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Sara M. Mosteller
University of Tennessee - Knoxville, smostell@vols.utk.edu

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I am submitting herewith a thesis written by Sara M. Mosteller entitled "The Effect of Local Element Density on Processing of Visual Hierarchical Patterns: An Infant ERP Study." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Arts, with a major in Psychology.

Gregory D. Reynolds, Major Professor

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Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

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The Effect of Local Element Density on Processing of Visual Hierarchical Patterns: An Infant ERP Study

A Thesis Presented for the
Master of Arts
Degree
The University of Tennessee, Knoxville

Sara M. Mosteller
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Abstract

Previous research with infants, children, and adults has shown that global, or configural, information is processed before local, or featural, information in high density visual hierarchical patterns (Freeseman, Colombo, & Coldren, 1993; Ghim & Eimas, 1988; Kimchi, 1988; Navon, 1981; Navon, 1977). The current study used event-related potential to determine if a well documented bias toward global processing in infancy can be disrupted when the number and density of local elements is reduced through increasing the distance between elements. Infant responses were compared between high and low density conditions to global and local novel patterns and to familiar patterns. A significant interaction was found between stimulus type and stimulus density in the Late Slow Wave component. The findings are consistent with previous research which shows that infants process high density visual patterns at the global level, and also indicate that infants fail to effectively process either global or local information in low density hierarchical patterns.

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1. Introduction

The Gestalt principle of holism, or holistic processing, has been used in research to describe the configural, or global property of a stimulus (Wagemans et. al., 2012). This concept is consistent with a theory of holistic processing in which configural properties are processed initially and independently of local elements. In contrast to the Gestalt paradigm, constructivist theories explain holistic processing as selectively directed attention to the highest possible level of information evident in the stimulus. According to the constructivist model, perception of the configural stimulus property is built up from integration of features, but selective attention is then typically directed to the configural level (Cohen, Chaput & Cashon, 2002).

Gestalt principles of organization have been used to predict how infants group elements, based on proximity, into a coherent pattern (Quinn, Bhatt & Hayden, 2008). Hierarchical processing as a model for feature integration has been used to predict how infants process faces (Cohen & Cashon, 2001), and interpret cause and effect relationships (Cohen et. al., 2002). This research suggests that knowledge of basic mechanisms of hierarchical processing can also inform the general approaches infants may take to make sense of their visual environment. Studying hierarchical processing in infancy also enables one to examine fundamental mechanisms of attention on a very basic level, as infants have little previous experience which might influence how they perceive the organization of visual stimuli. In addition, previous research has shown that individuals with certain developmental disorders, including autism, utilize different processing strategies from the general population when presented with hierarchical visual patterns (Bolte, Holtmann, Poustka, Scheurich & Schmidt, 2006). This indicates that basic research in hierarchical processing may eventually inform clinicians of differences in how typically and atypically developing infants process complex visual information.

The current study examines how the number and spacing of featural information may impact processing at a configural level in typically developing infants. Specifically, the current study seeks to understand whether the most advantageous processing strategy can vary based on characteristics of the stimulus. This includes the possibility that it is most advantageous to process at the configural level of high density patterns, and at the featural level of low density patterns.

Global precedence

Consistent with both Gestalt and Constructivist paradigms, previous research in hierarchical processing of visual stimuli has largely shown that adults, children and infants older than 2 months are initially biased toward the global, as opposed to the local, level (Freeseman, Colombo, & Coldren, 1993; Ghim & Eimas, 1988; Kimchi, 1988; Navon, 1981; Navon, 1977). The global level of a hierarchical stimulus refers to the configural shape of a complex pattern, and the local level refers to the components that make up the pattern. When the shapes of the global and local levels of a stimulus are both identifiable, then selective attention is initially directed toward one level, temporarily suppressing processing of the other level. An initial bias toward the global stimulus level has been demonstrated across both visual and auditory modalities (Bouvet, Rousset, Valdois, & Donnadieu, 2011).

Navon (1977) used configural letter shapes made of smaller letters to test whether selective attention was initially directed toward the global or local stimulus level. In a series of studies, participants were shown a configural letter shape made up of smaller letter shapes. The global and local letter shapes were either identical or incongruent. Participants were asked to attend to either the global or the local level of the pattern. The global letter shape interfered with participants' ability to determine the local letter shape, but the local letter shape did not interfere with processing of the configural shape in the reverse task. It was concluded that processing of global stimulus characteristics preceded processing of features. This bias toward the global level can be explained by the Global Precedence Hypothesis. Global precedence can be described as a sequence of processing in which configural properties of a stimulus are processed before the fine details. Processing of the configural pattern, according to Navon (1981), falls between an initial perception of a figure or object against a background, and processing the fine details of the figure. Kimchi (2005) found that global precedence is strengthened with age, increasing from early childhood throughout adolescence.

Few element patterns and global-local biases

Martin (1979) conducted a follow up study in response to the global precedence effect discovered by Navon (1977), to demonstrate that neither a set sequence of processing in which global features always precedes processing of local features, nor a sequence in which configural features are always perceptually constructed from local elements, accounts for perceptual biases in all conditions. When participants were presented with configural patterns composed of 20 elements, adults took longer to process the local letter shapes. On the other hand, when they were presented with patterns which contained 11-12 elements, adults took longer to process the configural letter shape. In response to this finding, Navon (1983) found that global precedence is contingent upon the number of elements comprising a configuration only in certain cases. Participants were shown triangular and rectangular configurations comprised of smaller rectangles or triangles. Navon found that, when shown rectangular patterns made up of fewer elements, participants demonstrated a global bias regardless of the number and spacing of elements, whereas triangular patterns tended to be more reliant on density and element size.

Overall, he concluded that global precedence remains intact despite some variability in processing strategy with certain shapes.

On the other hand, Kimchi (1992) proposed that global precedence occurs in many element patterns, but not few element patterns, because elements of many element patterns are viewed as texture, indifferentiable from the whole, while elements of few element patterns are perceptually separable from the configuration. This explanation indicates that Gestalt grouping principles may be limited to many element patterns. Kimchi (1990) conducted a study in which preschool, first and third grade students were shown disproportionally enlarged triangular and rectangular patterns, in which the size of the local elements was maintained (identical texture), and proportionally enlarged patterns for which the number of local elements was not changed, but the size of the local elements was enlarged (identical spatial relationships between elements). Kimchi found that all age groups demonstrated a shift in differentiating the spatial relationships between the local elements of the configuration as the number of elements reached 9 or greater.

While most research conducted with few element patterns has found effects through enlarging the local elements, texture perceived in many element patterns has also been manipulated by increasing the distance between local elements, creating few element patterns with reduced density. In healthy adult populations, most evidence suggests that increasing the distance between local elements does not necessarily result in a local bias. This result is different from studies in which the local elements are enlarged. Navon (1983) found that sparse patterns elicited slower reaction times than dense patterns, but that a global bias still remained in adults. Kimchi (1988) also found that larger local elements were more salient than smaller elements in few element patterns, indicating that size does facilitate a shift toward processing at the local level in few element patterns. Montoro and Luna (2009) explored the relationship between interelement distance and global precedence, compared with heterogeniety of spacing, and found that inter-element distance did not reverse global precedence in healthy adults, while heterogeneity of element size and spacing did.

Studies with animals, clinical populations, and young children have shown that inter-element spacing, without manipulation of the size of the local elements, can affect a global bias in certain populations. Spinozzi, Truppa, & Lilla (2003), found that increasing the distance between local elements reinforced an already present local bias in Capuchin monkeys. In the sparse stimulus condition, the monkeys were impaired in their ability to recognize the configural pattern. It should be noted, however, that the reason for this impairment probably resulted from the monkeys' not being able to integrate the local elements into a configural shape. The results of this study could potentially support an information processing explanation of the initial global bias in which perception of the global form is constructed from the local elements (Cohen et. al, 2002) , and suggest that increased element spacing could increase the difficulty of perceiving the global configuration.

Montero, Luna, and Humphreys (2011) found that increased stimulus density and connectedness of hierarchical triangular and rectangular shapes both facilitated global processing in patients with simultanagnosia. Simultanagnosia is described by the authors as a neurological condition, typically caused by bilateral parieto-occipital damage, in which single elements can be processed individually, but multiple elements cannot be processed simultaneously. As the distance between local elements was increased by decreasing the number of local elements from 24 to 8, the patient became impaired in his/her ability to recognize the configural pattern. However, this effect was decreased when a line was drawn to connect the local elements, creating the appearance of continuity which was broken by inter-element spacing. For control subjects, accuracy of rapid responses was greater in the sparse condition, presumably because of the lack of global interference when local stimuli were attended. The results of this study suggest that stimulus density and connectedness could enhance global precedence and increase the global interference observed in studies with many element patterns.

Dukette and Stiles (2001) increased the distance between local elements of hierarchical letter stimuli by reducing the number of elements and retaining the element size. The standard stimuli contained approximately 19 elements and were arranged in a 5x7 matrix, and the sparse stimuli contained approximately 11 elements and were arranged in a 3x5 matrix. The dense and sparse stimuli were presented to children ages 4 to 8 and adults, and participants were then asked to copy the stimulus. A condition in which participants copied the stimulus, not from memory, served as a control. The low-density configural pattern disrupted 4 to 5 year old childrens' representation of the configural, but not the component, letter shapes, relative to the other age groups. The authors concluded that manipulation of stimulus density disrupted younger childrens' memory for the global configuration relative to older children and adults. However, the study did not control for the facility older children would be expected to demonstrate with letter shapes, based on experience. Collectively, the findings of these studies indicate that, consistent with a constructivist model of attention, configural processing may occur through integration of local features, and that this process may be disrupted through manipulating the density of local elements.

Infant research in hierarchical processing

Previous research in infant visual processing has utilized hierarchical letter stimuli to detect selective attention to global and local stimulus features (Colombo, Freeseman, Coldren, & Frick, 1995; Colombo, Mitchell, Coldren, & Freeseman, 1991; Freeseman, Colombo, & Coldren, 1993; Ghim & Eimas, 1988). Rather than relying on reaction time to discrimination of global and local features, previous infant studies have utilized a novelty discrimination paradigm. After being familiarized with a stimulus, infants are shown presentations of the novel stimulus, as well as stimuli with changes to the configuration (novel global), and stimuli with changes to the local elements (novel local). Differential responses to the novel stimuli based on global or local changes are observed, including look duration in a paired comparison task, (Colombo et al., 1995; Colombo et al., 1991; Freeseman et al., 1993; Ghim & Eimas, 1988), and differential responding in ERP waveforms (Guy, Reynolds, & Zhang, 2013).

The global precedence effect has been observed through an initial preferential responding to novel global stimuli in newborn infants (Cassia, Simion, Mulani, & Umilta, 2002), in 3 and 4 month old infants (Colombo et al., 1995; Colombo et al., 1991; Freeseman et al., 1993; Frick, Colombo & Allen, 2000; Ghim & Eimas, 1988), and in 6 month old infants (Guy, et al., 2013). However, all research to date examining global precedence in infancy has used hierarchical patterns containing 13 or more elements, with the exception of the Cassia et al. (2002) study, which found global precedence in newborns with patterns containing eight elements. In the experiments included in the study (Cassia et al., 2002), infants were shown diamond or cross shaped configural patterns composed of diamond or cross shaped local elements. In a follow up study, the authors failed to find this precedence when spatial frequency of the local elements was controlled (the local elements were represented by a contour but not “filled in”). An alternative explanation of the findings of this study are that newborns detected configural changes on the basis of greater sensitivity to low spatial frequency or featural changes such as the rotation of segments of the configuration. However, Cassia et al. (2002) also state that these same sensory biases are present in adults, and that newborns and adults possess similar inherent perceptual biases.

Research examining hierarchical pattern processing in infancy has been unclear as to whether bias toward the global stimulus level differs based on individual differences in individual attention, which is assessed by peak look duration. Briefer look durations in infancy are associated with greater control of shifts in visual fixation, and with greater processing efficiency (Colombo et al., 1991). It is suggested by Colombo (2001) that the ability to visually scan and integrate features of an object develops with age during early to mid infancy. However, it is possible that individual differences in looking behavior reflect differential rates of development related to control over visual fixation.

Colombo and colleagues (1991) tested the hypothesis that looking behavior influences processing bias, specifically, if short lookers initially processed hierarchical stimuli at the global level, whereas long lookers processed at the local level. Four month old infants were tested with hierarchical shapes made up of letters. The results of this study showed that short lookers discriminated the global stimulus level following 15 seconds of familiarization, and the local stimulus level following 30 seconds. Long lookers discriminated the global stimulus level after 30 seconds of familiarization, and the local level after 45 seconds. Freeseman and colleagues (1993) examined the global precedence effect with briefer familiarization times and found that short lookers demonstrated a global precedence after 10 seconds of familiarization time, and shifted to a local precedence with twenty to 30 seconds. Long lookers did not demonstrate evidence of discrimination of the novel global stimulus level until they had reached 40 seconds of familiarization. For this study and for the Colombo and colleagues (1995) study, infants were shown configural patterns in the shape of a diamond or an hourglass, and local components were

N or Z letter shapes. The configurations were composed of 13 elements. The spacing between local elements was not specified.

Frick, Colombo and Allen (2000) manipulated familiarization times with 3 month old infants in order to assess how short and long lookers shift from a global to local bias. They found that, with 30 seconds of familiarization, short looking infants demonstrated a preference for familiar and novel local stimuli, whereas with 20 seconds of familiarization, short looking infants demonstrated a preference for novel global stimuli. Long looking infants demonstrated a preference toward novel global stimuli after 30 seconds, and no preference after 20 seconds of familiarization. After reaching 60 seconds of familiarization, short looking and long looking infants were able to discriminate both global and local stimulus properties. The authors concluded that, following 20 seconds of familiarization, short looking infants processed the global stimulus level and failed to discriminate the local level. At 30 seconds, the infants began to process local stimulus features and also demonstrated a familiarity preference as they became sensitive to the local level. Likewise, long lookers first discriminated the global stimulus level, and after 60 seconds of familiarization demonstrated recognition of both global and local stimulus features.

Much previous research in infant hierarchical processing indicates that infants typically prefer to process hierarchical stimuli at the global level. Processing in infancy occurs in a predictable sequence, with the global stimulus level attended to first, followed by the local level. A current model of hierarchical processing speculates that the featural stimulus level is suppressed as the configural level is processed, and then processing shifts to the local level and configural processing is inhibited (Cohen et. al., 2002). The findings of Frick and colleagues

(2000) indicate that, following independent processing of the global and local stimulus levels, infants demonstrate flexibility in recognizing both types of novelty.

An alternative perspective on infant hierarchical processing is the view that infants can be biased toward processing and discriminating the local stimulus level, based on looking behavior (Colombo et al., 1995, Guy et al., 2013). Colombo and colleagues (1995), found qualitative differences between long looking and short looking 4-month-old infants. Short lookers processed global features of hierarchical letter stimuli before local features. Short looking infants discriminated global changes with twenty seconds of familiarization time, and local changes with forty seconds of familiarization. The short lookers were able to discriminate both global and local features in the minimum amount of time given for each task, while the performance of long lookers varied and a local bias was not achieved until 60 seconds of familiarization time. Long lookers did not show any evidence of global processing in this study. The findings suggest that global-to-local processing may be a condition of individual looking behavior rather than a fundamental strategy in infancy.

In addition to looking behavior, the characteristics of visual stimuli could reduce infants' ability to process at a global level. Palomares, Pettet, Vildavski, Hou and Norcia (2010) used visual evoked potentials to test adults' and infants' ability to discriminate contours based on dot and line arrangement in abstract visual patterns. In the first study, 4 to 5.5 month old infants were shown line and dot arrangements which alternated every 500 ms, with 50 ms separating the presentations. The orientation of lines or the collective direction of dots in each pattern were either horizontal or random. Unlike adults, infants were only sensitive to changes in the orientation of line patterns, from which they could gain orientation cues from the local elements. They were unable to discriminate the orientation of static dot patterns based on their collective arrangement. In a follow up experiment, the authors tested infants again with varied density in line and dot collections which formed a circular or horizontal pattern. Trials lasted for 10 seconds of accumulated look time to the stimulus. Sensitivity to the configural pattern increased as infants were shown higher density patterns in which the elements were spaced more closely, for both lines and dots. The results of this study suggest that, like adults, infants become increasingly more sensitive to the configural properties of hierarchical patterns as the elements are spaced more closely. Unlike adults, infants are unable to process at a configural level when presented with low density patterns. However, the study examined the spectral breakdown in EEG data at occipital electrodes. This indicates that the authors were primarily interested in sensory responses to the visual patterns, rather than responses associated with cognitive processes. Their measures were limited in terms of informing the more general cognitive mechanisms involved in integration of local elements into a configural pattern.

Methods of infant ERP

ERP analysis is used to isolate voltage fluctuations in the EEG created by automatic responses to an event (exogenous potentials) or mental processes (endogenous potentials, Picton et al., 2000). Because changes in voltage potential from a specific site on the scalp can be measured in milliseconds, temporal resolution is considered a strength of the ERP method. The signal-to-noise ratio is low in a single ERP trial, so repeated trials that are time-locked to the onset of a stimulus presentation must be averaged together in order to observe the event related changes (Picton et al., 2000; Reynolds, Courage, & Richards, 2010). ERP averages can show changes in the EEG which take place while the stimulus is being processed.

In infant ERP analyses, the Nc (negative central) component is defined as a negative-going peak in the waveform. The peak occurs between 350-750 ms (or 400-800ms) after the onset of the stimulus (Reynolds, Courage, & Richards, 2010; Reynolds & Richards, 2005), and is primarily seen over frontal (Courchesne, Gantz & Norcia, 1981; Reynolds & Richards, 2005) and central (Reynolds & Richards, 2005) electrode sites. The Nc component has been associated with attentional engagement to a visual stimulus, and a general orienting response (Courchesne et al., 1981; de Haan & Nelson, 1997; Reynolds & Richards, 2005). Increased (negative) amplitude of the Nc component has been shown to reflect a response to stimulus novelty (de Haan & Nelson, 1997; Reynolds, Courage, & Richards 2010; Reynolds & Richards, 2005). Nc has previously been localized to an area of the cortex involved in attentional orienting and engagement, including the anterior cingulate gyrus (Reynolds et al., 2010; Reynolds & Richards, 2005).

The Late Slow Wave occurs between 1000-2000 ms after the onset of the stimulus presentation (de Haan & Nelson, 1997). Reduced amplitude in the LSW is also thought to reflect recognition memory of a familiar stimulus, as compared with a novel stimulus (de Haan, 2007; de Haan & Nelson, 1997; Reynolds & Richards, 2005). Lower amplitude of the LSW specifically indicates that the familiar stimulus has been previously processed. This contrasts with the response to novel stimuli, which is more robust.

The current study

Guy and colleagues (2013), examined individual differences in 6-month-old infants in an ERP and look duration study, using a novelty detection paradigm with familiar, novel local, and novel global hierarchical letter stimuli. This study was designed to provide greater insight into the cognitive mechanisms underlying previous findings, which had shown individual differences in infant visual processing by examining LSW responses to novel vs familiar objects (Reynolds, Guy & Zhang, 2011). Infants were shown brief presentations of configural shapes composed of letters. Each configuration was composed of 24 elements. The authors found a global precedence effect in the grand averaged ERP waveform with 20 seconds of familiarization. However, an analysis of the ERP waveform by looker type showed that the effect was driven entirely by short lookers, who showed increased Nc amplitude to novel global stimuli compared with novel local and familiar stimuli, and a reduced LSW amplitude at midline frontal and central electrode sites to familiar and novel local, but not novel global, stimuli. Long lookers showed evidence of a local bias in processing in the LSW analysis at parietal sites. This result was consistent with the findings of Colombo and colleagues (2005), who found that long lookers can demonstrate a local bias. The findings of this study show that the relative salience of global vs. local stimulus features can be observed in ERPs, and that infants process many element patterns arranged in relatively dense configurations at a global level. The current study sought to determine if lack of stimulus density in few element patterns could disrupt infants' ability to detect the configural pattern of hierarchical figures and/or increase the relative salience of the local elements.

The purpose of the proposed study was to investigate the effects of stimulus density on hierarchical visual processing in infancy. For the present study, I assessed Nc and LSW responses of 7.5-month-old infants to hierarchical letter stimuli in two density conditions. Following 20 seconds of familiarization, infants were shown brief presentations of the familiar stimulus, as well as novel global stimuli, in which the configural shape had been changed, but the familiar local elements comprised the configuration, and novel local stimuli, in which the local elements comprising the configuration had been changed, but no changes had been made to the configural shape. 7.5 months was selected as an age for the study so that processing strategy could be observed without the interference of the potential featural bias previously demonstrated by long lookers (Colombo et al., 1991, Colombo et al., 1995, Guy, et al., 2013). For the high density condition, it was predicted that a global bias would be observed, resulting in increased Nc amplitude to the novel global stimulus type compared with the novel local and familiar stimulus types, and reduced amplitude LSW following the familiar stimulus, compared with the novel global stimulus type. The increased Nc amplitude would demonstrate increased engagement toward the novel stimulus based on recognition of configural changes, and the reduced amplitude LSW to the familiar stimulus would indicate recognition memory for the familiar stimulus, compared with the novel global but not the novel local stimulus types. In the low density condition, it was predicted, consistent with the typical processing strategy adopted by adults and older children to few element patterns, that a local precedence would be observed through increased Nc amplitude to novel local stimuli, compared with familiar or novel global stimulus types in the few element condition. In the low density condition, a lack of bias (either global or local) could potentially be observed instead of a local bias, resulting in no significant differences in ERP responses between the novel global and novel local stimulus types. ERP results from the study should show if processing strategy of low density patterns qualitatively differs from that of high density patterns in infancy, and if processing of low density patterns during familiarization results in a bias toward local features.

2. Method

Participants

A sample of 39, 7.5-month-old infants were recruited from the surrounding area through mailers and recruitment calls. The criteria for accepting participants included that the baby was born full term (at least 38 weeks gestation), without complications and with normal birthweight. Eleven infants were retained in the high density condition, and 10 infants were retained in the low density condition. Two infants were omitted from the study based on experimenter error, and 15 infants were not included in the final data set due to fussiness and excessive artifact in the EEG data.

Apparatus

Infants were seated 55 cm away from a 27" LCD (Dell 2707) monitor, in a sound-attenuated room. A digital camcorder (Sony DHR HC28) was centered above the monitor and directly in front of the infant. Infant fixations were judged through an online video stream from the testing room to the adjacent experimental control room. Netstation software, produced by Electrical Geodesic Incorporated (EGI), was used to record the video and the synchronized EEG data.

Visual Stimuli

Patterned Stimuli: A familiarization stimulus and test stimuli were created of geometric patterns made of white letters on a black background. The configural patterns were composed of letter shapes, and the size of the local elements remained constant across conditions while the spacing between them varied. High density patterns were arranged in a 6x7 matrix single spaced, each containing 15 to 18 letter elements. Low density patterns were also arranged in a 6x7 matrix, double spaced, each containing 7 to 8 letter elements. Each infant was shown a familiar stimulus, as well as 14 to 15 novel global and 15 novel local stimuli. The patterned stimuli appeared on a thirty degree square in the center of the monitor.

Sesame Street characters: Video clips of Sesame Street characters were shown to infants as needed in order to redirect their attention to and fixation on the center of the screen. The Sesame Street stimulus appeared as a 15 degree square in the center of the monitor.

Procedure

Parents were first read and asked to sign an informed consent to the study while their infant was fitted for an EEG cap. Following their consent and payment, the infant was seated in front of the computer monitor. The EGI sensor net was applied and impedances to the electrodes measured. Two experimenters were present to apply the net. The first experimenter applied and adjusted the net. The second experimenter distracted the infant with a toy rattle during the application. On average, the application took about 5 minutes.

The experiment took place in 2 phases. In the first phase, infants accumulated 20 seconds of looking to the familiarization stimulus. The amount of familiarization time is consistent with previous literature demonstrating a global processing bias in younger infants (Colombo et al., 1995; Guy, et al, 2013). For participants in this study, familiarization time ranged from 15.196 s to 32.012 s for the high density group, (*M* = 21.096, *SD* = 5.596), and from 13.636 s to 29.688 s, (*M* = 20.667, *SD* = 5.785) for the low density group. Familiarization time was not included in the average for one infant in the low density group because the stimulus presentation was invisible in the video recording during the familiarization procedure. The familiarization stimulus was used as the familiar stimulus during the testing phase. The familiarization stimulus was a randomly selected geometric pattern from the test stimuli, and the familiarization stimulus varied across infants throughout the study. Six familiarization stimuli were used. In the second phase of the experiment, test stimuli were briefly presented for 500 ms. The amount of time following a stimulus presentation varied between 1.6-2 seconds. Test stimuli consisted of the familiar stimulus, novel global stimuli (for which the configural pattern had been changed but the local letter shapes were identical to the familiar stimulus) and novel local stimuli (for which the configural pattern remained consistent with the familiar stimulus but the local elements had been changed). Familiar, novel global, and novel local stimuli were presented in a pseudo-random order, with equal probability. The stimulus presentations were grouped into blocks of thirty. All stimuli, including the familiarization stimulus and novel stimuli, were single spaced (high density) or double spaced (low density), depending on the condition.

[Appendix A, Figure 1]

EEG was recorded during this final phase for later ERP analysis. Test stimuli were shown while the infant was visually fixated on the screen. Sesame Street clips were played when the infant became bored or fussy, until his/her attention had returned to the screen.

EEG recording and analysis

For recording EEG, the Electrical Geodesics Incorporated (EGI), Geodesic EEG 300 (GES 300) system was used. The system includes the Hydrocel Sensor Net, the NetAmps Hardware, and the NetStation recording system. The cap contains 124 out of 128 electrodes held in place by elastic bands. The electrodes are mounted on pedestals with electrolytic sponges. The cap was presoaked in a potassium chloride solution before being applied to the infant's head. The cap was positioned through referencing pedestals corresponding to the mastoid, nasion, and vertex, and the other 120 electrodes distributed in a Geodesic configuration over the scalp based on the elasticity of the net. The average distance between scalp electrodes was 21 mm. A video recording was used to determine where the infant was looking during experimental sessions.

When the net is properly applied, electrode impedances measure at 10-50 kΩ. The EGI system uses high-impedance amplifiers connected to a computer A/D card in a PowerPC-based computer system. A MAC OS program that comes with the EGI system conducted A/D sampling, data storage, calibration, and measure impedances. Stimulus onsets and marking of stimulus type were synchronized between computers in the control and testing rooms, through NetStation, so that the corresponding EEG could later be segmented for ERP analysis. The sampling rate of the EEG is about 250 Hz (4 ms samples) and band-pass filters were set from 0.3 to 30 Hz, with 20K amplification.

EEG data was prepared for analysis through removal of artifact (changes in the raw EEG greater than 250 μV), and poor recordings. Channels containing artifact were marked and replaced using a bad channel replacement algorithm. In order for the data for each participant to be analyzed, 8 artifact-free trials for each stimulus type must have been obtained. Trials looked at for the ERP average began 100 ms prior to the onset of a stimulus (this period of time served as a baseline), through 1.5 seconds following the stimulus onset. ERP averages were created to examine the Nc and LSW responses. The components were examined based on the mean data from grouped clusters of electrodes. The Nc response was examined over midline frontal and central electrode sites from 350-650 ms following stimulus onset. This window was shortened from the standard window of 350-750 ms based on the increased age of the infants and visual inspection of the component in the averaged waveforms. The LSW response was examined over left and right frontal, temporal, and parietal sites at 1-1.5 seconds following the stimulus onset.

3 way mixed-design ANOVAs were conducted to determine significant interactions and main effects. Stimulus density was analyzed as a between subjects factor (2: high density, low

density), stimulus type was analyzed as a within subjects factor (3: familiar, novel global, novel local), and electrode site was analyzed as a within subjects factor, varying by component and by region. Electrode clusters were determined based on where the experimental effect appeared strongest in the averaged waveforms. Significant effects found in the ANOVA were followed up separately for high and low density groups with a repeated measures ANOVA (LSW) and with paired comparisons using paired samples *t*-tests.

3. Results

Peak look duration and total looking time during familiarization were both determined from coding looking behavior to the familiarization pattern in a frame-by-frame analysis. Difference scores were obtained by subtracting the mean amplitude of the ERP response to novel stimuli (either global or local) and the familiar stimulus. Absolute values were reported for the difference score in order to control for differences in the polarity of the waveform. No significant correlations were observed in Nc or the LSW for infants shown high density patterns between length of familiarization or peak look, and difference in amplitude between novel global, novel local, and familiar stimulus types. Likewise, no significant correlations were found between length of familiarization or peak look, and difference in amplitude between novel and familiar stimulus types for infants shown low density patterns.

<u>Nc Component</u>

Two separate 2 way mixed-design ANOVAs were conducted to determine significant interactions and main effects, with stimulus density as a between subjects factor (2: high density, low density), and stimulus type as a within subjects factor (3: familiar, novel global, and novel local). The electrode sites examined were midline central and frontal clusters.

[Appendix B, Figure 1]

No main effect of stimulus type *F*(2,18) = 1.117, *p* = .349, $\square_{p}^{2}$ = .11, or interaction between density and stimulus type *F*(2,18) = .682, *p* = .518, $\square_{p}^{2}$ = .07, were found at central electrode sites. Likewise, no main effect of stimulus type *F*(2,18) = 1.188, *p* = .328, $\square_{p}^{2}$ = .117, nor interaction between stimulus type and density, *F*(2,18) = .570, *p* = .576, $\square_{p}^{2}$ = .06, were found at fronto central electrode sites. Finally, no main effect of stimulus type *F*(2,18) = .649, *p* = .534,

$\square_{p}^{2}$ = .067, or interaction between density and stimulus type *F*(2,18) = .13, *p* = .987, $\square_{p}^{2}$ = .001, were found at frontal electrode sites.

Late Slow Wave Component

Three separate 3 way mixed design ANOVAs examined stimulus type as a within subjects factor (3: familiar, novel global, novel local), density as a between subjects factor (2: high density, low density) and electrode site as a within subjects variable (2: right hemisphere, left hemisphere). Each ANOVA assessed differences in mean amplitude between stimulus types for both density conditions at either frontal, temporal, or parietal electrode sites. Amplitude was calculated between 1 and 1.5 seconds following stimulus onset.

[Appendix B, Figure 2]

No main effect of stimulus type, *F*(2,18) = .966, *p* = .399, $\square_{p}^{2}$ = .097, or interaction between stimulus type and density condition *F(*2,18) = .132, *p* = 877, $\square_{p}^{2}$ = .014, were found at frontal electrode sites. Likewise, no main effect of stimulus type, *F*(2,18) = .553, *p* = .585, $\square_{p}^{2}$ = .058, or interaction between stimulus type and density condition *F*(2,18) = 1.040, *p* = .374, $\square_{p}^{2}$ = .104, were found at temporal electrode sites. At parietal electrode sites, a significant interaction was found between stimulus type and density, *F*(2,18) = 4.280, *p* = .03, $\square_{p}^{2}$ = .322. A repeated measures ANOVA was conducted separately for each condition (low and high density), showing a main effect of stimulus type in the high density condition at right parietal electrodes, *F*(2,9) = 3.553, *p* = .049 $\square_{p}^{2}$ = .261. A follow up *t*-test showed that mean amplitude to the novel global stimulus (*M* = -9.081 µV, *SD* = 11.17), was significantly greater than to the familiar stimulus (*M* = -.519 µV, *SD* = 11.38), *t*(10) = 3.701, *p* = .004. There was no difference between mean amplitude to the familiar and novel local (*M* = 1.382, *SD* = 19.42) stimulus, *t*(10) = -.426, *p* =

.679. At left parietal electrode sites, a main effect of stimulus type was found for the high density group, $F(2,9) = 4.079$, $p = .033$, $\square_{p}^{2} = .290$. A paired samples *t*-test showed that mean amplitude to the novel global stimulus ($M = -6.253$, $SD = 11.80$) was significantly greater than amplitude to the familiar stimulus ($M = -1.570$ µV, $SD = 11.31$), $t(10) = 2.381$, $p = .039$. No differences were found between mean amplitude to the familiar and the novel local ($M = 2.464$, $SD = 14.\ 321$) stimulus types, $t(10) = -1.231$, $p = .237$. No main effect of stimulus type was found at right parietal electrodes in the low density condition, $F(2,8) = .280$, $p = .759$, $\square_{p}^{2} = .03$, or at left parietal electrodes in the low density condition, $F(2,8) = .354$, $p = 707$, $\square_{p}^{2} = 038$.

4. Discussion

The aim of the current study was to determine if infants' processing strategy differs depending on the characteristics of a visual stimulus. Specifically, the study tested whether infants' tendency to process the configural level of a hierarchical visual pattern (Ghim & Eimas, 1988, Freeseman et al., 1993, Colombo et al., 1995, Guy et al., 2013), could be manipulated through presenting low density patterns, which are more difficult for children and adults to process at a configural level. It was hypothesized that, consistent with previous research, infants would attend to the global stimulus level of high density patterns, and that this would be evidenced by higher amplitude Nc to the novel global stimulus, and a higher amplitude LSW to the novel global stimulus compared to the familiar stimulus as well. It was predicted that infants who were presented with low density patterns would fail to show global precedence and instead demonstrate a local bias through increased LSW amplitude to the novel local stimulus, compared to the familiar stimulus.

The results of the Nc analysis indicate that 7.5 month old infants did not demonstrate differences in attention between stimulus types in the high density condition, or in the low density condition. However, in the LSW analysis, infants demonstrated recognition memory for the familiar stimulus and discrimination of differences between the novel global and familiar stimulus only in the high density condition. No evidence of processing any of the stimulus types was apparent in the low density condition. These results indicate that global processing can fail to occur, depending on the accessibility of the configural stimulus level.

Nc

Nc is a negative deflection in the waveform between 350-650 ms following stimulus onset, and (negative) amplitude is thought to reflect general attention to visual stimuli, and can be measured specifically as an index of infant attention to stimulus novelty (de Haan & Nelson, 1997; Reynolds, Courage, & Richards, 2010; Reynolds & Richards, 2005). We found no significant differences in Nc amplitude in this study. This could indicate that infants did not find the familiar stimulus any more or less salient than the novel stimuli. Nc amplitude differences were strongest over frontal and central electrode sites.

LSW

In contrast to the Nc component, results of the current study did show a significant interaction between stimulus type and density. This effect was found at both right and left posterior parietal electrodes. Further comparisons showed that response to the novel global stimulus differed significantly from response to the familiar stimulus. No differences were found in the high density condition between the familiar and novel local stimulus. This finding replicates previous studies in showing that infants were able to recognize changes to the configural stimulus level, but not the featural level. No significant differences were observed in in the low density condition between stimulus types. This indicates that infants failed to process the low density stimuli at any level of organization.

These results indicate that infants' tendency to process the global level of high density patterns is not necessarily driven by differences in attention, reflected by the Nc component. Rather, recognition of novelty simply requires more robust processing later on as a product of recognition memory. The findings of the study did not adequately explain mechanisms involved in processing low density patterns. It is unclear if and how infants were able to process low density stimuli. It may be that processing of the global stimulus level was disrupted in the low density condition, which would be consistent with an information processing model of infant attention (Cohen et. al., 2002). However, it is unclear why infants were unable to process the low density stimuli at the local level. A limitation of the current study could be relatively small sample size. Therefore, more work is needed to determine the impact of stimulus density on recognition memory, as a follow up to the work of Dukette and Stiles (2001), and to clarify why infants demonstrated so little flexibility in processing strategy as the task varied across conditions.

Overall, these results indicate that in typically developing infants, a global processing bias is enhanced with increased numbers and density of local elements, and ultimately fails in processing of low density patterns. Another factor which could be explored in greater detail in the future is the impact of individual differences in looking behavior on processing high vs low density patterns. Finally, it is possible that increasing stimulus density could enhance processing of traditional hierarchical stimuli in atypically developing infants. The relative robustness of the global bias in the high density condition, and lack of a robust local bias in the low density condition, could indicate that infants are universally biased to construct configural meaning from featural stimuli (Cohen et al., 2002).

5. Conclusion

The finding of this study does not necessarily support the prediction that processing strategy differs qualitatively between high and low density visual patterns. However, it does indicate that global bias in processing strategy can be disrupted through manipulating stimulus density. As expected, infants processed high density hierarchical patterns at a configural level. However, when presented with low density patterns, infants did not show any evidence of processing the stimuli on either the configural or featural level. Previous research has remained inconclusive over whether infants can flexibly recognize both configural or featural information, depending on which level is the most accessible to them. The findings of this study are more consistent with those studies indicating that infants consistently process hierarchical patterns in a configural-to-featural sequence, with processing of local information only occurring after a representation has been developed of the configural pattern. This interpretation could be used to explain why infants failed to process the differences between stimulus types at either level when the configural organization was not apparent to them (in the low density condition).

The study indicates that recognition memory for the global stimulus level is not necessarily preceded by significant differences in magnitude of attention between stimulus types. This is evidenced by the fact that no differences were found in the Nc component across stimulus types or as a result of the stimulus density. This result conflicts with a previous ERP study showing increased attention to the global stimulus level in the Nc component (Guy et. al., 2013). More work is needed to determine if additional controls used in this stimulus set made configural changes in the high density stimuli less salient than stimuli used in previous studies. This could include the uniform height and width of the stimuli, or the presence of contour but no filled in shape. Another factor could be the difference in age groups tested in previous studies and in the current study.

This project is the first to study neural mechanisms of attention and memory involved in processing of low density patterns. The results lend support to the idea that representation was adequately developed for the global stimulus level only in high density patterns. The lack of significant differences in engagement between stimulus types indicates that differences in processing strategy were not due to differences in magnitude of attention between global and local stimulus levels (Kimchi & Palmer, 1982). However, the findings are inconclusive over how low density stimuli are processed since there is no evidence that infants processed these patterns at all. Future work could explore in greater depth how infants process relationships between low density stimuli in both static visual patterns and more ecologically relevant stimuli, such as pictures. Future work could also explore how infants integrate local features to process high density versus low contours, and why increasing stimulus density enhances how infants remember spatial relationships at the configural level.

Finally, future work is needed to provide general insight into how infants approach hierarchical visual stimuli when the configural level is ambiguous, as may be the case in low density patterns or as a result of other manipulations which impact goodness of form. At what point do infants begin to process low density stimuli, and what strategy might be employed in the absence of an immediate local bias?

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Appendices

Appendix A

Stimulus Types by Density

Familiar Stimulus Familiar Stimulus

Novel Global Stimulus Novel Local Stimulus Novel Global Stimulus Novel Local Stimulus

Figure 1. On the left (top) is an example of a familiar stimulus used in the high density condition, and on the right (top) is an analogous familiar stimulus used in the low density condition. On the bottom left of each set (high and low density) is an example of a novel global stimulus in which the configural level has been changed, but the local elements remain identical to the familiar pattern. On the bottom right of each set is an example of a novel local stimulus, in which the configural level is identical to the familiar stimulus, but the elements have been changed.

Appendix B

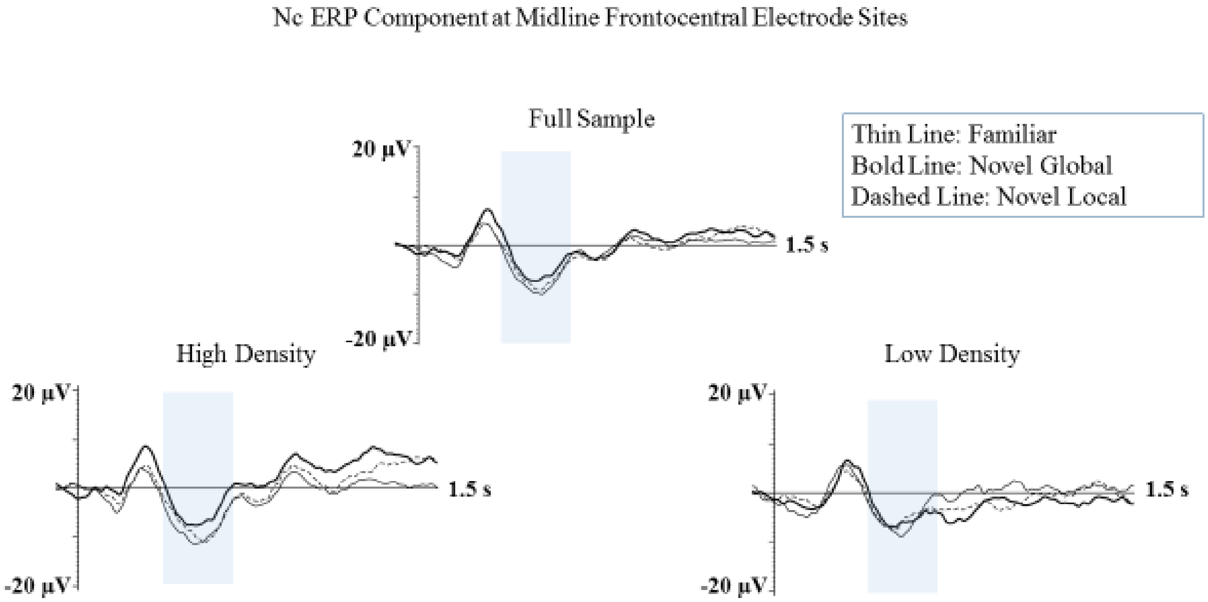

Figure 1. Nc component amplitude is represented as a negative going deflection in the shaded region (350-650 ms) for familiar, novel global, and novel local stimulus types. Nc component amplitude was assessed at frontal and central electrodes.

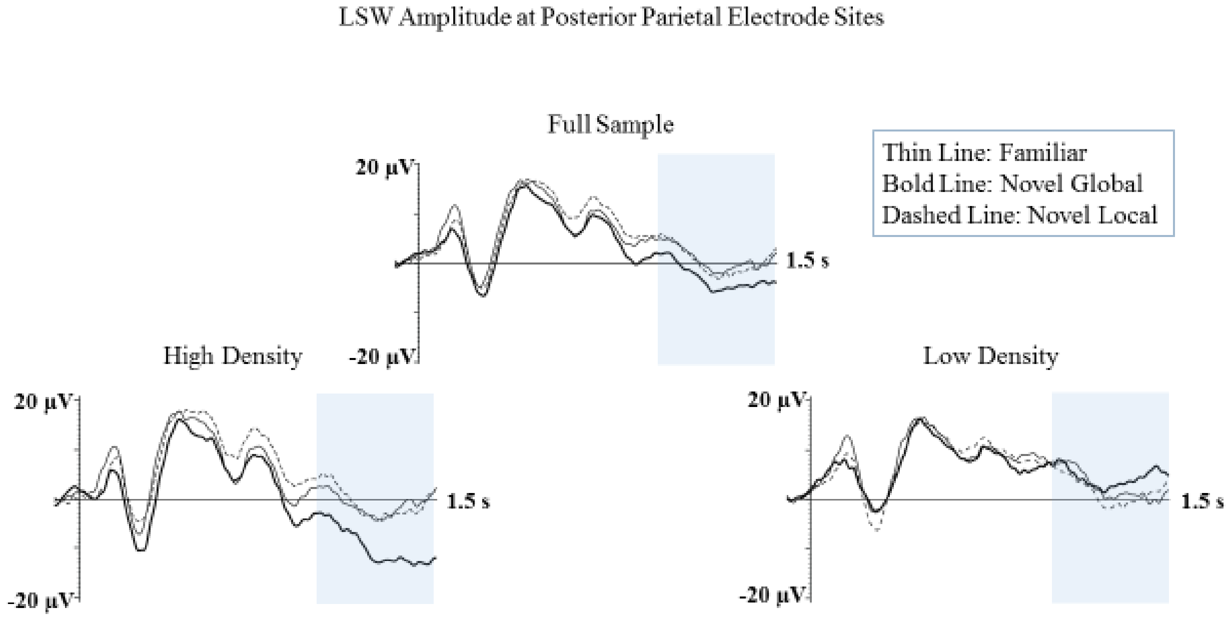

Figure 2. Late Slow Wave component amplitude is represented for familiar, novel global, and novel local stimulus types. Average amplitude was calculated for the time frame indicated in the shaded region (1-1.5 s). LSW amplitude was determined at right parietal electrode sites.

Vita

Sara Mosteller earned a Bachelors degree in Psychology and Music from Berea College in 2011 before beginning a Masters program in Experimental Psychology at the University of Tennessee in 2012. She is currently focusing her study in infant attention using ERP measures.