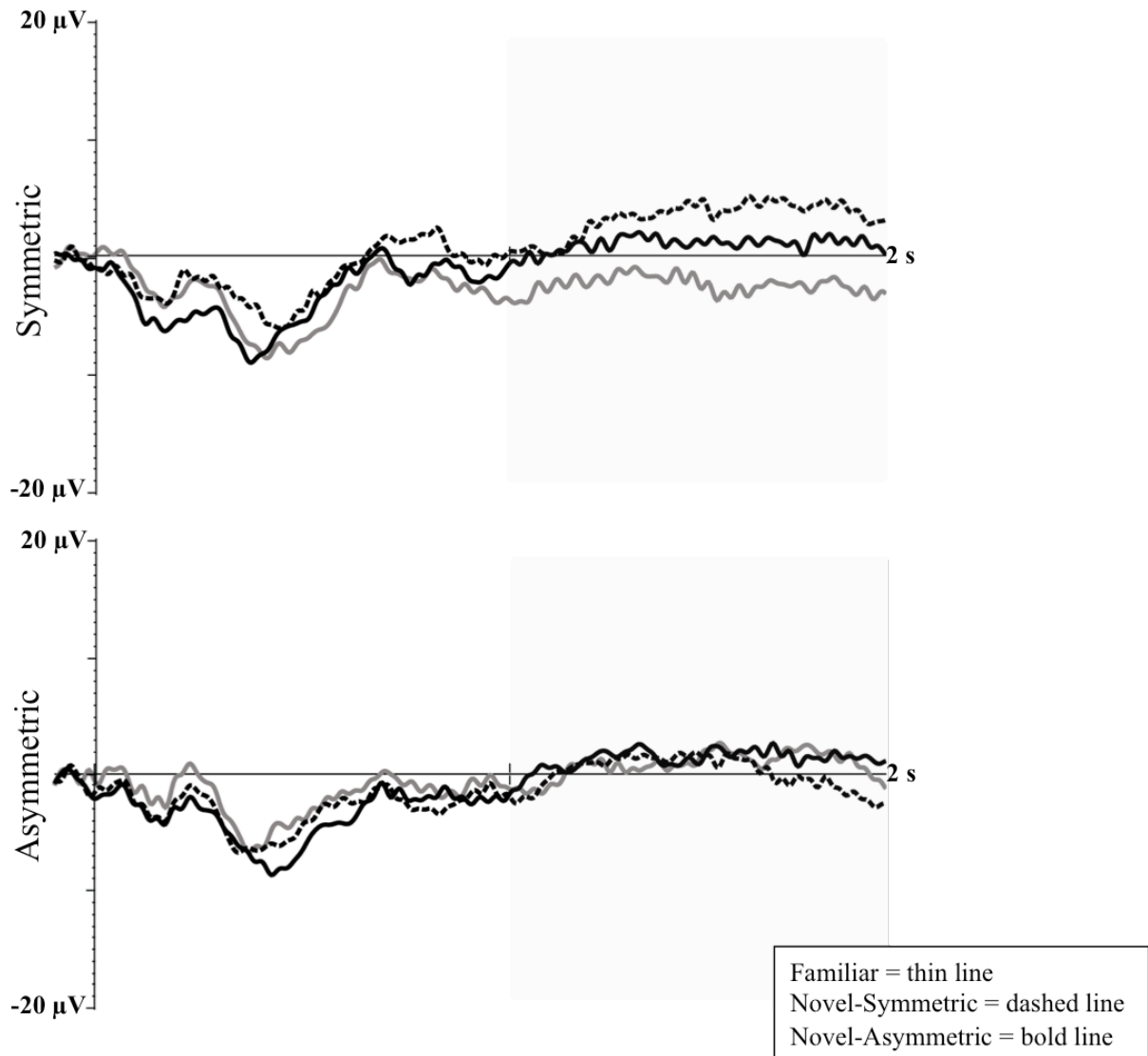
Figure 15: LSW familiarization condition by stimulus type interaction at right temporal electrodes comparing responses to familiar, novel symmetric, and novel asymmetric stimuli
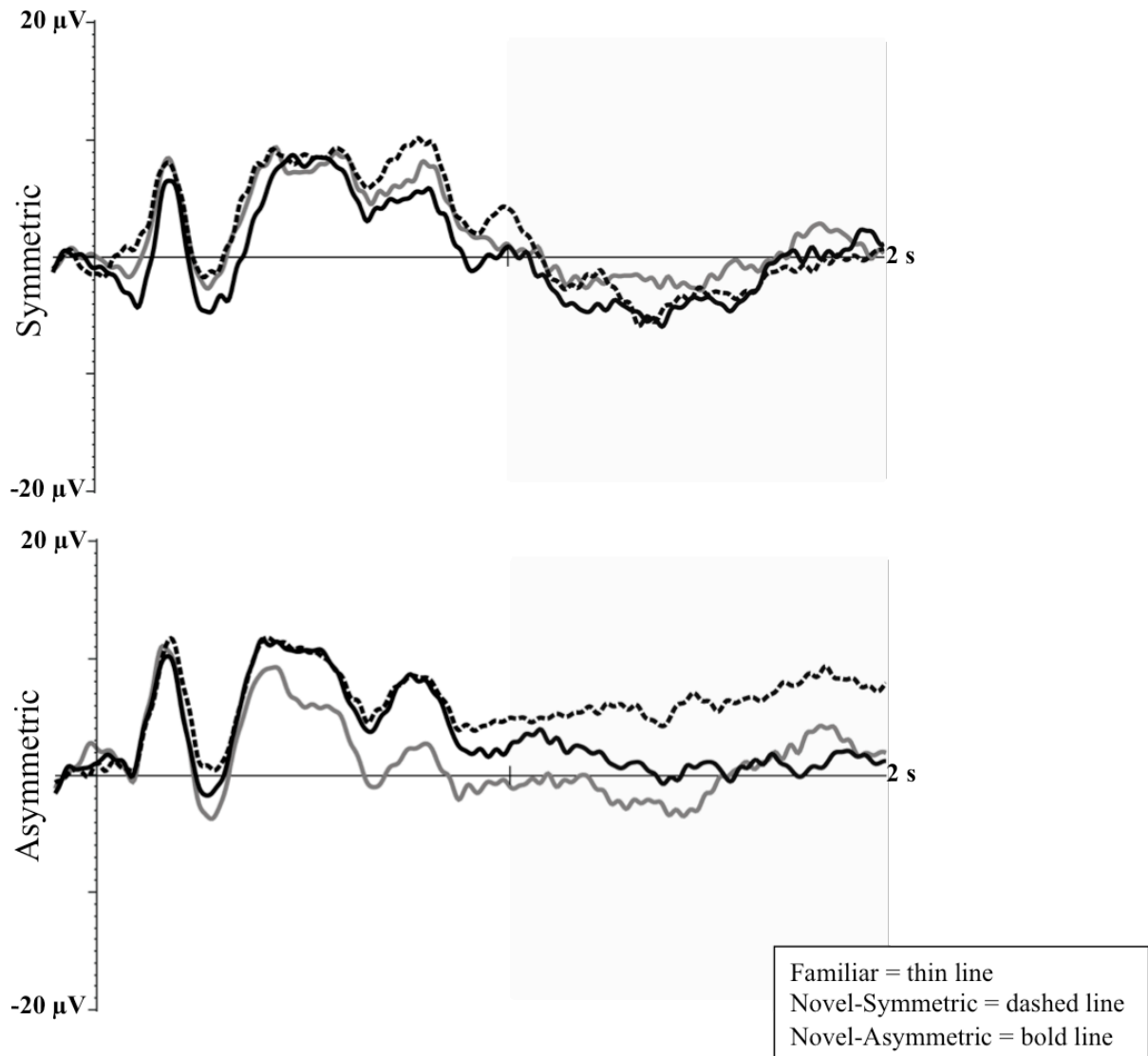
Figure 16: LSW familiarization condition by stimulus type effects at right parietal electrodes

comparing responses to familiar, novel symmetric, and novel asymmetric stimuli

Vita

Margaret Guy was born in Cincinnati, Ohio on November 10, 1984. She graduated from the University of Cincinnati in 2007 with her Bachelor of Arts degree in Psychology. After spending a year working with youth at an inpatient psychiatric facility, Margaret began working towards her doctoral degree in Experimental Psychology, with a focus on development, at the University of Tennessee.