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THE EFFECTS OF VISUAL BLUR ON INFANT PREFERENCE BEHAVIOR

by

Maria Pagano

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in partial fulfillment of the requirements for the degree of Doctor
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Abstract

THE EFFECTS OF VISUAL BLUR ON INFANT PREFERENCE BEHAVIOR

by

Maria Pagano

Advisors: Professors Louise Hainline & Israel Abramov

Does the development of sensory processing effect preferential looking behavior? Three experiments were performed, each with a sample of 13 three- and four-month-old infants to provide insight into this question. In addition, a fourth experiment was conducted to determine if a curvilinear preference behavior known to be present by three months of age could be reproduced when using adult subjects.

Experiments 1 and 2, used paired presentations of "unfiltered" stimulus pairings known to elicit specific behavioral preferences during the first three months of development and "filtered" stimulus pairings that mimicked the information processed by the visual system of a one-month-old infant. It was hypothesized that when infants viewed the clear stimulus pairings behavioral preference would be consistent for the age range tested. However, when the same group of infants were shown filtered stimulus pairings, preference behavior would revert to preference consistent with one-month-old behavior. Results of these two studies demonstrated that development of sensory processing was related to changes in pattern preference and that the development of pattern preference could better be explained using a Linear Systems Model.

Experiment 3 examined the influence of spatial frequency and contrast at the fundamental frequency component of an image on infant pattern preference. Infants viewed paired presentations of clear rectilinear stimuli alongside its curvilinear counterpart which had been equated for amount of spatial frequency contained in the rectilinear stimulus. It was hypothesized that equating the stimulus pairings for spatial frequency would produce the same behavior as filtering had done in Experiments 1 and 2. Consistent with our predictions infants did not significantly prefer either of the stimuli.

Twenty adult participants took part in Experiment 4 where preference behavior was examined in both clear and filtered conditions to determine if a relationship existed between adult and infant preference behavior. Additionally, adult subjects took part in either one of two ranking tasks in order to examine possible underlying mechanisms responsible for adult preference behavior. While the adult preference behavior did not appear related to infant preference behavior across all testing conditions we nonetheless did find significant preference behavior across all clear condition stimulus presentations.

Acknowledgments

During this entire process it was quite easy to feel alone and isolated but fortunately that was not the case in my situation. At each breaking point on those more than often occasions when I felt I couldn't continue and pleaded with others to talk me out of this there always seemed to be someone there who could provide sensibility.

At every turn of my academic career my mentor Louise Hainline has been the individual who always knew something about myself that I didn't. As I explained at my defense, I'm not even sure why she hired me after our first meeting. She has nurtured, at almost every turn, my academic career and my growth as a person. Over the years you have given me such wisdom, that my only hope is that I can attain the goals you have given me the opportunity to pursue. It's difficult to explain just exactly how working with you has changed my life and the life of my daughter. Things just simply "got better".

At every other turn, there was Israel Abramov, who when times got tough.......Yelled. I can honestly say you are the true academic; your students ALWAYS came first. More importantly, you have given me your passion for knowledge and the want to impart that knowledge to others. My best to you and Leora always.

The remaining members of my committee also deserve to be acknowledged. If not for their patience, and editing; for simply having to "shlep" this thing around with them. Dave Owen deserves special thanks for dual

service as committee member and statistics tutor. If I had to give Dave a nickel for every time he had to explain the most simplest of statistical analysis, he and Kitty could travel the world wine tasting for the rest of their days.

City University should be proud of Francis Degan Horowitz. It is expected that professors should take time with their students, however when the President of City University takes the time from her busy schedule to serve the student body she represents, a standard is set that many more of us should follow.

Gerry Turkewitz deserves to be acknowledged for his guidance when it came to my understanding of Schnerla. While I still think "effective stimulus intensity" could be defined along an infinite continuum, there is still hope for me. I've picked up *Developmental Time and Timing* for yet another reading in the hopes that maybe one day I'll get it right.

While my committee kept me focused on my academics, it was my friends and colleagues at the Infant Study Center who helped me relax (even when I was working). Friday nights are just not going to be the same when Marty and I stop in for "just one" at 12th Street. I'll have no weekly dissertation crisis to bend his ear with; which of course by the end of the night he would solve. I guess now Marty, I'll just have to find some other universal riddles for you to solve. Just remember, when your on that stool, no advice you can give is bad. Florence, you taught me how to be a lady, and always had a hug and smile ready for me when I just couldn' t bring myself to act like one. Beth, thanks for the hours of discussion about nothing, that helped clear my head. While Shaiu and Simeone are cited in the text for their contribution to this work, a simple cite can't express my thanks to them for the hours spent writing and revising computer programs. It would have taken me at least two more years to finish if you both were not around. I also can't forget Mike; who on many occasions, took the photometer out, then set it up, then put it away, then took it out, then set it up, then put it away, then took it out .... The Hemingway Writer's Group (Warren, Julie, and Simon) deserves mention. If it were not for them I never would have had a proof-read version of my abstract ready to go when I was offered a job.

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There were many individuals who never gave-up on me. But there were never individuals like Aunt Ester, Uncle Frank, Thelma Christopher, Albert Christopher and Donna Kelly, who on a constant basis reminded me of how proud they were of me. I just couldn't let you down.

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From every doctoral exam, to conference, to presentation and finally, through the dissertation years Russell Christopher has been the one individual who shed every blood, sweat, and tear of my graduate career. I'm so glad you're home and were able to be there for me when it counted most. But then again, I can't ever remember a time you weren't there.

Finally, to my parents Juda and Anthony; despite your best efforts I've achieved something of which I can truly be proud. It's most unfortunate you can't say the same. Pride was something my grandparents, Maria and Giachino Pagano had and I'm fortunate in that they passed it on to me.

This dissertation is dedicated to the following family members who demonstrated long ago that a woman can and does handle everything that comes her way.

Felicia Marchetta
Rose Alini
Barbara Pagano
Donna Kelly
Thelma Christopher
Ti Ti Zee Pagano
Louise Pagano
Doreen Bennanati
Kathleen Sagona
Maritza Alini
Esther Pagano

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INTRODUCTION

The content of an inexperienced infant's perceptual world has long been the object of theoretical speculation and empirical analysis. In 1890, William James described the human infant's initial experience with environmental stimulation as one of disorder and confusion. Contemporary theories of infant perception, on the other hand, which are supported by empirical evidence have now acknowledged that from birth the human infant is receptive and responsive to visual stimulation from the environment. In fact, it has been well documented that the human infant does not simply respond to random forms of environmental information, but displays selective visual attention to specific objects in his or her surroundings (Fantz, 1956 Brennan, Ames & Moore, 1966; Cohen, 1972; Banks and Salapatek, 1981).

1.1 Overview of Infant Preferential Looking Paradigms

1.1.1 Fantz and The Visual Interest Test.

The concept of infants as organisms that directly attend to only specific information from the world was first supported by empirical study when Robert Fantz in 1956 pioneered the technique he referred to as the *Visual Interest Test.* Application of the Visual Interest Test provided not only the necessary methodological vehicle needed for the study of infant perception but was also simple to implement. While lying in a supine position, infants were presented with two patterns, one to the left of midline and one to the right. A peephole in the center of the board on which the patterns were displayed allowed the investigator to record the side of the display on which the infant fixated its gaze. The results from this type of testing provided evidence of a non-equivalent fixation between the different stimuli once the patterns were detected. In other words, when a particular pattern was presented alongside another pattern modified or varied along some dimension, infants responded with a reliable differential fixation response or *visual preference* toward one stimulus of the pairing. Currently, the original Fantz paradigm is formally referred to as the *Preferential Looking Technique.*

1.1.2 Contemporary Variations and Uses of Preferential Looking Paradigms.

Throughout the years researchers have modified the original Fantz preferential looking paradigm and the results obtained from these experiments have been utilized to generate hypotheses across many different areas of infant development. For example, Teller and her colleagues (Dobson & Teller, 1978b;

Teller, 1979; Teller, Mayer, Makous, & Allen, 1982) used a variant of Fantz's method that they termed a *Forced-Choice Preferential Looking Technique*[1] to assess the quality and development of infant visual acuity[2]. Fagan and his collaborators (Fagan, 1972; Fagan & Singer, 1983; Fagan & Knevel, 1989) used infant preferential fixation responses[3] to pairs of human faces to develop the viewpoint that the direction of infant preference behavior was indicative of an infant's current as well as future level of intelligence. It has further been hypothesized (Held, Gwiazda, Brill, Mohindra, & Wolfe, 1979) that infants, beyond exhibiting preferential responses for certain stimuli over others, at times preferred "not" to fixate a stimulus and exhibit what has been termed a *negative preference*[4].

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[1] The primary difference between a Preferential Looking task and a Forced-Choice Preferential Looking task is the dependent measure. While the former task utilizes some direct measure of infant behavior such as direction and length of fixation, the latter preferential task measures a blind observer's approximation with respect to which side of a presentation contains the stimulus.

[2] The Forced-Choice Preferential Looking Technique used by Teller (1979) to estimate infant acuity takes advantage of the fact that infants prefer to fixate something over nothing. Infants were presented with a square-wave grating which contained black and white stripes, that varied in size across presentations, alongside a blank field of equal average luminance. It was hypothesized that if infants could detect the stimulus they would prefer to fixate the patterned image over the blank field. If on the other hand, infants could not resolve the pattern, since both stimuli were comprised of equal average luminance, no preferential response would be found.

[3] The Preferential Looking Technique used by Fagan and Singer (1983), commonly referred to as a Novelty Preference Design, typically provides researchers with information regarding whether or not infants prefer to fixate one type of stimulus pattern or form to another type of stimulus pattern. This is accomplished by presenting infants with two stimuli over a fixed period of time and recording infant fixation times for both stimuli. If fixation to one stimulus is significantly different from the stimulus it is paired with and significantly different from a baseline of 50% it is commonly agreed among researchers that a preference was shown for the stimulus.

[4] Held et al. (1979) maintained that the use of behavioral measures like the Forced-Choice Preferential Looking technique underestimated evaluations of infant visual acuity. In

(continued...)

In summary, researchers have consistently reproduced and reported differential fixation behavior across different ages during infancy. Therefore, when generalized into a rule, infant preference behavior whether for patterned over unpatterned stimuli or for fixating one type of patterned stimulus over another type of patterned stimulus has provided the basis for the most used and most empirically well documented technique in infancy (Brennan, Ames, & Moore, 1966; Fantz, Fagan & Miranda, 1975; Banks & Salapatek, 1983; Kleiner, 1987) over the past quarter of a century. Moreover, recent applications of preferential looking techniques have attracted widespread experimental interest in the area of research that is specifically concerned with understanding the development of form and pattern perception over the first six months of life.

1.2 Interpreting Preference Results: What are Infants Attending to and Models which Attempt to Explain Why?

Interestingly however, while most researchers have acknowledged the methodological utility of preferential looking paradigms, a comprehensive agreement has yet to be reached with regard to why infants consistently demonstrate a preference for one type of form or pattern over another. Two principal issues surrounded the debate with regard to what motivates infant

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[4] (...continued)
fact, Held et al. (1979) found that infants significantly preferred to fixate an average luminance blank field over gratings that varied in black and white stripe width, when stripe width was beyond reported infant measures of estimated acuity. These findings led Held et al. (1979) to conclude that the preference for the blank field over the grating implied visual discrimination by the infants tested, just as conclusively as the commonly observed preference for the grating over the blank field implied discrimination.

differential fixation responses. First was the problem of defining the property or properties contained within a stimulus pattern that elicit significant infant preferential behavior. Several such dimensions have been classified and the critical variables believed to account for differential fixation have included pattern complexity, number of angles, stimulus intensity, curvilinearity, and contour density (See reviews by, Fantz, Fagan, & Miranda, 1975; Karmel and Maisel, 1975; Banks & Salapatek, 1981). Consequently and concurrently disputed are the underlying mechanisms responsible for the shifts in selective attention found during specific periods throughout infancy. The commonly accepted interpretation links shifts in preference behaviors to the development of the infant visual system. In fact, evidence from a variety of disciplines (Banks & Bennett, 1988; Atkinson & Braddick, 1989; Norcia, Tyler, & Hamer, 1990; Hainline & Abramov, 1992) has suggested that while some functioning is apparent in the optical, oculomotor, retinal, geniculate and cortical parts of the infant visual system, the level of functioning is less immature when compared to the visual system of the adult. However, like the various stimulus dimensions believed to account for infant preference, researchers have not been able to agree upon exactly which of the aforementioned visual immaturities known to exist underlies differential fixation response behavior.

Efforts by researchers to uncover the mechanisms responsible for preference behavior, and the dimension or dimensions responsible for the selective attention of infants have been further complicated by the creation of an abundant list of patterns and shapes used to test infant preference. For example, Fantz et al. (1975) presented infants a range of stimuli that varied from simple black squares to complicated geometric arrangements. Karmel and Maisel (1975) used only different size black and white checks which formed a checkerboard pattern to obtain preference information. As further research was conducted within this area of development, new stimuli were inevitably added to the already abundant list of patterns currently identified.

1.2.1 Fantz and the Hierarchical Stimulus Dimension Model. Two decades of research provided Fantz and his collaborators (Fantz & Nevis, 1967; Fantz et al., 1975; Fantz & Fagan, 1975; Fantz & Miranda, 1975) the initial opportunity to organize the then existing information obtained from studies of infant preference. The *Hierarchical Stimulus Dimension Model* proposed by Fantz et al. (1975) described the components of a stimulus hypothesized to be relevant in the determination of the development of visual attention to specific patterns over the first six months of life. Preference for a particular form or pattern was premised on the relative prepotency of a particular stimulus dimension or the strength of that dimension to elicit differential fixations across infancy for one type of stimulus over another during differing phases of infant development. Several such dimensions of stimulus patterning could be found, for example, pattern definition, pattern quantity, pattern configuration, pattern subtlety, variety within a stimulus, and variations in depth. However, the first three of these dimensions were hypothesized to form the basis from which perception of form develops. Therefore preference for any given stimulus was determined not simply by the age of the infant, but also by the dimension along which the stimulus varied, be it pattern definition, pattern quantity, or pattern configuration.

According to Fantz et al. (1975) the primary determinant for stimulus fixation exhibited by infants from birth to one month of age were those stimuli prominent along the dimension of *pattern definition,* with preference for a pattern or stimulus which contained sharp contours, high figure-ground contrast, and wide lines. For example, when Fantz and his colleagues (Fantz et al., 1975; Fantz & Fagan, 1975) presented infants who were under the age of five weeks old paired stimulus patterns that contained either large or small unconnected black squares, equated along the dimension of number, they reported finding highly significant differential fixations for the larger square stimulus over the smaller square stimulus of the pairing in all cases. Moreover, they reported finding an inverse relationship between the amount of pattern definition and the age of the infants tested. For example, at 1 month of age infants significantly fixated the larger black square of the pairing 75% of the time whereas mean fixation time linearly decreased to 60% as the age of the infants increased to five months.

In addition to high figure-ground contrast, sharp contours, and wide lines, other variables were also reported to affect the prominence of pattern definition within a stimulus. For example, the absence of brightness gradations and other subtleties were also believed to interfere with the visibility of the most prominent parts of an image. Studies by Fantz and Nevis (1967) reported finding longer fixation times by infants during the first two months of life toward each of eight black and white patterns when those patterns were paired with figures that contained bright colors, subtle shading, or out-of-focus photographing. However, following two months of age infant responses to most black and white pairings decreased rapidly when compared with these other types of stimuli presented.

The data from studies conducted by Fantz and his collaborators (Fantz et al., 1975 and Fantz & Nevis, 1967) revealed many instances in which infants preferred stimuli prominent along the dimension of pattern definition. On the other hand, a subsequent decrease in the prepotency of pattern definition to elicit fixation was found when infants older than one month of age were tested. Moreover, the attentional shifts that occurred after this age in the majority of cases were toward the stimulus of the pair that contained the preferred feature of the next category of the developmental hierarchy. Consequently, by one month of age infant discriminations by pattern definition are superseded by the next level of discrimination within the hierarchy, *pattern quantity.*

Fantz and Fagan (1975) operationally defined pattern quantity in terms of several dimensions. Therefore pattern quantity was not restricted simply to the number of elements contained within a stimulus, but also included the number of line segments, and the number of angles within a pattern. Using the same stimuli described in the above section on pattern definition, Fantz and Fagan (1975) inversely related the stimulus size and the number of elements contained in each stimulus and investigated how preference behavior changed for these pairings over the first 5 months of development. When presented with patterns that varied along the dimension of stimulus quantity alone, infants showed age-related changes in preference for the stimulus that contained more unconnected black squares. That is, mean looking time for stimuli that contained the greater number of elements increased sharply from 1 month of age to 5 months of age and subsequently was accompanied by decreases in preference behavior for those stimuli that contained fewer items.

By three months of age infant pattern preference was observed to shift toward those patterns characterized by the *configuration* of the form. In particular, a specific pattern preference was found for those stimuli that were high along the dimension of curvilinearity. For example, Fantz and Nevis (1967) reported that older infants preferred a variety of bull's eye patterns over patterns containing straight, linear elements. More notable however, than the developmental consistency of a curvilinear preference at later ages was the earlier absence of this preference when the same stimulus pairings were shown to infants under the age of three months. Fantz and Nevis (1967) reported that neonatal preference responses increased from chance responding to a mean 70% preference response when bull's eye patterns were paired with linear patterns that contained the same number of line segments. According to Fantz et al. (1975), the prominence of differential fixation responses to pattern configuration was more important for behavior in the older infant, the child, and the adult since this type of discrimination was essential to the development of object recognition, spatial orientation, and reading.

1.2.2 The Hierarchical Stimulus Dimension Model and its Underlying Mechanisms. Various immaturities found in the young infant visual system were thought to dominate initial neonatal preference behavior. For example, incomplete development of visual processes like accommodation, fixation, convergence and other oculomotor abilities were purported to limit the infant's ability to find and maintain fixation of small details, fuzzy contours, and subtle pattern variations. According to the Hierarchical Stimulus Dimension Model, the behavioral results of these visual limitations were manifested in the infant's initial restriction of attention to stimuli high along the category of pattern definition. Furthermore, subsequent decreases in visual fixation based on pattern definition were attributed to improvement of these visual mechanisms[5]. Morphological development of the visual system thus makes it easier for the infant to shift attention from one dimension of stimulus variation to another higher level of stimulus variation that might have been earlier obscured by the

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[5] Most researchers would agree (see Atkinson & Braddick, 1989 and Hainline and Abramov, 1992 for reviews) that acuity, stereopsis and other basic sensory visual processes of the human neonate are poor. On the other hand, visual limitations do not appear to be a limiting factor for infant behavior. In fact, the human infant does not behave in the limited manner that should be consistent with such primal visual ability. Hainline and Abramov (1992) sum up this point well, "While infants may not, indeed, see as well as adults do, they normally see well enough to function effectively in their roles as infants" (pg.41).

primary requisite of clearly defined, large patterning. Therefore infant preference behaviors are initially dominated by fixations to stimuli that are most effective for the practice of visual skills that provide the most readily assimilated information for infants.

1.2.3 Hierarchical Stimulus Dimension Model Summary. In summary, the Hierarchical Stimulus Dimension Model proposed by Fantz (1975) explained the development of infant preference to specific forms and the shifts in preference that occurred during the first six months of life in terms of three broad phases of visual selectivity. Initially, the many visual immaturities found in the neonatal visual system restricted infant visual fixation to those stimuli that contained high pattern definition. Age-related changes in pattern preference that also coincided with an infant's ability to discriminate a broad selection of patterns based on pattern definition led to the secondary basis of infant attention. Consequently, pattern quantity became the primary means for infant discrimination. While the onset of selective discrimination by pattern quantity overlaps pattern definition, the former phase of the hierarchy became predominant by two months of age. Finally, by four months of age infants were found to differentially fixate stimuli based on the dimension of form, and in particular preferred curvilinear stimuli to linear counterparts.

It should be noted, however that the Hierarchical Stimulus Dimension Model proposed by Fantz and his colleagues did not claim that visual preference for pattern quantity and configurational features suddenly emerged with development. Instead discrimination and preference at higher levels were obscured earlier, in part by the primary requirement for high pattern definition, size and contrast. Therefore, cognitive development was directly limited by the various immaturities found in the neonatal visual system and described previously.

1.2.4 Karmel and The Contour Density Model. In addition to the numerous studies conducted over the years by Fantz and his colleagues, additional empirical support has also been shown for developmental shifts in infant preference behavior by other researchers (Brennan et al., 1966; Ruff & Turkewitz, 1975; Banks & Salapatek, 1981). Commonly however, these researchers have also provided their own models and paradigms believed to account for the development of pattern perception. One such model, proposed by Karmel and his colleagues (Karmel, 1969; Karmel & Maisel, 1975;) described the selective development of infant preference behaviors in terms of a *Contour Density Model* of pattern preference (Karmel & Maisel, 1975). The primary determinant of infant looking behavior was defined by the total amount of contour contained within each pattern and could be quantified by calculating the number of inches of black-white edges contained in a pattern. Typically, pairs of black and white checkerboard patterns or random black and white check patterns varying in size were presented to infants. The actual predictor variable (*contour density units*) was determined by calculating the square root of the number of black-white transitions contained in the projected patterns. Therefore a 12 x 12 checkerboard matrix containing 1-inch black and white squares, displayed at 30 cm, contained 289 inches of black-white transition or contour pattern and a contour density of 17.0.

Karmel (1969) tested his model by presenting infants between the ages of 13 and 20 weeks of age all possible pairings of four black and white checkerboard patterns with four random check patterns while he measured preferential looking time. The principle finding of this research revealed age-related increases in the amounts of contour preferred by infants. That is, older infants looked significantly longer at the smaller checkerboard patterns that contained greater amounts of contour whereas younger infants preferred to fixate the larger checkerboard patterns that contained smaller amounts of contour.

The above data led Karmel (1969) to maintain that the Contour Density Model better described the development of form perception across infancy than did the Hierarchical Stimulus Dimension since the contour density unit offered a quantitative measure of stimulus dimensions that the Hierarchical Stimulus Dimension did not. However the Contour Density Model was limited by the dimension it quantified. Researchers (Banks & Salapatek, 1981; Gayl et al., 1983; Kleiner, 1987) have argued in response to Karmel (1969) that the visual environment of an infant was not restricted simply to black and white checkerboard patterns or to patterns that contained clearly defined black-white transitions at the boundaries. Consequently, the Contour Density Model could not account for infant preference to patterns that contained fuzzy contours, small amounts of contrast, and complicated designs.

1.2.5 Stimulus Intensity as a Predictor Variable of Preference Behavior.

Contour density units were not the only type of quantitative dimension to have been investigated as a possible necessary factor guiding the development of infant preference behavior. As Ruff and Turkewitz (1975) have noted, several quantitatively related stimulus dimensions are possible. In fact, Ruff and Turkewitz (1975) investigated the utility of what Schneirla termed *effective stimulus intensity*[6], which was broadly defined in their study by the attribute of stimulus size. It was hypothesized that quantitative variables, like size, and brightness would be the principal determinant of looking behavior in younger infants since quantitatively determined responsiveness was basic to the development of all higher level processes. Therefore, if the effectiveness of stimulus intensity declined with maturation, then as infants interacted more with their environment they should thus become more capable of responding to complex and nonquantitative aspects of their environment such as form.

The preceding hypothesis was tested by Ruff and Turkewitz (1975) by modifying the bull's eye and stripe stimulus pairings used by Fantz et al. (1975) along the dimension of size. Infants between the ages of 6 and 24 weeks were

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[6] Stimulus intensity was described by Ruff and Turkewitz (1975) as a quantitative variable which might be the principle determinant of looking behavior in younger infants. While stimulus intensity could be considered a general attribute of stimulation, and therefore could be described along a number of intensity related dimensions,(for example, brightness), Ruff and Turkewitz (1975) manipulated only the stimulus variable of size in their study.

randomly presented with either an intermediate sized bull's-eye pattern paired with one of the four remaining different sized striped stimuli or an intermediate sized striped stimulus paired with one of the four remaining different sized bull's-eye patterns. The results of this study demonstrated that infants younger than 10 weeks of age fixated the larger stimulus of the pairing for significantly longer amounts of time than the smaller stimulus regardless of whether the stimulus was curvilinear or rectilinear. On the other hand, infants older than 10 weeks of age responded differentially solely on the basis of pattern configuration. That is, infants preferred the curvilinear stimulus of the pairing, size notwithstanding.

If the findings reported by Ruff and Turkewitz (1975) were compared with the results of the studies done by Fantz and Fagan (1975), clear parallels between the data could be found. First, each study reported that the younger infants of the samples tested preferred the larger stimulus of a pairing to the smaller stimulus. Next, each study reported age-related increases in the time that infants spent looking at the curvilinear stimulus over its rectilinear counterpart. However, the conclusions drawn from each of these studies to explain why younger infants preferred the larger of the two stimuli and why older infants preferred the curvilinear stimulus of each pairing were conceptualized in very different manners. Fantz et al. (1975) explained infant preference and shifts in infant fixation behavior in terms of his Hierarchical Stimulus Dimension Model. On the other hand, Ruff and Turkewitz (1975) argued that the preferential results they obtained were a direct result of how much "effective intensity" was contained within a particular stimulus. Therefore how long an infant fixated a stimulus was dependent on the variable effective stimulus intensity as indexed by size. Furthermore, Ruff and Turkewitz (1975) described their results in support of Schneirla's stimulus intensity paradigm. That is, the quantitative aspects contained within a stimulus were responsible for maintaining younger infants' fixations toward the larger stimulus of the pairings.

1.3 So many Variables ... So Little Time

All of the empirical research that has provided support for the above models proposed several different variables and possible mechanisms that could account for the development of infant preference behavior. Variables like stimulus intensity, contour density, complexity, and concentricity have serious limitations, however. For example, when the two dimensions of size and quantity were manipulated by Fantz and Fagan (1975) and the value along one dimension was held constant, changes in value along the opposing dimension were accompanied by changes in preferential looking. In other words, when the size of the elements and the number of the elements were put in opposition, size dominated the preferential responses of the younger infants tested whereas quantity, and then form dominated the preferential responses of the older infants. However, size and quantity are not the only variables which could be confounded across experiments because pattern size and pattern quantity are not the only relevant stimulus dimensions of visual selectivity. An infinite number of patterns that might contain identical number and size of elements exists, and therefore if one was to vary the linearity, regularity, or symmetry of element configurations within stimulus pairings, differential preference responses might reasonably be observed. In addition, the predictor variables used in these studies (contour density units, pattern definition, pattern intensity, pattern quantity, and pattern configuration) are limited by the fact that these only provided preference information for those stimulus dimensions that have been thoroughly examined. Consequently, the models derived by the empirical study of these variables lacked the ability to predict preference behavior for all stimulus patterns.

None of the models discussed above which attempted to explain the development of infant preference have suggested reasonable guidelines for the generalization of results obtained from their studies to additional studies using unexplored patterns. For example, Fantz et al. (1975) varied the degree of curvilinearity within a stimulus and reported subsequent decreases in preference behavior as the line segments became more linear. It could be argued however that an infinite number of rectilinear "type" stimuli could be constructed to pair with an equally infinite number of curvilinear "type" stimuli. As a result, one would be in the position of having to continue to add a considerable number of dimensions before enough had been included to allow a general description of the phenomenon under investigation. Thus, researchers would be in the position of having not only to expand the already broad list of stimulus dimensions that influence visual preference but would also be required to detect the relationship among those dimensions for each experiment conducted.

1.4 The Linear Systems Model: Toward a Better Understanding of the Development of Pattern Preference

It was not until Banks and Salapatek (1981) applied the technology obtained from Linear Systems Analysis to the study of infant pattern vision that major advances were made toward a general understanding of the stimulus dimensions influential in determining an infant's preference to any number of patterns. The Linear Systems Model offered two primary advantages over the models discussed above; First, the sinusoidal component information contained within a pattern could be effectively utilized to characterize that image. This capability gave researchers the opportunity to quantify stimuli along one specific finite dimension. As previously discussed, earlier models characterized stimulus component information along dimensions that reasonably could include an infinite number of patterns. Moreover, the Linear Systems Model provided a means for determining those characteristics that were contained within a particular pattern to which an observer's visual system would most likely be sensitive. Earlier models simply did not have the technology available to characterize the sensitivity of the human visual system to patterns and therefore could only speculate as to the physiological mechanisms responsible for infant preference behavior. Thus, the Linear Systems Model could be utilized to predict the visibility and possible preference response to any two-dimensional pattern (Banks & Salapatek, 1981; Gayl, Roberts, & Werner, 1983; Morison &

Slater, 1985).

1.4.1 The Basic Assumptions of a Linear Systems Model. The Linear Systems Model combined the use of three concepts: *Fourier's Theorem* from mathematics forms the basis for the analytical technique under discussion and is used to describe any two-dimensional pattern in terms of its sinusoidal components; the *Contrast Sensitivity Function* or CSF of the observer, derived from psychophysical or electrophysiological threshold measures is used to describe the sensitivity of an observer's visual system to various spatial frequencies at differing levels of contrast; and the *Modulation Transfer Function,* which describes the input-output relationship between a pattern and an observer's visual system. In terms of the current discussion the input-output relationship described refers to the way in which the intensity distribution contained in any two-dimensional image is transferred by the visual system of an observer. The following sections provide a detailed description of how each of these separate paradigms have been used to predict pattern preference.

1.4.1.1 Fourier's Theorem The pattern information input into the human visual system is described by the intensity distribution of that pattern which in turn can be described via Fourier's theorem. That is, when applied to the visual domain, Fourier's Theorem states that any two-dimensional visual stimulus can be analyzed into the unique set of sinusoidal components of which it is composed. Therefore, even a complex, two-dimensional visual stimulus can be described exactly by the combination of a series of sine waves. The procedure used to obtain the particular set of sine waves that must be added to obtain some given waveform is accomplished by a *Fourier Analysis*[7] of the pattern or image, while the resulting set of sinusoidal components which are obtained are commonly referred to as the *Fourier Components* of the given waveform.

1.4.1.2 The Contrast Sensitivity Function. In terms of the current discussion, an individual observer's visual system is considered, like all optical systems, to filter different spatial frequencies selectively due to imperfections in its optical structures. For example, the optics of the eye will filter the stimulus to produce the retinal image, which in turn is coded and altered by the nervous system. Therefore if the visual system under analysis were to be treated as a linear filtering mechanism[8], the characteristics or sensitivity of that mechanism (in this case the human visual system) to the sinusoidal properties of any two-dimensional pattern could be empirically derived by the system's CSF.

The limited set of patterns presented to an observer to measure individual CSFs are sine-wave gratings of varying spatial frequency and contrast. A sine-wave grating can be described as a repeated series of dark-light transitions

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[7] Fourier Analysis of an image produces all the information needed to specify the spatial frequency, contrast, and phase of a pattern's constituent sine wave gratings. It is these three Fourier components which are what the observer's visual system must transfer.

[8] In many respects the human visual system is nonlinear. However provided that certain restrictions are acknowledged when stimuli are presented, for example the use of stimuli whose contrast is not significantly above threshold, the linear systems approach can be used successfully to make predictions regarding infant behavioral responses to a large variety of visual patterns (See Cornsweet, 1978; Banks and Salapatek, 1981; De Valois and De Valois, 1988; Hainline and Abramov, 1992 for reviews and a detailed description of classifications of linear systems).

whose luminance varies sinusoidally across the grating. Sine wave-gratings can also be characterized in terms of the three parameters which make up the sinusoid: namely, spatial frequency, contrast, and phase. The spatial frequency of a sine-wave grating is represented by the number of dark-light transitions within a specified unit area commonly termed cycles per degree of visual angle or cpd[9]. Many dark-light transitions, or several light and dark bars spaced closely together per degree of visual angle are said to contain high spatial frequency content. On the other hand, broader dark-light transitions or fewer alternating light and dark bars per degree of visual angle contain low spatial frequency content. The spatial frequency of a specific waveform is described by the number of oscillations per unit distance, in the case described above, in cycles per degree. Thus a waveform containing several oscillations in space over a specified area would be considered a high spatial frequency waveform, whereas a waveform containing fewer oscillations over the same specified area of space would be considered a low spatial frequency waveform.

The contrast[10] component of a sine-wave grating, sometimes referred to as the grating's amplitude, is measured by calculating the difference in

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[9] The spatial frequency of a sinusoid is generally expressed in terms of cycles per degree of visual angle, however one can use the unit area of inches or cycles per millimeter. If, however, the frequency of a sinusoid is expressed in terms other than degrees of visual angle, we would also have to specify the viewing distance. By referring all measures to visual angle, we have completely specified the size of the retinal image.

[10] The contrast of a visual pattern is related to the amplitude in the sense that both are measures of the height of the waveform. Amplitude of a sine wave is the distance from peak to trough of the wave divided by 2 and usually is discussed in terms of the power of a waveform, which is described as amplitude squared.

brightness between the brightest and dimmest part of a grating. Black and white stripes are defined as containing high contrast whereas dark gray and light gray stripe pairings contain low levels of contrast. In terms of a sinusoidal waveform, the conventional definition of contrast most often used is given by the Michelson contrast shown in equation 1. That is, where *Lmax* is the maximum luminance level of the light stripes and *Lmin* is the minimum luminance level of the dark stripe.

$$C=\frac{L_{\max}-L_{\min}}{L_{\max}+L_{\min}} \tag{1}$$

The third component, phase, refers to the grating's sinusoid position with respect to some reference point when compared with other sinusoidal components contained in the sine-wave grating. Two gratings which might contain the same spatial frequency, and contrast will differ in absolute[11] phase if the peak and troughs of their sinusoids do not coincide. The resulting *phase shift*[12] determines if the sine-wave grating begins with a dark-light stripe pairing

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[11] When describing sinusoids, one should distinguish between two different usages for the term phase. As described in the above text, phase, or more precisely absolute phase, refers to the position of a sinusoid with respect to some fixed location. Relative phase, on the other hand refers to the relative phase angles or differences in absolute phase among the multiple frequencies in a pattern. For a further discussion of phase properties see DeValois and DeValois (1991).

[12] It is generally assumed that the phase shift is zero for all spatial frequencies. This assumption means that the lens does not laterally displace some sine wave gratings and not others. Since the phase shift produced by most lenses, including the optical system of the human eye, are relatively small near the optic axis only small errors are introduced by assuming that phase shifts are zero.

or a light-dark stripe pairing.

1.5 General Properties of the CSF

According to the Linear Systems Model, it is these three components, (spatial frequency, contrast, and phase) which must be transferred through the visual system of an observer. The results of this transfer can then be used to determine the sensitivity of the visual system under investigation to each of these components which in turn is hypothesized to affect the visibility of a pattern. Consequently, knowledge of the visibility of a pattern could then be used to possibly predict preference behavior. For example, if pattern X and pattern Y were paired together and the level of visibility for pattern X was known to be greater than the visibility for pattern Y, then it should follow that a preference would be expected for pattern X, since pattern Y was not clearly visible.

An adult's CSF can be obtained by presenting an observer with sine-wave gratings that randomly vary across different high and low spatial frequencies. The contrast of the sine-wave is then adjusted until the subject can reliably distinguish it from a uniform field. A normalized adult CSF, typically represented by an inverted, U-shaped curve of the same average luminance, plots the observer's contrast sensitivity, defined as the inverse of the contrast required to attain threshold, as a function of spatial frequency. The CSF could also be used to determine the visual "window" or range of object sizes that are visible at threshold contrast.

While the CSF of an observer could be used to specify the properties important in the representation of pattern vision, it also serves to provide some overall basic properties of pattern vision. Visual acuity, for example, can be defined as the highest frequency grating an observer can detect at 100% contrast, while the contrast sensitivity values represented by the CSF provides an index of how well an observer can detect different frequencies at threshold.

Another important property of pattern vision which is represented by the CSF is low spatial frequency attenuation. In the case of adult CSFs, sensitivity to low spatial frequencies is poorer than it is to spatial frequencies of an intermediate range. Currently the most prevalent explanation for this low-frequency cut off is described as a direct result of lateral inhibitory neural processing in the visual system (Banks & Salapatek, 1981; DeValois and DeValois 1991).

1.6 The Modulation Transfer Function

Once the CSF of an observer's visual system and the characteristics of a pattern are known, the *Modulation Transfer Function*, representing the input-output relationship between observer and pattern can then be calculated. This is accomplished by multiplying the Fourier Amplitude Spectrum[13] of the image by the transfer function of the visual system under study. The resulting mathematical function, in theory, describes the visibility of the image formed by

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[13] The Fourier Amplitude Spectrum plots the contrast of each sine-wave component as a function of spatial frequency.

the visual system under investigation. Consequently, the ability of an individual to resolve the spatial frequency and contrast components contained within a specific pattern once that visual system's sensitivity to these components becomes known is possible within a Linear Systems Model.

1.7 Application of the Linear Systems Model to the Study of Infant Preference Behavior

When applied to the study of infant pattern vision, the Linear Systems model has been quite successful in predicting behavioral preferences and a significant amount of empirical data has been accumulated concerning the development of infants spatial CSFs (Hainline & Abramov, 1992; Banks & Dannemiller, 1987; Banks & Salapatek, 1978; Atkinson, Braddick & Moar, 1977). Regardless of the method preferred to determine the infant CSF, (forced-choice preferential looking[14], visually evoked potentials[15], eye-movement voting[16]), a

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[14] CSFs obtained by using the Forced-Choice Preferential Looking Technique are accomplished by presenting the infant with a choice of something over nothing. The "something" in this case is a series of sine wave gratings that vary along the dimension of spatial frequency and contrast. A blind observer then determines which side he or she believes the infant to have fixated, and once that observer's "hit" rate falls below some predetermined criterion, it is hypothesized that the infant can no longer discriminate the sine wave grating from a blank field of equal average luminance.

[15] The Visually-Evoked Potential (VEP) uses electrodes attached to the scalp to record the EEG during presentation of sine-wave gratings and a particular variant, the sweep VEP, is often used to obtain infant CSFs. In this variant, one of the stimulus parameters is increased through a series of values during presentation to the infant until some criterion response level is reached. For example, Norcia, Clarke, & Tyler (1990) varied the contrast of square-wave gratings in a series of steps from low to high or from high to low while keeping spatial frequency fixed to find the contrast at which the averaged evoked response falls within the EEG signal's noise and subsequently measured grating acuity by holding contrast constant over a range of low to high spatial frequencies.

[16] Eye Movement Voting (EMV) (Hainline & Abramov, 1997) is a technique adapted from

(continued...)

general agreement exists among researchers that a gradual improvement occurs during the first year of life in both sensitivity to contrast and in the range of spatial frequencies detected by the human visual system. Figure 1 illustrates the normalized CSF's of infants between the ages of 1- and 6-months of age and a normalized adult CSF. As shown, with increasing development of the infant visual system, the peak of the CSF shifts laterally to higher frequencies and upward to higher sensitivities.

It could be argued, in comparison with the other models discussed thus far, that the Linear Systems Model is much more efficient in describing the development of infant pattern preference. The primary methodological improvement of the Linear Systems Model being the ability for researchers to predict infant preference behavior for any pattern based on the physical characteristics of the pattern and the sensitivity of the infant visual system to those components. Therefore one can hypothesize that infants might preferentially fixate that stimulus which contained those contrast and spatial frequency components corresponding to the peak of their contrast sensitivity function. For example, inspection of Figure 1 shows that when compared with adult sensitivity, infants overall are far less sensitive to high spatial frequencies.

(...continued)
the Forced- Preferential Looking method that uses gratings of fixed spatial frequency and contrast that drift either to the right or to the left of a computer screen at some fixed velocity. CSFs are calculated based on the following hypothesis: If the grating is above threshold, it engages eye movements on the part of the observer. A blind observer then judges the direction the stimulus moved, based on the observer's eye movements. If the observer "votes" correctly, the contrast of the grating is reduced until the voter makes an error or if the initial vote is an error, increased until the voter is correct.

Figure 1. Age-related changes in the development of the CSF. Data were obtained from eye-movement voting data (Hainline & Abramov, 1997) using sinusoidal gratings that drifted at 7 deg/sec.

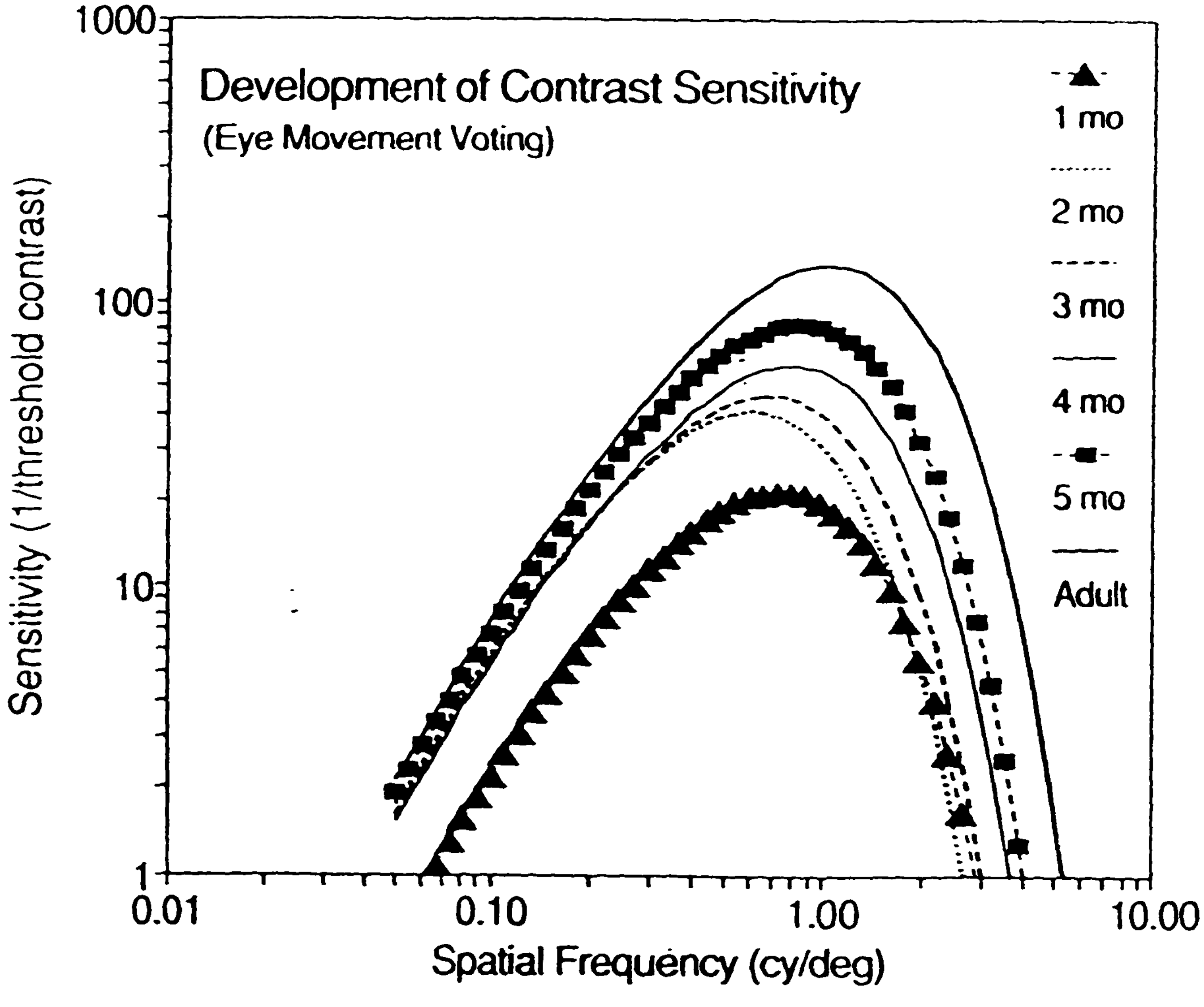

Development of Contrast Sensitivity
(Eye Movement Voting)
1 mo
2 mo
3 mo
4 mo
5 mo
Adult
Sensitivity (1/threshold contrast)
1000
100
10
1
0.01
0.10
1.00
10.00
Spatial Frequency (cy/deg)

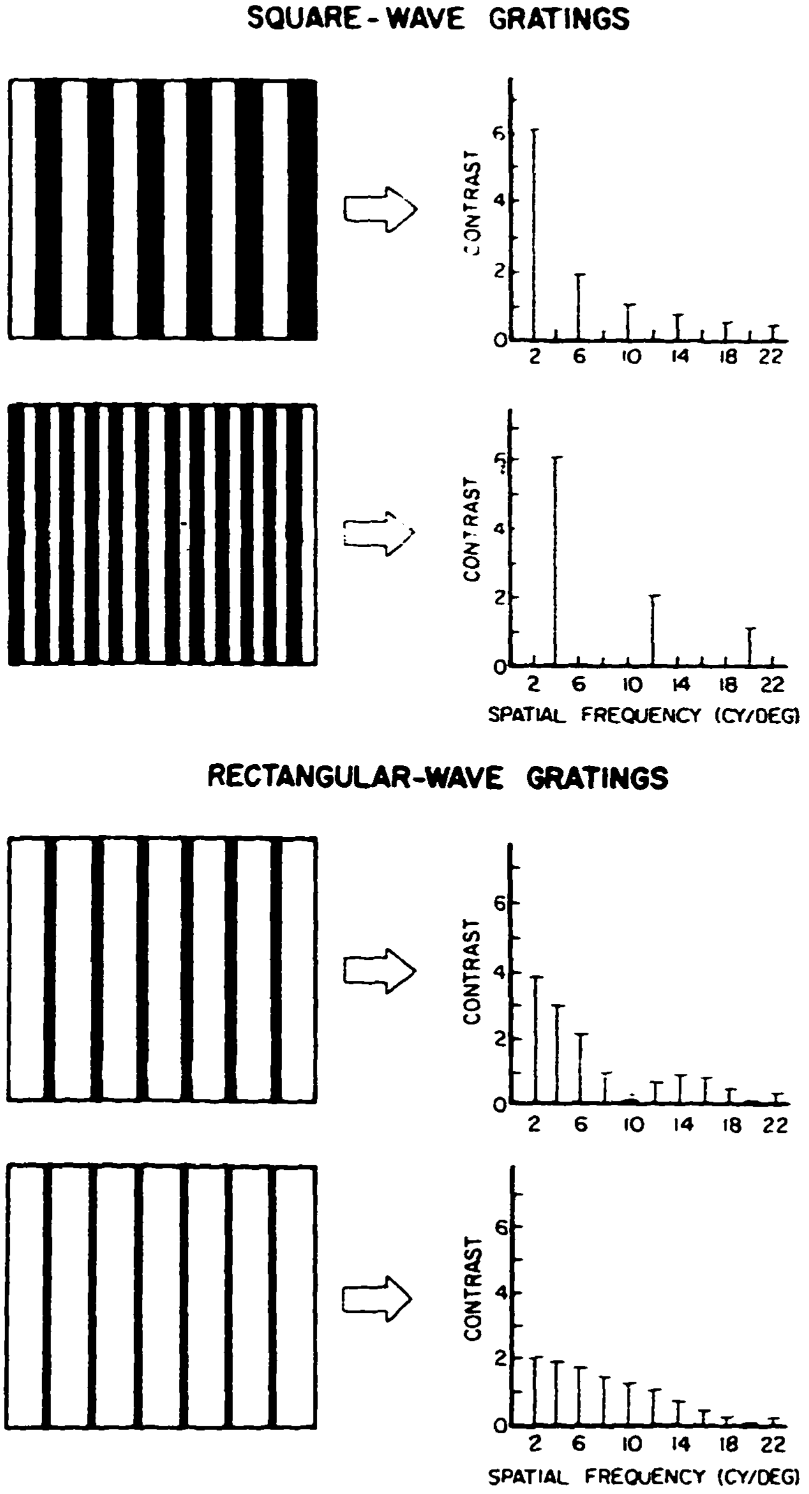
Figure 1

If one were to present an infant with two sets of patterns, one containing high spatial frequency components, and the other containing low spatial frequency components, it would be reasonable to hypothesize the following: Infants would prefer to look at the stimulus containing the low spatial frequency components because the stimulus containing high spatial frequency components would be less visible.

1.8 Replication Studies using the Linear Systems Model: Fantz et al (1975) and Karmel (1975) Revisited

In fact, a number of extant studies have been conducted in which the results of previously reported preference findings (Dannemiller & Stephens, 1988; Kleiner, 1987; Banks & Ginsburg, 1985; Slater, Earl, Morrison & Rose, 1985 Gayl, Roberts, & Werner, 1983; Banks & Salapatek, 1975) have been reinterpreted within the Linear Systems Paradigm. For example, Banks and Salapatek (1981) reexamined the preferential looking time results derived from visual acuity estimates reported by Fantz et al. (1975). Interestingly, it was reported by Fantz et al. (1975) that two different estimates of 1-, 2-, and 3½-month-old infant visual acuity could be obtained when a square wave grating of equally spaced light and dark stripes and a rectangular wave grating of six dark stripes separated by wider light stripes were each paired with a constant luminance unpatterned stimulus. Figure 2 gives examples of square wave and rectangular wave gratings used by Fantz et al. (1975) along with the contrast and spatial frequency information obtained via Fourier Analysis by Banks and

Figure 2. Example of the stimuli used by Fantz et al. (1975) and reanalyzed by Banks and Salapatek (1981). Two square wave gratings of differing stripe widths are shown in the upper left, with its corresponding Fourier Amplitude Spectra to the right. Two rectangular wave gratings of differing black line width are shown in the lower left with its corresponding Fourier Amplitude Spectra to the right.



SQUARE-WAVE GRATINGS

RECTANGULAR-WAVE GRATINGS

Figure 2

Salapatek (1981) for each stimulus. Infants who took part in the Fantz et al. (1975) study were reported to differentially fixate the rectangular wave grating for longer periods of time when that stimulus contained finer black lines as opposed to a square wave grating that contained finer line patterns when these stimuli were separately paired alongside a plain ground. Banks and Salapatek (1975) however, demonstrated that the results reported by Fantz et al. (1975) could readily be predicted using the Linear Systems Model. This was accomplished by first analyzing both the square-wave gratings and the rectangular-wave gratings, that were presented to infants by Fantz et al. (1975), using Fourier Analysis in order to determine the Fourier Amplitude Spectrum of each stimulus. Next, the Fourier Amplitude Spectrum of the images was compared with the age-appropriate CSF of the infants to determine the relationship between the results reported by Fantz et al. (1975), the Fourier components of the images, and the peak values of the infant CSF. In other words, Banks and Salapatek (1981), examined the Fourier Amplitude Spectrum of the images to determine which Fourier Components would and would not be "passed" through the visual system of the infants tested by Fantz et al. (1975). The criterion used to determine which contrast and spatial frequency information would be transferred was the CSF corresponding to the different age groups of infants tested.

The Fourier Amplitude Spectra shown in Figure 2 revealed both the square-wave grating and the rectangular-wave grating contained many different

Fourier Components. However, the component of particular interest to the analysis conducted by Banks and Salapatek was the spatial frequency component of greatest amplitude or the *fundamental frequency component.* As defined by Banks and Salapatek, the fundamental frequency component contained the greatest amplitude and a spatial frequency of 1/X, where X is measured by calculating the distance between the midpoints of adjacent dark stripes. In most cases the lowest spatial frequency component of the spectrum is found at the fundamental component.

Examination of the fundamental component of the square wave grating by Banks and Salapatek (1981) revealed that decreases in stripe width were accompanied by no change in the amount of contrast contained in the image. However, while contrast was not affected by decreased stripe width, an inverse relationship between stripe width and the spatial frequency of the fundamental was found. That is, as stripe width decreased, this decrease directly affected the distance between the midpoints of adjacent dark stripes. In turn, the value of X was decreased, resulting in increased spatial frequency at the fundamental.

The same Fourier Analysis and examination of the fundamental component were also conducted for the rectangular wave grating. In this case Banks and Salapatek (1981) found decreases in the level of contrast at the fundamental component as the black lines of the rectangular-wave grating were made finer. Interestingly however, decreased levels of contrast were not accompanied by an increase in the spatial frequency component. In fact, the spatial frequency component remained the same as the black lines of the rectangular-wave grating were made finer. Decreased stripe width had not affected the spatial frequency component of the rectangular-wave grating because reducing the black lines had not changed the distance between adjacent dark stripes. Consequently, the fundamental of the grating remained constant at 1/X cpd for all stripe widths.

From the above examination of the fundamental components and the CSF's of the infants tested, Banks and Salapatek (1981) were able to predict the detectability to each of the different square-wave and rectangular-wave gratings used by Fantz et al. (1975). When compared, the fit between the predicted results of Banks and Salapatek (1981), and the observed results of Fantz et al. (1975) was quite good. This finding led Banks and Salapatek (1981) to conclude that the information regarding contrast and spatial frequency at the fundamental component could be linked to an infant's visibility of an image and consequently might also be responsible for infant preference behavior. In other words, infants' detection of the aforementioned patterns could be determined by their sensitivity to the fundamental component.

A reanalysis of the results reported by Karmel and Maisel (1975) which showed increased preference responses by infants to checkerboard patterns increasing in complexity and amount of information was also conducted by Banks and Salapatek (1981). In accord with the reanalysis of the Fantz et al.

(1975) data, the reanalysis of the findings by Karmel and Maisel (1975) also revealed that infants of different age groups most preferred the checkerboard pattern whose spatial frequency component at the fundamental fell at or within the infant's peak sensitivity.

1.8.1 Evaluating the Replication Studies of Banks and Salapatek (1981)

An extensive literature can be found (Dannemiller and Stephens, 1988; Banks and Ginsburg, 1985; Kleiner, 1987; Gayl, Roberts, and Werner, 1983; Slater, Earl, Morrison and Rose, 1985) which provides reanalysis of extant preference studies. However, it could be argued that these reanalyses do not provide an explicit test of one model of visual preference against another because these studies did not provide predictions that differed from the preference behavior reported in the original Fantz et al. (1975) and Karmel (1975) studies. For example, Banks and Salapatek (1981) utilized the Linear Systems Model and explained post-hoc the infant preference behaviors reported by Karmel and Maisel (1975) and Fantz et al. (1975). Therefore, it could be reasonably assumed that the finding's presented by Banks and Salapatek (1981) did not directly test the assumptions put forth by the Linear Systems Model. In other words, by discerning the input-output relationship between the visual system of an observer and the sine-wave components which constitute a pattern, could a priori predictions be made when infants are shown two patterns that differ along some dimension?

1.9 A priori Preference Predictions Using the Linear Systems Model

It is possible that an even more direct measure of the potential of the Linear Systems model to predict infant preference responses could be obtained by altering the contrast and spatial frequency components of pairs of stimuli known to elicit reliable differential preferences; as described above several sets of such stimuli exist, (Brennan, et al., 1966; Fantz et al.,1975; Fantz & Miranda, 1975). By manipulating the contrast and the spatial frequency components of selected stimulus pairings based upon the CSF of the intended observer, the possible influence that sensory processing has on the direction of fixation during preferential looking tasks could be investigated. This would be accomplished by reconstructing those stimuli known to elicit preferences in younger infants by using Fourier analysis in combination with the CSF's of both the younger and older infants being tested. If the development of contrast sensitivity was the variable responsible for the reported changes in preference behavior of infants, then the following prediction could be made; stimuli constructed to mimic what is seen by younger infants in terms of contrast and spatial frequency, when shown to older infants, would revert the preference behavior of the older infant to the preference responses of a younger infant.

Hainline and her colleagues (Hainline & Abramov, 1992; Bauer, Riddell, & Hainline, 1994; Pagano, Riddell, & Hainline, 1994) have suggested such a series of studies. The research conducted by Pagano et al. (1994) used acute/obtuse stimulus pairings that had been previously shown (Cohen & Younger, 1981; Slater, Morris & Brown, 1991) to elicit differential novelty preference results across infancy to test the utility of the Linear Systems Model. Groups of infants between the ages of 4 and 5 months were presented with one of four sets of stimulus pairings. Two sets of acute/obtuse stimulus pairs were taken directly from studies by Cohen and Younger (1981) and Slater et al. (1991). The remaining two sets of "filtered" stimuli were modified using the Fourier Amplitude Spectrum of the stimuli and the CSF of a 1-month-old infant and a 6-month-old infant. Two predictions were made by Pagano et al. (1994): First, the group of infants which viewed the original or unfiltered acute/obtuse stimulus pairings would produce novelty preference behavior consistent for their age range. That is, when infants were familiarized or habituated to an acute angle those same infants would preferentially fixate an obtuse angle during a paired presentation test phase. In addition, when infants were habituated to an obtuse angle, infants would preferentially fixate the acute angle of the pairing. On the other hand, the group of infants who viewed the filtered stimulus pairings would produce novelty preference behavior consistent with that of a younger infant. In this case, no novelty preference response should be found, regardless of which stimulus the infant was habituated to.

As hypothesized, the infants who took part in the Pagano et al. (1994) study, when presented with unfiltered acute and obtuse angle pairings, produced the same novelty preference response as reported by Cohen and Younger (1981) and Slater et al. (1991) for their specific age group. However when another group of 4-and 5-month-old infants were presented with filtered acute and obtuse stimulus pairings, two distinct fixation response patterns were found. First, the group of infants habituated to the filtered obtuse angle showed a significant novelty preference response (mean looking time equaled 76%) for the filtered acute angle. On the other hand, the group of infants habituated to the filtered acute angle continued to fixate the filtered acute angle for a significantly longer period (64%) during subsequent test trials.

The results obtained by Pagano et al. (1994) prompted a post-hoc analysis of the results reported in Slater et al. (1991) to determine if the 3-day-old-infants used in the latter study displayed the same pattern of novelty preference as reported by Pagano et al. (1994). Interestingly, the same behavioral novelty preference pattern was found when the Slater et al. (1991) results were reanalyzed. That is, the neonates tested by Slater et al. (1991) could also be broken down into two groups of infants: Those infants who produced a significant novelty preference when habituated to the obtuse angle and those infants who showed a familiarity preference when habituated to the acute angle.

Based on the reanalysis of the results reported by Slater et al. (1981), Pagano et al. (1994) concluded that the older infants tested in their study did in fact produce the younger form of novelty preference behavior reported in previous studies (Cohen & Younger, 1981; Slater et al, 1991). Furthermore it was determined by Pagano et al. (1994) that because the results of both studies were congruent, infant novelty preference was influenced by the development of sensory processing which is related to the development of contrast sensitivity. However Pagano et al. (1994) were also quick to caution that the results obtained in the filtered portion of their study could be interpreted in another way, since the primary finding was based on a post-hoc analysis of the data.

The more relevant interpretation of the Pagano et al. (1994) finding to this discussion described the data in terms of the Hierarchical Stimulus Dimension Model. Pagano et al. (1994) hypothesized that when filtered, the acute angle could have taken on a "more curvilinear" appearance than the obtuse angle. This was due to the fact that filtering appeared to "smooth" and "round" the apex of the acute angle thereby producing a stimulus with an apparent curvilinear component. On the other hand, the obtuse angle when filtered appeared to retain its sharp linear apex. This being the case, then the results reported by Pagano et al. (1994) could easily be explained in terms of preference for curvilinearity over rectilinearity as suggested by the Hierarchical Model proposed by Fantz et al. (1975).

1.10 Can Infant Preference Behavior Reliably be Predicted Using the Linear Systems Model?

The fact that the results reported by Pagano et al. (1994) could be explained both by the Linear Systems Model and the Hierarchical Stimulus Dimension Model returns the issue to which model or models more effectively predicted infant preference behavior. It was with this question in mind that the following series of studies were undertaken. That is, the primary purpose of the research presented in the following chapters was to determine if using a Linear Systems Model to describe infant preference behavior allowed the a priori prediction of preference behavior. This was accomplished by using stimulus pairs known to elicit specific preference behavior during specific periods of infant development and restructuring those stimuli to mimic what is believed to be viewed through the visual system of a younger infant. Consequently, two hypotheses are tested. First, when presented with "unfiltered" versions of stimulus pairs, infant preference behavior was predicted to replicate previous findings and therefore should be related to age of the infants tested. On the other hand, when infants are shown the restructured or filtered sets of stimulus pairings, older infants should demonstrate preferential response behavior consistent with that of younger infants.

Experiment #1 and Experiment #2 were designed to investigate the utility of the Linear Systems Model. This was accomplished by presenting older groups of infants with the original curvilinear and rectilinear stimulus pairings used by Fantz et al. (1975) along with sets of the same stimuli, restructured to mimic what is believed to be seen by the visual system of a 1-month-old infant. If the development of contrast sensitivity does indeed affect preference behavior, then when shown the restructured sets of stimulus pairings, older infants should demonstrate preferential response behavior consistent with that of younger infants.

Experiment #3 further tested the utility of the Linear Systems Model and examined the possible underlying mechanisms which are believed to lead to the direct development of pattern perception. Namely, the hypothesis was that the direction of an infant's visual preference will be related to spatial frequency at the fundamental component of the stimulus and to lower spatial frequency at the fundamental component in general as opposed to the infant's peak sensitivity to that component as reported by Banks and Salapatek (1981).

Finally, Experiment #4 tested adult subjects to uncover the depth of the curvilinear over rectilinear preference response. If as reported by Fantz et al. (1975) the development of form discrimination was crucial to performance of tasks later in life such as object recognition, social responsiveness and reading, then one might reasonably hypothesize that the preference for curvilinear form would be found in adulthood. If so, could a relationship be found between adult and infant preference behaviors?

A single series of studies cannot address all the questions we have or provide definitive answers to all the issues raised in the preceding discussion. However, investigation of the relationship between infant sensory processing, and the development of form perception, will further our knowledge of the content of infant perceptual development. Moreover, it will contribute to our understanding of how infants construct knowledge about their environment.

[2]

EXPERIMENT #1

EXPERIMENTAL DESIGN AND METHOD

2.1 Subjects

Fifteen 4- and 5-month-old infants, 10 male and 5 female, took part in this study. Subjects were selected from the infant population who were taken to the Brooklyn College Infant Study Center by their parents to have their accommodation and convergence screened using paraxial photorefraction[17]. Only those infants who met the following criteria were selected for inclusion in

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[17] Photorefraction is a method used by many researchers (Braddick, Atkinson, French, & Howland, 1979; Dobson, Howland, Moss, & Banks, 1983; Abramov, Hainline, & Duckman, 1990) to screen infants for refractive errors. The particular protocol used to screen infants at the Brooklyn College Infant Study Center involves taking a series of photographic flash pictures of an infant as they change their accommodation toward little dolls that light-up and play music which have been placed at 5 distances from the observer. The amount of light reflected from the fundus of the eyes is then qualitatively and quantitatively measured to determine if the infant has correctly accommodated to the various targets demands.

this study; (1) Infants who ranged between 4 and 5 months of age. This age group of infants was chosen because they were presumed to differentially fixate patterns based on form configuration as described by Fantz et al. (1975). Consequently, all infants were expected to show a significant preference during the unfiltered condition testing portion of the study for the curvilinear stimulus over the rectilinear stimulus. (2) Infants born near or at full range term; (3) Infants who were near or close to normal birth range weight; (4) Infants who did not spend any time in the *Neonatal Intensive Care Unit* (NICU) due to serious illness.

Of the fifteen infants who took part in this study, two were excluded because of failure to complete sessions due to fussiness. The final sample of thirteen infants, (mean age = 147.7 days; SD = 28.5 days) were healthy (mean birth weight = 3184.3 grams; SD = 648 grams), and full-term (mean gestation = 39.4 weeks; SD = 1.5 weeks).

2.2 Photorefraction

Either before or after having taken part in the preferential looking task, each infant was "photorefracted" to determine his or her current measure of accommodation and convergence. The paraxial photorefraction system, method and technique used were directly taken from Abramov et al. (1990). Qualitative analysis revealed that all infants who participated in this study accommodated and converged appropriately for their age.

2.3 Unfiltered Stimuli

A subset of two curvilinear and rectilinear stimulus pairings used by Fantz et al. (1975) to test infant preference behavior were chosen for this study. The stimulus pairings are described as either "Pairing" 1 or "Pairing" 2 . Thus the Pairing number described the set of curvilinear and rectilinear stimuli paired together for presentation. Each individual stimulus within a pairing was further distinguished in terms of "C" for curvilinear and "R" for rectilinear with its corresponding pairing number following the letter. Therefore, stimulus Pairing 1 contained the curvilinear stimulus C1 and rectilinear stimulus R1 and stimulus Pairing 2 contained the curvilinear stimulus C2 and rectilinear stimulus R2. Approximate values were used to recreate the stimuli for this study because the actual stimulus parameters, for example, width and length of the stimuli, reported by Fantz and his colleagues (1975) were not consistently described across experiments. Figure 3 shows the stimulus Pairing 1 and the stimulus Pairing 2 chosen for use in this study. The Pairing 1 curvilinear stimulus (C1) was constructed of two 1.7 cm wide by 13 cm long curved black line segments positioned at the center of a 15.2 cm wide by 20 cm long white ground. A 4.5 cm distance separated each of the curved line segments creating an image that measured 8.4 cm wide across the top of the figure by 13 cm long. The entire C1 stimulus (figure and ground) subtended approximately 28.4° by 36.8° of visual angle at a viewing distance of 30 cm, while the figure portion of the C1 stimulus subtended 15.9° by 24.5° of visual

Figure 3. Unfiltered Pairing 1 and Pairing 2 stimuli used in Experiment 1. Stimuli were taken from a larger group of curvilinear and rectilinear pairings used by Fantz et al. (1975).

Unfiltered Stimulus Pairings: Experiment 1

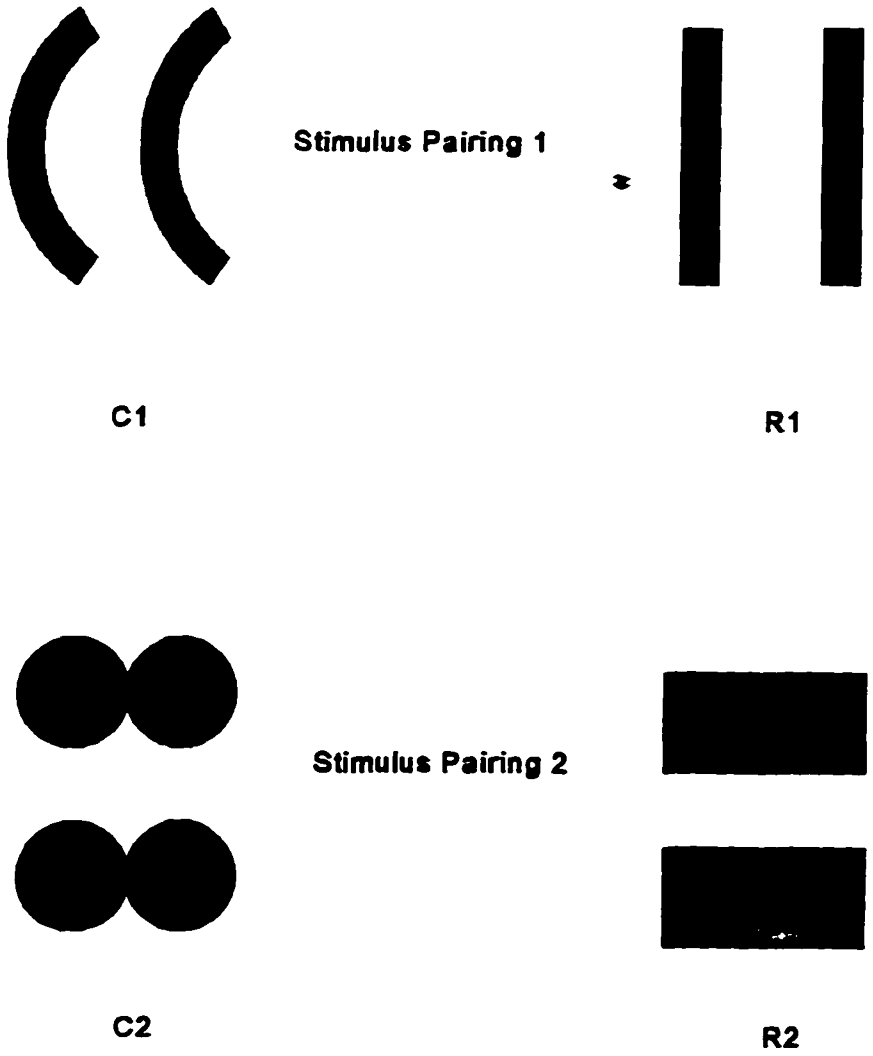

Figure 3

angle. Mean average luminance[18] of the C1 stimulus was approximately 150 cd/m^2.

The Pairing 1 rectilinear stimulus (R1) was constructed of two 1.9 cm wide by 12.6 cm long, black rectangles positioned at the center of a white 15.2 cm wide by 20 cm long ground. A 5 cm distance separated each of the line segments thus creating an image that measured 8.8 cm wide across the top of the figure by 12.6 cm long. The entire R1 stimulus (figure and ground) subtended approximately 28.4° by 36.8° of visual angle, while the figure portion of stimulus R1 subtended 16.7° by 23.7° of visual angle. Mean average luminance of the R1 stimulus was approximately 200 cd/m^2.

The Pairing 2 curvilinear stimulus (C2) was constructed of two pairs of adjoining 5.1 cm in diameter black circles situated along the horizontal plane of a 15.2 cm wide by 20 cm long white ground. Each pair of circles were separated by a distance of 6.9 cm from the point where the pairs of circles were joined, thereby creating an image that measured 10.2 cm wide by 13.9 cm long. The entire C2 stimulus (figure and ground) subtended approximately 28.4° by 36.8° of visual angle, while the figure portion of stimulus C2 subtended approximately 19.3° by 26.1° of visual angle. Mean average luminance of the C2 stimulus was approximately 210 cd/m^2.

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[18] Luminance for all stimuli used in this study were measured using the Photo Research PR-703a Spot Spectra Scan, Fast Spectral Scanner and were calculated by obtaining the average of the lightest area of the stimulus and the darkest area of the stimulus under the same illumination used during testing conditions.

The Pairing 2 rectilinear stimulus (R2) was constructed of two 10.2 cm wide by 5.1 cm long black rectangles positioned along the horizontal plane of a white 15.2 cm wide by 20 cm long ground. A 3.8 cm distance separated the rectangles, thereby creating an image that measured 10.2 cm wide across the top of the figure by 14 cm long. The entire R2 stimulus (figure and ground) subtended approximately 28.4° by 36.8° of visual angle, while the figure portion of stimulus R2 subtended 19.3° by 26.3° of visual angle. Mean average luminance of the R2 stimulus was approximately 160 cd/m^2.

2.4 Filtered Stimuli

Each Pairing 1 and Pairing 2 stimulus was Fourier analyzed to obtain its two-dimensional Fourier Amplitude Spectrum using Visilog 4.0 Software[19]. The Fourier Amplitude Spectrum of each stimulus was then further modified by rescaling amplitude and its corresponding spatial frequency components by multiplying the amplitude at each spatial frequency by a normalized spatial contrast sensitivity function[20] appropriate for a 1-month-old infant. Multiplication of the Fourier Amplitude Spectrum by the 1-month-old CSF, in effect, removed the contrast and spatial frequency components that could not be "transmitted" by

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[19] Visilog 4.0 software is produced by NOESIS Corporation © 1995

[20] As stated previously, each individual visual system will uniquely filter the information contained in a pattern. Thus, each person will have their own distinct CSF. In order to "normalize" a spatial contrast sensitivity function we must divide all the mean values by some constant. For example if all mean values are divided by maximum sensitivity, then normalization is with respect to the maximum sensitivity. While normalized contrast sensitivity functions will differ from experiment to experiment (as stated earlier, different methods of obtaining CSF's will produce different results) the basic shape and parameter values of CSF's are generally agreed upon by researchers in the field.

the one-month-old visual system. Since the stimuli used in this study were viewed by infants between the ages of 4-and-5 months, a further manipulation of the resulting rescaled or "filtered" Fourier Amplitude Spectrum was necessary. This was accomplished by inversely filtering or dividing the 1-month old, filtered Fourier Amplitude Spectrum by a normalized 6-month-old[21] CSF. The effected result of this manipulation thus returned contrast and spatial frequency components to which both the 1-month-old and 6-month-old are equally sensitive to the one-month-old amplitude spectrum. Had we multiplied the amplitude spectrum both times, first by the CSF of the intended observer, in this case a 1-month-old and then multiplied the amplitude spectrum by the CSF of the actual observer, in this case a 6-month-old, the resulting amplitude spectrum would have produced an "overfiltering" or "doubling" of those spatial frequencies which the 1-month-old and the 6-month-old are equally sensitive.

The problems raised by this are best appreciated by considering some low spatial frequency, to which a 1-month-old and a 6-month-old are approximately equally sensitive; at that frequency, multiplication of the Fourier Spectrum by the 1-month-old CSF would result in little to no rescaling at that component. However, if we were to resynthesize the filtered image at this point and presented that image to a 6-month-old, we would not be accounting for the

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[21] We chose to use the normalized CSF of a 6-month-old because the age range of infants tested covered 4 months 0 days to 5 months 30 days. The mean CSF in this case would have been the 5-month-old CSF, however little difference can be found between the 5- and 6-month-old CSF's and therefore the upper end of the age range was chosen for inverse filtering.

occurrence of the natural filtering which took place by the 6-month-old visual system. Consequently, when the 6-month-old viewed the image an additional level of filtering or squaring at this frequency component would have naturally occurred.

Since it was necessary to consider the CSF of the intended observer, in this case the 6-month-old, we needed to rescale those components of the filtered amplitude spectra to which the 6-month-old visual system was also sensitive. As previously explained this compensation is accomplished by inversely filtering the 1-month-old amplitude spectrum by the 6-month-old amplitude spectrum before resynthesizing the image. Consequently, when the image is now viewed by the 6-month-old, its visual system will naturally negate the inverse filtering imposed by dividing the 6-month-old amplitude spectrum by the 1-month-old amplitude spectrum.

The following equation (Equation 2) used to filter the Pairing 1 and Pairing 2 stimuli was derived from Kelly's (1979b) spatio-temporal resolution model and from the logarithmic form used by Hainline & Abramov (1997):

$$S=kv(2\pi)^2(x^2+y^2)-10-\sqrt{\frac{x^2+y^2}{F_{\max}}} \qquad (2)$$

Where S is sensitivity (reciprocal contrast at threshold), k is a scale factor, v is stimulus velocity, F_{max} is the spatial frequency at the peak of the CSF and X and Y refer to the polar coordinates of the image obtained via Fourier analysis. The parameter values used to obtain the one-month-old and six-month-old CSF functions are derived from eye-movement voting data obtained by Hainline & Abramov (1997) and are given in Table 1. All modifications to the original Visilog 4.0 software package were programed in C language by Dr. Shuai Chen of the Brooklyn College Infant Study Center.

The qualitative changes to the Pairing 1 and Pairing 2 stimuli are presented in Figure 4. The resulting "filtered" images appeared "blurred" or "smeared" when compared with the unfiltered Pairing 1 and Pairing 2 stimuli. Filtering the images also produced a reduction in the level of contrast and removed high spatial frequencies that were not within the range of the 1-month-old infant's visual system. In the case of the Pairing 1 and Pairing 2 stimuli all of the contrast and high spatial frequency components were found along the outer edges of the stimulus pairings, which resulted in a greater effect of filtering in these regions.

While filtering the images affected the appearance of the patterns, the visual angle subtended by the figure and ground portion of the filtered Pairing 1 and Pairing 2 stimuli remained the same as the unfiltered Pairing 1 and Pairing 2 stimuli. Mean average luminance of the filtered Pairing 1 and Pairing 2 stimuli were approximately 190 cd/m^2 (C1), 190 cd/m^2(R1), 200 cd/m^2 (C2), and 210 cd/m^2 (R2).

Table 1

Values Used to Filter Stimuli in Experiment 1. Values were Taken from Eye-Movement Voting Data of Hainline & Abramov (1997)

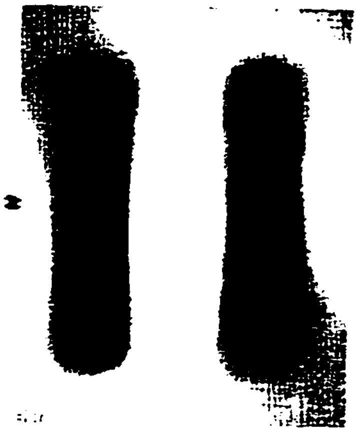
Age	K	V	Fmax
1-month-old	15	1	0.45
2-month-old	12	1	0.70
6-month-old	10	1	1.0
Adult	6	1	2.5

Figure 4. Filtered Pairing 1 and Pairing 2 stimuli used in Experiment 1. As discussed above, each individual has his or her own CSF. Therefore when viewing the stimuli the reader is naturally applying his or her own filter. Therefore, the reader is not actually looking at the image through the visual system of a 1-month-old infant. Since however, the CSF of a 6-month-old closely approximates the CSF of an adult the images shown in this figure do approximate how information is transferred through the visual system of a 1-month-old. The reader may also turn to Figure 14 of the text which shows the effects on the Pairing 1 and Pairing 2 stimuli when filtered by a 1-month-old CSF and inversely filtered by an adult CSF.

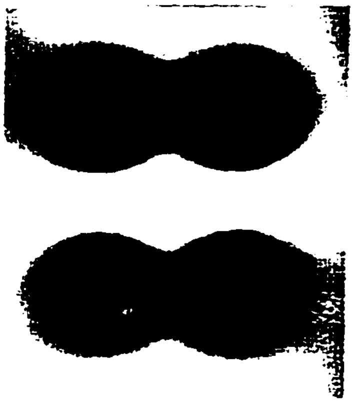
Filtered Stimulus Pairings: Experiment 1

C1

Stimulus Pairing 1

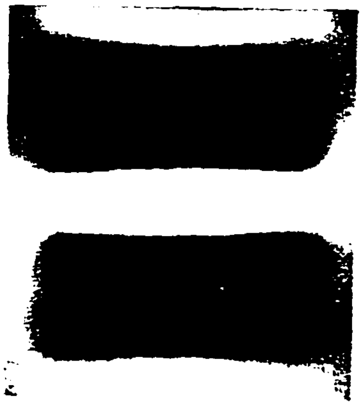


R1



C2

Stimulus Pairing 2



R2

Figure 4

2.5 Preferential Looking Procedure

A within subjects design was used and each infant was randomly presented with two unfiltered paired presentations of Pairing 1 and Pairing 2 stimuli and two filtered presentations of Pairing 1 and Pairing 2 stimuli. Since each stimulus pairing was counterbalanced for left/right order, all infants viewed a total of eight paired stimulus presentations.

Infants were taken to a testing room painted flat, granite grey and were centrally seated on an assistant's lap 30 cm in front of a viewing theater painted the same color as the walls (Figure 5). Parents were seated behind the infant and were instructed not to speak or to cue the infant in any way. If anytime during the experiment the infant became distressed, the trial was stopped and did not continue further until the research assistant or parent comforted the child. Infant head and body movements were not restricted.

When the infant was judged to be in a calm and alert state, a curvilinear/rectilinear pairing was displayed on a 58.42 cm by 5.4 cm piece of white posterboard. A 3 cm in diameter peephole drilled through the center of the poster board allowed the experimenter to view left/right fixations made by the infant. The testing room was dark, except for two 40 watt fluorescent light bulbs mounted out of the infant's view, which illuminated the stimuli. Infants were judged to be fixating a stimulus if either the right or the left stimulus could be observed as a corneal reflection of the infant's pupil. Each presentation

Figure 5. Sketch of viewing theater used for presentation of stimulus pairings to infants.

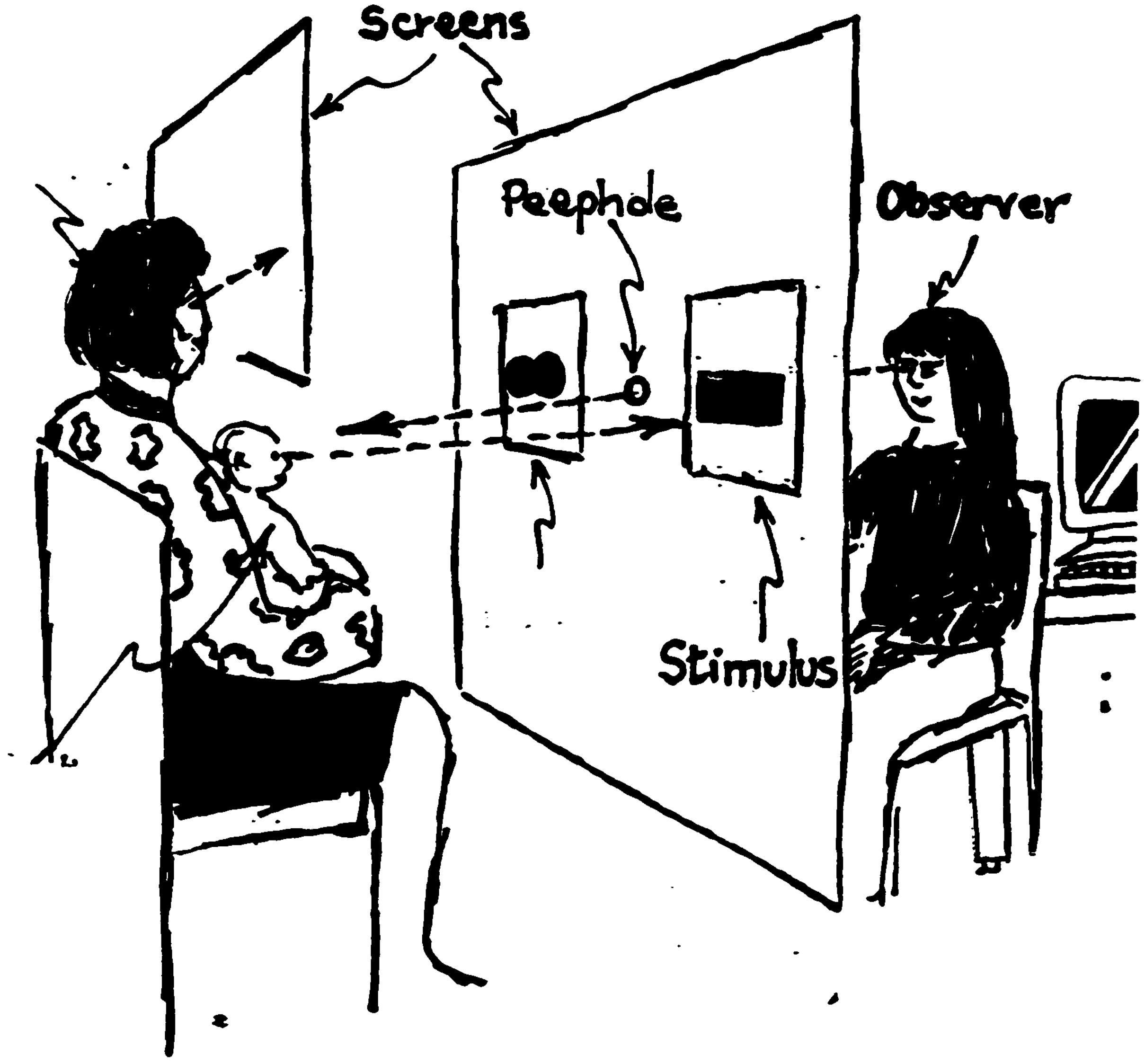


Figure 5

continued until a total of ten seconds accumulated looking time at either of the stimuli occurred. During interstimulus intervals the infant was turned away from the stimuli while the experimenter prepared the next set of pairings for presentation. Looking time was recorded by keyboard press on a NEC PowerMate 286 computer programmed in C language by Dr. Simeon Doytchinov of the Brooklyn College Infant Study Center to record right, left and "off target" fixations.

Reliability of fixation time scoring was assessed with the help of an independent observer, who was not present during the initial testing procedure. The independent observer later viewed and scored fixations from videotape for five of the infants chosen at random. Inter-observer reliability between the original observer and the independent observer was good. The correlation coefficient between the two observers fixation time measures was 0.92.

[3]

RESULTS

3.1 Infant Looking Time Profile

Experiment 1 focused on an infant's ability to discriminate between unfiltered and filtered versions of curvilinear and rectilinear stimulus pairings. Therefore, how long, and where an infant looked with regard to the Pairing 1 and Pairing 2 stimuli were the primary variables analyzed. The duration of each trial varied both between infants and within the course of a session for an individual baby. However, the total accumulated looking time toward the stimulus pairs for each trial was the same for all infants. That is, regardless of the total number of trials to complete an experimental session or the amount of time spent looking off target, each subject's total accumulated looking time toward a stimulus pairing totaled 10 seconds. As a result, total looking time for each paired presentation equaled 20 seconds since all infants viewed the stimulus pairs twice.

A percentage preference looking time score toward each stimulus was obtained by dividing the amount of time spent looking at a particular stimulus by 20 and multiplying that number by 100. For example, if an infant fixated stimulus C1 over two presentations for a total of 15 seconds and stimulus R1 for a total 5 seconds, the percentage preference looking time for the C1 stimulus was recorded as 75% ((15/20) * 100) and the percentage preference looking time for the R1 stimulus was recorded as 25% ((5/20) * 100).

3.2 Procedure for Data Analysis

The data were analyzed to determine if, as hypothesized, differences in mean percentage preference looking time could be found between presentations of unfiltered curvilinear and rectilinear stimulus pairings and filtered curvilinear and rectilinear stimulus pairings. Moreover, it was hypothesized that when infants viewed unfiltered curvilinear and rectilinear stimulus pairings, a significant preference would be found for the unfiltered curvilinear stimulus. On the other hand, when those same infants were presented with filtered curvilinear and rectilinear stimulus pairings, no differential fixation response between the stimulus pairings was anticipated. Alpha level for the following analysis was set at 0.01.

3.2.1 ANOVA Analysis of Mean Percentage Looking Time. Means and standard errors were computed for the Pairing 1 and Pairing 2 preference percentage looking time scores for the unfiltered and filtered stimuli and are given in Table 2. The mean percentage preference looking times from this experiment were analyzed by holding the level of stimulus dimension (curvilinear versus rectilinear) constant[22] across a 2 x 2, level of filtering (unfiltered versus filtered), by stimulus pairing (Pairing 1 versus Pairing 2) within-subjects design ANOVA [23].

A main effect was found at the level of filtering, $\underline{F}\ (1,12) = 24.21, \underline{p} < .0001$, whereas no difference was found for pairing of stimulus viewed. In addition, no significant two-way interaction was found between the level of filtering and the stimulus pairing viewed by infants.

3.2.2 ANOVA Results As hypothesized, infants who viewed the unfiltered Pairing 1 and Pairing 2 stimuli fixated the curvilinear stimulus of the pairings for significantly longer periods of time when compared with its unfiltered rectilinear counterpart. Those same infants however, when presented with filtered Pairing 1 and Pairing 2 stimuli demonstrated no preferential fixation

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[22] Since all infant fixation times were converted to percentages it was necessary to hold one factor of stimulus dimension constant within the factorial design because the marginal means for the variable of filtering must always equal .50. Therefore any analysis which included both stimulus dimensions of curvilinear and rectilinear stimuli would never produce a main effect for filtering.

[23] Two separate ANOVA's could have been conducted for this analysis; as reported, one holding the stimulus dimension of curvilinearity constant and the other holding the stimulus dimension of rectilinearity constant. It is not necessary to report the results of the rectilinear analysis since this ANOVA would produce exactly the same results as the ANOVA holding the stimulus dimension of curvilinearity constant. This occurs because we are using percentage data and therefore the group means for the curvilinear and rectilinear stimuli are not independent of each other. It should also be noted that the results for all of the Experiments that follow will be reported in the same manner. That is, only the results for the stimulus dimension of curvilinearity will be reported.

Table 2

Mean Preference Percentage Looking Times Pairing 1 and Pairing 2 Stimuli.

Mean percentage preference scores are given only for the curvilinear stimulus of the pairing. Rectilinear stimulus values can be calculated by subtracting the curvilinear value from 100%. Standard errors are the same for both curvilinear and rectilinear stimuli.

Stimulus Dimension		n	M	SE
Unfiltered				
	C1 Stimulus	13	74.4*	4.3
	C2 Stimulus	13	77.9*	3.2
Filtered				
	C1 Stimulus	13	53.2	2.5
	C2 Stimulus	13	64.8	3.7

*$p < .01$. Indicates difference between curvilinear and rectilinear stimulus pairings.

response to either stimulus of a pairing. While infants did continue to look longer at the curvilinear stimulus across filtered pairings, mean fixation for the unfiltered C1 stimulus decreased from 74.4% to 53.2% when the stimulus was filtered. Although the reduction in looking time for the C2 stimulus was not as large as the reduction in looking time for the C1 stimulus, a decrease in looking time was nonetheless evident. When filtered, mean percentage preference looking time for the unfiltered C2 stimulus decreased from 77.9% to 64.8%. Additionally, no significant difference was found between the C1 and C2 unfiltered and filtered stimuli. The effects of filtering on infant preference behavior are illustrated in Figure 6a (Type 1) and Figure 6b (Type 2).

3.2.3 Analysis of Mean Percentage Looking Time from 50%. The information provided by the preceding ANOVA was important, but it was also necessary to analyze whether mean percentage preference times were significantly different from a hypothetical baseline of 50%. Since the original amount of time that an infant fixated a stimulus was converted to percentage data, any mean percentage preference looking time significantly different from 50% would provide additional support for a preference for that stimulus. For example, while the factorial design used in this experiment revealed that infants significantly preferred to fixate the unfiltered C2 stimulus 77.9% of the time to its unfiltered rectilinear counterpart, that same looking time when compared with 50%, might not differ from this baseline measure. If this were the case it could be argued that while infants fixated the curvilinear stimulus significantly longer

Figure 6a. Mean percentage looking time as a function of stimulus pairing and level of filtering for the Pairing 1 stimuli. The asterisk indicates that the mean looking time was also significantly different when compared to a baseline of 50%. The data are presented as a line graph for purposes of clarity.

Figure 6b. Mean percentage looking time as a function of stimulus pairing and level of filtering for the Pairing 2 stimuli. The asterisk indicates that the mean looking time was also significantly different when compared to a baseline of 50%. The data are presented as a line graph for purposes of clarity.

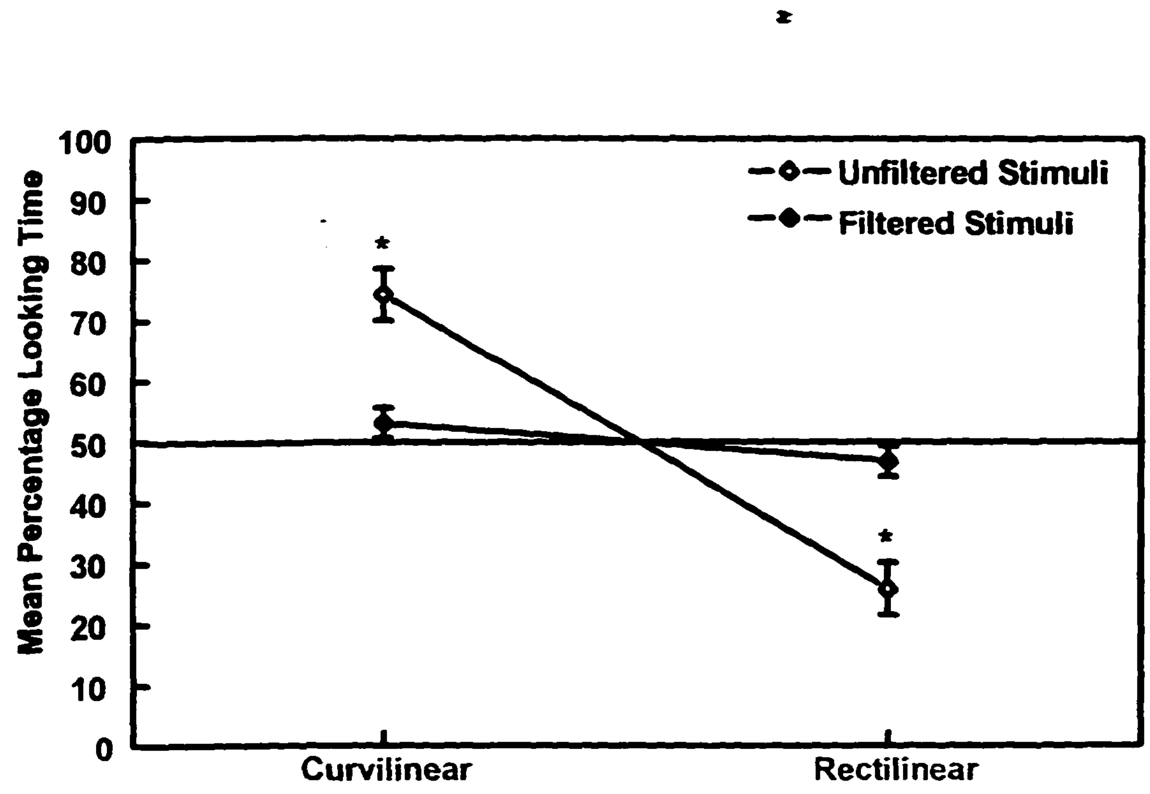
*
Mean Percentage Looking Time
100
90
80
70
60
50
40
30
20
10
0
—◇— Unfiltered Stimuli
—◆— Filtered Stimuli
*
*
Curvilinear
Rectilinear

Figure 6a

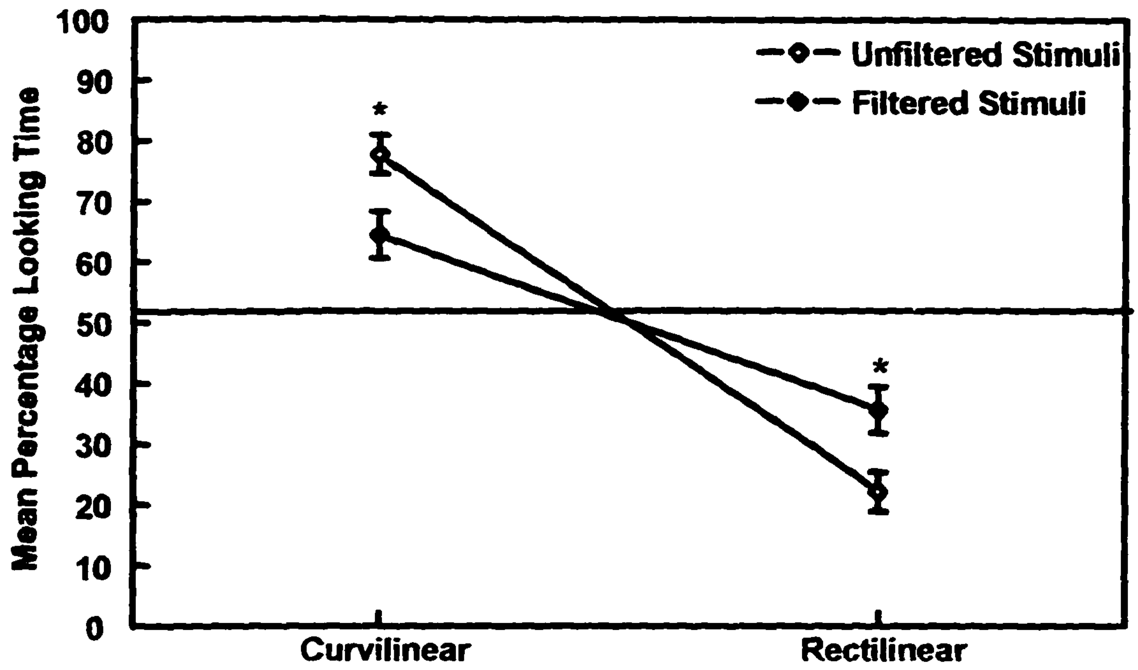
Mean Percentage Looking Time
100
90
80
70
60
50
40
30
20
10
0
Unfiltered Stimuli
Filtered Stimuli
*
*
Curvilinear
Rectilinear

Figure 6b

than the rectilinear stimulus, these results had not differed from baseline and therefore the preference observed for the C2 stimulus could not accurately have been determined from these results. Conversely, the same situation could occur in the case of the filtered C2 stimuli. That is, while the factorial design revealed a significantly lower mean preferential fixation response to the filtered C2 stimulus (64.8), this response could very well differ from a baseline of 50% and would therefore indicate that while the filtered C2 and R2 stimuli had not differed from each other, infants did prefer to look at the C2 stimulus for a significantly longer period of time when compared to some baseline measure.

3.2.4 Results: Mean Percentage Looking Time Versus 50% Baseline.

Four paired t-tests[24] were conducted to determine if differences could be found between the mean percentage preference looking time for each of the unfiltered and filtered curvilinear stimuli used in this study and a baseline of 50%. Because four separate paired t-tests were being utilized, the alpha level for each test was adjusted by dividing the original alpha level, (.01) by the number of tests being conducted (4). Therefore in order for any mean preference percentage looking time to be considered significantly different from 50% the t-value would have to have been significant at the .0025 alpha level.

The unfiltered C1 stimulus, $t\ (12) = 5.68$, $p < .0001$, and the unfiltered C2

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[24] As explained with the ANOVA analysis, because the mean percentage preference looking times of the curvilinear and rectilinear stimuli are not independent of each other we can ascertain the mean, standard error, and level of significance of one stimulus once the mean, standard error and level of significance for the other stimulus is known.

stimulus, $t\,(12) = 8.59$, $p < .0001$ both significantly differed from a baseline of 50%. Moreover when these results were combined with the results from the ANOVA analysis they strongly replicated the findings of Fantz and his colleagues (1975) in that infants over the age of 3 months preferred the curvilinear stimulus of the pairing to its rectilinear counterpart. However, when the filtered C1 and C2 stimuli were compared against 50%, a significant difference, $t\,(12) = 13.96$, $p < .002$ was found between the C2 stimulus and 50% whereas no difference was found between the filtered C1 stimulus and 50%.

[4]

DISCUSSION

4.1 Overview of Results

The principle finding of Experiment 1 reveals that it is possible to change 4-and 5-month old infant preference to a form consistent with the preference behavior of younger infants. This was accomplished by creating stimuli that provide the older infant with the same spatial frequency and contrast information transmitted through the sensory system of a younger infant. However it is also apparent that filtering did not have the generalized effect we anticipated across preference behavior. That is, the effect of filtering on mean differential fixation response while not significantly different from 50% in the case of the filtered C1 stimulus did significantly differ from baseline in the case of the filtered C2.

4.2 Comparison of Results with those Reported by Fantz et al. (1975)

As hypothesized it was expected that the results obtained in the unfiltered condition of this experiment would approximate and support the findings reported by Fantz et al. (1975). Interestingly, not only did we replicate the findings of Fantz et al. (1975), but our mean percentage looking times were higher for each of the unfiltered curvilinear stimuli[25]. Fantz et al. (1975) reported a 62% preference for the C1 stimulus and a 69% preference for the C2 stimulus whereas our infants preferred the C1 stimulus 74.38% of the time and the C2 stimulus 77.88%.

One possible explanation for the higher percentage preference looking times found in this study might be directly related to the restricted age range of the sample chosen for our study. That is, in order to ensure that infants would preferentially fixate the curvilinear stimuli of the pairings, we chose 4- and 5-month old infants, whereas the mean preference times reported by Fantz et al. (1975) were derived from a sample of infants between the ages of 2- and 5 months. Since we chose the upper end of the age-range, mean preference time may have been higher, simply because the infants were older.

Because our filtered stimuli approximated what is seen through the visual system of a one-month-old infant, we were also interested in comparing our mean percentage looking times with the findings reported by Fantz and Miranda (1975) for the same Pairing 1 and Pairing 2 stimuli. While the filtered images

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[25] It was not possible to statistically compare the results of our study with those reported by Fantz et al. (1975) since the raw data from many of these studies were not available.

used in this study were constructed to mimic the visual system of a 1-month-old infant and the sample of infants used in the latter study were 1-week-old infants the results should nonetheless be approximately the same. In their study Fantz and Miranda (1975) reported a mean looking time of 56% for the C1 stimulus and that finding closely approximates the mean looking time of the infants who viewed the filtered C1 stimulus (53.2%). On the other hand, mean fixation of the filtered C2 stimulus, was found to be substantially greater (64.8%) than that reported for the sample of one-week-old infants, whose mean fixation was only 49.2%.

4.3 Unexpected Findings: Problems with Stimulus Generalization

We did not expect and therefore did not hypothesize that filtering would differentially effect infant preference behavior. Since mean preference looking times reported in this study for the unfiltered C1 and C2 stimuli were approximately the same, we assumed that filtering would have had an equal impact across mean preference times. That is, both sets of stimulus pairs should have shown approximately equal decrements in looking time. This however, was not the case. In fact, when the means of each percentage preference looking time of the filtered curvilinear stimuli are compared, a difference of over 11%, was apparent.

The possible reason or reasons why filtering had a greater effect on fixation time for the filtered C1 stimulus are unclear. One possible line of reasoning which could be used to examine the different preference results of our testing was discussed in the introduction of this paper. That is, the reanalysis performed by Banks and Salapatek (1981) of the Fantz et al. (1975) findings suggested that preference behavior in infants was effected by the contrast and spatial frequency at the fundamental frequency of the Fourier Amplitude Spectrum. It is therefore possible that while mean percentage looking time in the unfiltered condition of the stimulus pairings produced similar results, filtering the C1 and C2 stimuli might have changed the fundamental frequency component. In other words, if after filtering, the C2 stimulus maintained spatial frequency and contrast at the fundamental component that were within the range of the infant's peak CSF and the C1 stimulus did not, then higher looking times would be expected because the C2 should appear more visible and thus more preferable. However, it is also possible that infant looking times were based on the stimulus dimension of form as proposed by the Hierarchical Model. Because the curvilinear stimuli used in this study were different, filtering may not have effected the "curvilinearity" property of the C2 stimulus in the same way the C1 stimulus was effected. For example, when Fantz and Fagan (1975) varied the degree of curvature from bull's-eye patterns to stripes by increasing the radius of curvature of the arcs, a corresponding decline in fixation was noted. It would follow, according to the Hierarchical Stimulus Dimension Model that the decrease in fixation found for the filtered C1 stimulus might be due to a reduction in curvilinear properties which did not effect the C2 stimulus in the same way.

The results of Experiment 1 tend to support our hypothesis and provide evidence that the development of infant preference might be better explained by using a Linear Systems Model. Moreover, it seems that shifts in preference behavior could be directly related to the development of the infant CSF, which in theory, is related to the sensory development of the infant. However, the reduction in looking time which occurred when infants viewed the filtered Pairing 1 and Pairing 2 stimuli raises further issues with regard to how generalizeable these findings are because our results were not consistent in the manner predicted. While significant decreases in mean percentage preference looking times were reported across both the C1 and C2 filtered stimuli, when compared to unfiltered C1 and C2 stimuli, only the filtered C1 stimulus was found not to differ from baseline.

4.4 Can the Linear Systems Model be used to Generalize Preference Behavior? Overview of Experiment #2

Because it was possible to explain the results found in Experiment 1 both by using the Linear Systems Model and the Hierarchical Stimulus Dimension model, an additional experiment was necessary. Experiment 2 was an attempt to further investigate the hypothesized effect of filtering and its influence on infant pattern perception by selecting an additional set of curvilinear and rectilinear pairings for investigation. However, unlike the stimuli used in Experiment 1, the stimuli chosen for this experiment only differed along the dimension of orientation. The first stimulus pairing chosen consisted of a bull's eye pattern constructed so that the line segments contained in the image were situated along a horizontal axis and a rectilinear stimulus containing horizontally placed line segments. The next stimulus pairing was chosen simply because it differed along only one dimension from the stimulus pairing just described; the second curvilinear/ rectilinear stimulus pairing was rotated by 90 degrees. Therefore instead of viewing a bull's eye pattern situated along a horizontal axis, infants saw a bull's eye pattern situated along a vertical axis. When presented with unfiltered versions of the stimulus sets described above, it was predicted that infants would differentially fixate the curvilinear stimulus of the pairings over its rectilinear counterpart, thus replicating the results reported by Fantz et al. (1975)

However, when the same group of infants are presented with filtered versions of the stimulus pairs, we predicted that preference behavior would not only revert to a younger form of discrimination, but no significant difference would be found between the stimulus pairings in terms of the amount of time spent looking at the curvilinear stimulus of the pairings. That is, since both sets of stimulus pairs differed along only the dimension of orientation, this should have no impact on the amount of spatial frequency and contrast information contained in the images. Consequently, when the images are filtered, the difference between the looking times of the stimuli used in the following experiment should not deviate in the manner in which fixation time differed between the C1 and C2 stimuli.

[5]

EXPERIMENT #2

EXPERIMENTAL DESIGN AND METHOD

5.1 Subjects

Fourteen 4- and 5-month-old infants, 8 female and 6 male took part in this study. Subjects were chosen by the same criteria described in Experiment 1. Of these infants, one was excluded from analysis due to fussiness. The final sample of 13 infants (mean age = 140.3 days; SD = 23 days) were healthy (mean birth weight = 3375.2 grams; SD = 453.6 grams), and full-term (mean gestation = 39.5 weeks; SD = 2.3 weeks).

5.2 Photorefraction

Either before or after taking part in the preferential looking task, each infant was "photorefracted" to determine his or her current measure of accommodation and convergence. The paraxial photorefraction system, method and technique were the same used in Experiment 1. Analysis revealed that all infants accommodated and converged appropriately for their age.

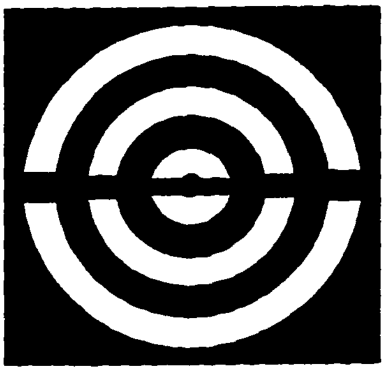
5.3 Unfiltered Stimuli

Two additional curvilinear and rectilinear pairings of Fantz et al. (1975) stimuli were chosen for this experiment and are illustrated in Figure 7. As with the Pairing 1 and Pairing 2 stimuli, Fantz et al. (1975) reported a significant preference for the curvilinear stimulus of each pairing by infants older than two months of age, while before two months of age no significant preference was found for either stimulus. Identification of the stimulus pairings was the same as detailed in Experiment 1. That is, stimuli were described in terms of "Pairing" and further distinguished by "C" for curvilinear and "R" for rectilinear with its corresponding pairing number following the letter.

The Pairing 3 curvilinear stimulus (C3) was constructed of three concentric white circles, on a 15.2 cm black background. The outermost circle measured 1.3 cm wide and 13.8 cm in diameter, the middle circle measured 1.3 cm wide and 8.7 cm in diameter and the innermost circle measured 1.2 cm wide and 3.3 cm in diameter. Each white circle was evenly spaced 1.2 cm apart. Thus, the appearance of the stimulus resembled a dartboard. Finally, a 14 cm long horizontal black line decreasing in width from the outermost circle at 1.2 cm, 0.9 cm for the middle circle and 0.6 cm for the innermost circle, was placed through the center of the pattern.

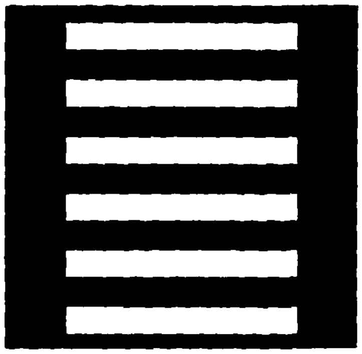
Figure 7. Unfiltered Pairing 3 and Pairing 4 stimuli used in Experiment 2. Stimuli were chosen from curvilinear and rectilinear pairings used by Fantz et al. (1975).

Unfiltered Stimulus Pairings: Experiment 2



C3

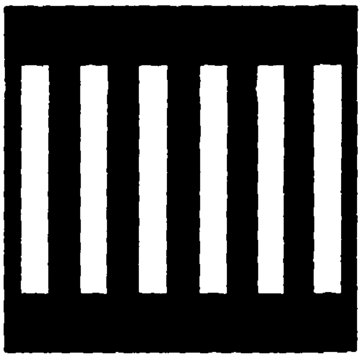
Stimulus Pairing 3



R3

C4

Stimulus Pairing 4



R4

Figure 7

The final form of the C3 stimulus was that of two sets, of three white and two black semicircles situated along a horizontal axis. The figure portion of stimulus C3 measured 13.8 cm by 13.8 cm and at a viewing distance of 30 cm subtended approximately 25.9° by 25.9° of visual angle, and the entire C3 stimulus (figure and ground) subtended approximately 28.4° by 28.4° of visual angle. Mean average luminance of the C3 stimulus a the lightest and darkest area was approximately 210 cd/m^2.

The Pairing 3 rectilinear stimulus (R3) was constructed of six 10.2 cm by 1.3 cm white rectangles situated horizontally against a 15.2 cm square black background. Each white bar was separated by 1.3 cm and the entire figure portion of the stimulus was positioned 2.5 cm from the outer edges and 0.5 cm from the top and bottom. Thus, the figure portion of the R3 stimulus measured 10.2 cm wide by 14.3 cm long. The figure portion of stimulus R3 subtended approximately 19.3° by 26.8° of visual angle at a viewing distance of 30 cm, while the entire R3 stimulus (figure and ground) subtended approximately 28.4° by 28.4° of visual angle. Mean average luminance of the R3 stimulus at the lightest and darkest area was approximately 210 cd/m^2.

The Pairing 4 curvilinear (C4) and rectilinear (R4) stimuli were constructed by rotating the Pairing 3 curvilinear and rectilinear stimuli by 90 degrees. While rotation of the Pairing 3 stimuli changed the orientation of the Pairing 4 stimuli from horizontal to vertical, the figure (13.8 by 13.8) and ground (15.2 by 15.2) measurements of the C4 stimulus were not effected. Thus, no change was affected to the visual angle of the image. On the other hand, rotation of the R4 stimulus by 90 degrees changed the measurements of the figure portion to 14.3 cm wide by 10.2 cm long. The R4 stimulus when rotated, subtended a visual angle of approximately 26.8° by 19.3°. Mean average luminance of the C4 stimulus was approximately 200 cd/m^2 and mean average luminance of the R4 stimulus was also approximately 200 cd/m^2 at the lightest and darkest areas.

5.4 Filtered Stimuli

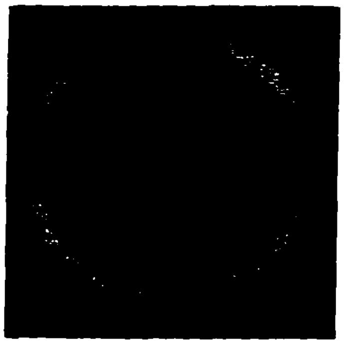
Figure 8 shows the effect of filtering on the Pairing 3 and Pairing 4 stimuli. Filtered Pairing 3 and Pairing 4 stimuli were constructed using the same protocol as described Experiment 1. Visual angle for each of the stimuli was not affected by filtering and therefore are the same as reported in the "unfiltered stimuli" section. Filtering however, did affect the mean average luminance for each stimulus; mean average luminance at the lightest and darkest area of the stimuli measured approximately 70 cd/m^2 (C3), 70 cd/m^2 (R3), 70 cd/m^2 (C4), and 70 cd/m^2 (R4).

5.5 Preferential Looking Procedure

The same preferential looking paradigm, apparatus, and timing procedures described in Experiment 1 were used for Experiment 2.

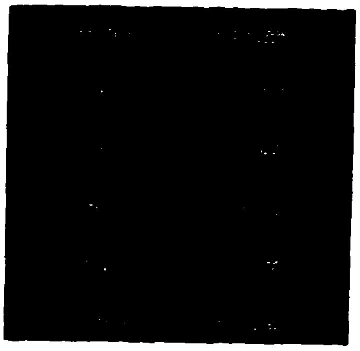
Figure 8. Filtered Pairing 3 and Pairing 4 stimuli used in Experiment 2. As described previously in Experiment 1 the reader will apply his or her own filter when viewing the stimuli. Figure 14 shows the results of filtering the Pairing 3 and Pairing 4 stimuli by a 1-month-old CSF and inversely filtering by the CSF of an adult.

Filtered Stimulus Pairings: Experiment 2

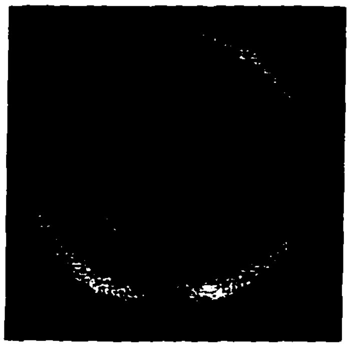


C3

Stimulus Pairing 3

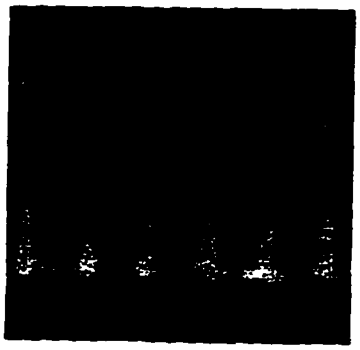


R3



C4

Stimulus Pairing 4



R4

Figure 8

[6]

RESULTS

6.1 Overview of Data Analysis

The primary difference between Experiment 1 and Experiment 2 was the pairing of stimuli viewed by each infant. Consequently, the results reported in this section were analyzed using the same line of reasoning and statistical procedures as reported in Experiment 1. First, each infant's fixation time was converted to a preference percentage looking time. Next, mean preference percentage looking times for the curvilinear stimuli were statistically analyzed for differences between unfiltered and filtered conditions and pairing of stimulus viewed. Finally, a series of 4 paired t-tests were performed which tested for differences between the mean preference percentage looking time of each curvilinear stimulus and a hypothetical baseline of 50%.

6.1.1 ANOVA Analysis of Mean Percentage Looking Time. Means and standard errors computed for the Pairing 3 and Pairing 4 percentage preference looking times for the unfiltered and filtered stimuli are shown in Table 3. Looking times from this experiment were analyzed using a 2 x 2, level of filtering (unfiltered versus filtered), by stimulus pairing (Pairing 3 versus Pairing 4) ANOVA which held the level of stimulus dimension constant along the dimension of curvilinearity. A significant main effect was found for the independent variable of filtering, $F(1,12)= 18.76, p < .0001$, whereas no main effect was found based on the level of pairing viewed. Finally, no significant two-way interaction was found between level of filtering and pairing of stimuli.

As hypothesized and consistent with the findings reported in Experiment 1, infants who viewed the unfiltered Pairing 3 and Pairing 4 stimuli fixated the curvilinear stimulus of the pairings for significantly longer periods of time when compared with its unfiltered rectilinear counterpart. Percentage preference looking times for the unfiltered C3 stimulus decreased by approximately 16% when infants viewed the filtered C3 stimulus, and infant fixation times for the unfiltered C4 stimulus decreased by approximately 14% when infants viewed the filtered C4 stimulus. In addition, the difference between mean preference percentage looking times of the unfiltered C3 and C4 stimuli was approximately 5% and the difference between the filtered C3 and C4 stimuli was approximately 2%. The effect filtering had on the mean preference percentage looking times are plotted in Figure 9a (Pairing 3) and Figure 9b (Pairing 4).

Table 3

Mean Preference Percentage Looking Times Pairing 3 and Pairing 4 Stimuli.

Mean percentage preference scores are given only for the curvilinear stimulus of the pairing. Rectilinear stimulus values can be calculated by subtracting the curvilinear value from 100%. Standard errors are the same for both curvilinear and rectilinear stimuli.

Stimulus Dimension		n	M	SE
Unfiltered				
	C3 Stimulus	13	74.1*	4.0
	C4 Stimulus	13	69.0*	4.2
Filtered				
	C3 Stimulus	13	57.8	3.1
	C4 Stimulus	13	55.4	3.3

*p < .01 Indicates difference between curvilinear and rectilinear stimulus pairing.

Figure 9a. Mean percentage looking time as a function of stimulus pairing and level of filtering for the Pairing 3 stimuli. The asterisk indicates that the mean looking time was also significantly different when compared to a baseline of 50%. The data are presented as a line graph for purposes of clarity.

Figure 9b. Mean percentage looking time as a function of stimulus pairing and level of filtering for the Pairing 4 stimuli. The asterisk indicates that the mean looking time was also significantly different when compared to a baseline of 50%. The data are presented as a line graph for purposes of clarity.

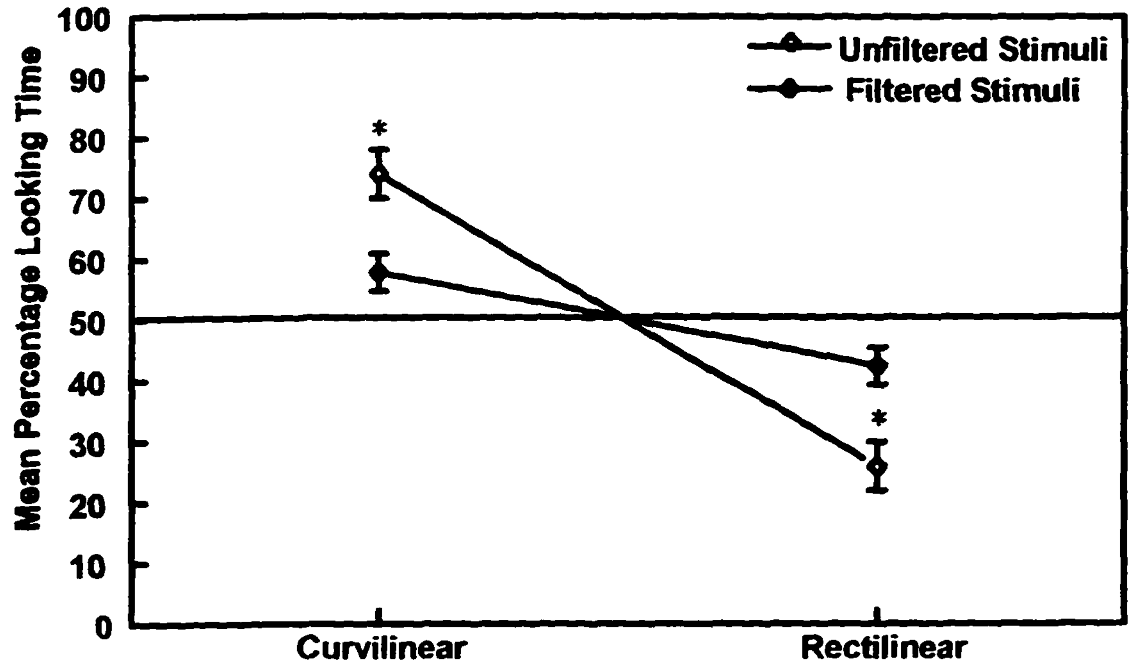

Mean Percentage Looking Time
100
90
80
70
60
50
40
30
20
10
0
Unfiltered Stimuli
Filtered Stimuli
*
*
Curvilinear
Rectilinear

Figure 9a

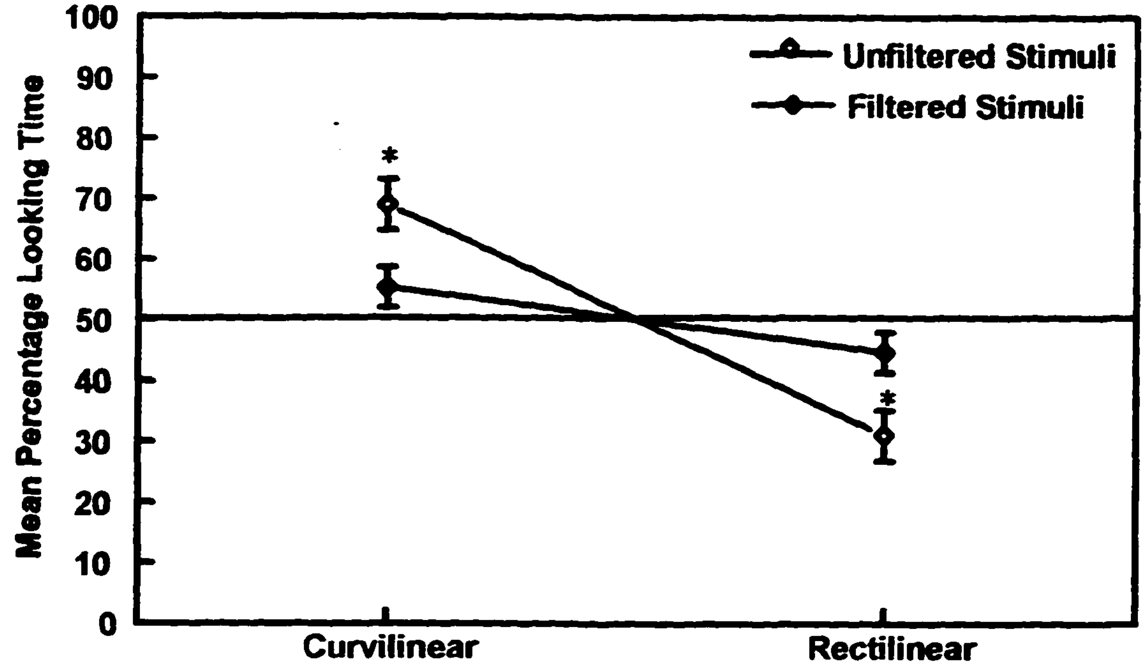

Mean Percentage Looking Time
100
90
80
70
60
50
40
30
20
10
0
Unfiltered Stimuli
Filtered Stimuli
*
*
Curvilinear
Rectilinear

Figure 9b

6.1.2 Analysis of Mean Percentage Looking Time from 50%. Four paired t-tests were performed to determine if differences could be found between the mean percentage preference looking time of each stimulus and 50%. Alpha levels for each paired t- test were adjusted accordingly to the .0025 level as explained in Experiment 1 by dividing the number of tests by the original alpha level used for this study.

Unfiltered Pairing 3 stimuli, $\underline{t}$ (12) = 6.06, $\underline{p} < .0001$ and unfiltered Pairing 4 stimuli $\underline{t}$ (12) = 4.54, $\underline{p} < .001$ were found to significantly differ from a baseline of 50%. However, when the filtered Pairing 3 and Pairing 4 stimuli were compared against 50% no significant differences were found at the .0025 alpha level. It could further be concluded that while infants fixated the filtered curvilinear stimuli for a longer period of time over its rectilinear counterpart, this behavior was not different from a baseline of 50% and therefore no preference for either stimulus of the pairing was demonstrated.

6.1.3 Results of Collapsing data from Experiment 1 and Experiment 2.

Of further consideration was the outcome of simultaneously examining the data reported in Experiment 1 and Experiment 2 in order to determine if differences could be found between experiments. For example, when the mean preference percentage times of Experiment 1 and Experiment 2 are examined in the same analysis, will similar patterns of fixation be found for all stimulus pairings across experiments or will significantly different patterns of fixation be found for the different pairs of stimuli used? Furthermore, if no differences were found between mean percentage preference looking times across Experiment 1 and Experiment 2 for the unfiltered and filtered conditions, then further discussion of these two experiments could be combined into one analysis.

Data from Experiment 1 and Experiment 2 were combined to form a 2 x 2 x 4, level of experiment (Experiment 1 and Experiment 2), by level of filtering (unfiltered and filtered), by stimulus pairing (Pairing 1, 2, 3, and 4), ANOVA, which included the independent variable of stimulus pairing as a nested variable within experiment. Like the individual analysis conducted for Experiment 1 and Experiment 2, one stimulus dimension, curvilinearity, was held constant across the ANOVA design.

Several sets of findings were obtained from the omnibus test by integrating across experimental design. First, a significant main effect, $\underline{F}$ (1,24)= 42.71,$\underline{p}$ < .0001, was found between unfiltered and filtered looking times whereas no significant main effect for level of experiment or stimulus pairing was found. In addition, no two-way interaction was obtained between level of filtering and level of experiment. Finally, no significant three-way effects were evident between level of filtering, stimulus pairing, and experiment.

[7]

DISCUSSION

7.1 Overview of Results

The omnibus analysis section for this experiment revealed a pattern of results consistent with the results reported in Experiment 1. First, when infants between the ages of 4 and 5 months of age are shown unfiltered curvilinear and rectilinear stimulus pairings, significant differential fixation responses were found for the curvilinear stimulus. On the other hand, when those same infants were presented with filtered stimuli hypothesized to mimic what is seen by the visual system of younger infants, the sample of infants we tested responded in a manner consistent with neonatal preference patterns. That is, no preference was found between the filtered curvilinear and rectilinear stimulus pairings. More importantly, however, no apparent difference was found between mean percentage looking time based on the pairing of stimuli viewed. In other words, unlike the differences found between the filtered C1 and C2 stimuli viewed in Experiment 1, infants who took part in Experiment 2 did not demonstrate a different pattern of fixation response time on the basis of whether they viewed Pairing 3 or Pairing 4 stimuli. As hypothesized the decrement in looking time from the unfiltered to filtered C3 and C4 stimuli did not differ in the manner found between unfiltered and filtered C1 and C2 stimuli. That is, while filtering produced a 21% decrease in looking time toward the C1 stimulus and a 13% decrease in looking time toward the C2 stimulus, filtering had approximately the same effect on mean preference percentage looking time toward the C3 and C4 stimuli. More precisely, Experiment 2 revealed a 16% decrease in looking time from the unfiltered to filtered C3 stimulus and a 13% decrease in looking time from the unfiltered to filtered C4 stimulus.

7.2 Comparison of Results with those Reported by Fantz et al. (1975)

When the preferential response times reported by Fantz et al. (1975) were compared with the unfiltered Pairing 3 and Pairing 4 stimuli used in this study, the same pattern of preference behavior was found across both experiments. Therefore, regardless of stimulus pairing, infants significantly fixated the unfiltered curvilinear stimulus of a pairing to its rectilinear counterpart. However, like the results of Experiment 1, a difference was found between the mean fixation times reported by Fantz et al. (1975) and the results of Experiment 2. The findings of this study showed that the C3 stimulus was preferred 74.1% of the time whereas the sample of infants tested by Fantz et al. (1975) preferred the C3 stimulus for 66%. On the other hand, while we found a 69% mean fixation response to the C4 stimulus, Fantz et al. (1975) reported a preference of 73% for the curvilinear stimulus. The difference between the mean preference percentage looking times reported in this study and the Fantz et al. (1975) study might be, as explained in Experiment 1, due to the fact that the Fantz et al. (1975) study contained a broader age range of infants. This possibility, however does not apply in the case of the C4 stimulus since we reported lower preference times for that stimulus when compared to Fantz et al. (1975). Therefore, it seems unlikely that the difference between mean preference times in the unfiltered conditions of Experiment 1 and Experiment 2 and the Fantz et al. (1975) study could be attributed solely to the age range of infants tested.

The data obtained from infants for this experiment when presented with filtered versions of the Pairing 3 and Pairing 4 stimuli were also directly compared with the preferential response behavior reported by Fantz and Nevis (1967). When infants under the age of 2 months were tested by Fantz and Nevis (1967), they reported a collective percentage preference[26] of 54% for the C3 and C4 stimuli and thus concluded that no differential fixation response could be found for the curvilinear stimulus of the pairing. The results of this study not

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[26] Fantz and Nevis (1975) and Fantz et al. (1975) did not report individual percentage preference looking times for each of the C3 and C4 stimuli.

only replicated the "lack" of a differential behavioral response, but also found a collective percentage preference of 56.6% when infants viewed the filtered C3 and C4 stimuli.

7.3 Comparing and Contrasting: Discussion of Results from Experiment 1 and Experiment 2

The independent results of both Experiment 1 and Experiment 2 demonstrate that infant pattern perception can be readily explained within a Linear Systems Model of pattern perception. In fact it could be argued that the Linear Systems Model is far more useful when explaining the development of infant preference behavior because once the input-output relationship between an infant observer and an image or pattern is obtained one can easily predict the visibility of that image and therefore the probability it will be preferred. As a result when compared to other models of infant preference like the Hierarchical Stimulus Dimension Model or the Contour Density Model, the Linear Systems model does not limit the predictive power of researchers to only those stimuli of a specific quantitative or qualitative dimension which may or may not necessarily be found across an infinite number of stimulus patterns.

While the results of Experiment 2 coincide with our predicted hypothesis, the fact remains that the findings reported in Experiment 1 are problematic. Although filtering the Pairing 1 and Pairing 2 stimuli produced the expected results, when the C2 stimulus was compared against baseline a significant difference was found and therefore it appears that filtering had a greater effect on preference behavior when infants viewed the Pairing 1 stimuli.

Consistent with the Linear Systems Model, a possible explanation for the results found in Experiment 1 can be found . It is quite reasonable to assume that contrast and spatial frequency at the fundamental component of the Fourier Amplitude Spectrum of the C2 stimulus was altered in a different manner from the other curvilinear stimuli. For example, if the unfiltered C1 and C2 stimuli contain a fundamental component closer to the peak CSF of the infant observer than their rectilinear counterparts then one would expect the results we obtained over the unfiltered conditions of Experiment 1. If after filtering however, the fundamental component of the C1 and C2 stimuli are differently effected then different preference results would be expected. Therefore, it would be beneficial to understand how changes, that might occur due to filtering, at the fundamental component change preference behavior across different stimuli; in this case the pairings tested across Experiment 1 and Experiment 2. In addition, it would also be interesting to establish the individual contributions toward preference of the two parameters which constitute the fundamental component; contrast and spatial frequency.

It is hypothesized that once the contrast and spatial frequency parameters at the fundamental component are known that preference behavior can be predicted from this information. Two lines of reasoning support the above hypothesis. First, in their reanalysis of the Fantz et al. (1975) acuity estimates Banks and Salapatek (1981) found evidence to suggest that infant preference for either sine-wave or rectangular wave gratings when paired with a blank field were a direct result of both the amount of spatial frequency contained at the maximum contrast at the fundamental component of these images. Next, differences between the Pairing 3 and Pairing 4 unfiltered and filtered stimuli reported in Experiment 2 were approximately the same. Since the only difference between the Pairing 3 and Pairing 4 stimuli were the rotation of the images (horizontal or vertical) one could reasonably expect no change in the spatial frequency and contrast components at the fundamental frequency.

While it is possible to explain the results of Experiment 1 and Experiment 2 in terms of a Linear Systems Model, two problems remain. First, the above conclusions are based on a post-hoc analysis of the data. Even though it appears that infant preference can be predicted once the input-output relationship between observer and pattern is known, we have not adequately provided support which can account for the different magnitude of decline in preference between the filtered Pairing 1 and Pairing 2 stimuli. Furthermore, our reasoning that infant sensitivity to both the spatial frequency and contrast at the fundamental frequency raises the issue of a possible confound between the two components. It is quite possible that since the fundamental component of the Fourier Amplitude spectrum is a product of spatial frequency and contrast, both components might have influenced the preference behavior of the infants we tested. On the other hand, it is also possible that only one of these components (spatial frequency or contrast) is the variable responsible for preference behavior. If the latter case were true, then the question becomes which fundamental component, spatial frequency or contrast, is responsible for the reported shifts in infant preference behavior over Experiment 1 and Experiment 2?

7.4 Spatial Frequency and/or Contrast: Which Determines Preference?

Experiment 3 was conducted to determine if changes in spatial frequency or changes in the amount of contrast at the fundamental component were the underlying cause of changes in infant preferential looking behavior. This was accomplished by first examining the Fourier Amplitude Spectrum of each of the unfiltered and filtered stimulus pairings used in Experiment 1 and Experiment 2 for differences in the spatial frequency and contrast at the fundamental component. Next, based on those differences, stimuli were constructed which directly test the assumption that spatial frequency at the fundamental component was not only responsible for younger and older infant preference behavior but also could explain the reported shifts in preference behavior found across Experiment 1 and Experiment 2.

[8]

EXPERIMENT #3

EXPERIMENTAL DESIGN AND METHOD

8.1 Preliminary Stimulus Evaluation

8.1.1 Unfiltered Condition Stimulus Analysis Each unfiltered Pairing 1, 2, 3, and 4 stimuli were Fourier analyzed in order to obtain the Fourier components of the stimuli used in this study. This information was then utilized to construct the Fourier Amplitude Spectrum of the image, which plotted contrast as a function of spatial frequency. Next, each component of the Fourier Amplitude Spectrum was multiplied by a normalized 6-month-old CSF. This next step was necessary because as previously explained the original Power Spectrum of the stimulus contained spatial frequency and contrast components that would not necessarily be transferred by the visual system of a 6-month-old infant. In other words, in order for us to have obtained a true representation of the fundamental component's contrast and spatial frequency information being transferred by the 6-month-old visual system, it was necessary to multiply the amplitude spectrum of the unfiltered or original image by a normalized 6-month-old CSF. Recall that the human visual system will naturally filter certain spatial frequencies and contrasts. Therefore, to produce an accurate description of the sine-wave components of an image which are transferred by an observer's visual system, the CSF of the intended observer must be taken into account. Had we not taken the 6-month-old CSF into account, the resulting plot might have contained incorrect information with regard to the contrast and spatial frequency transferred by the 6-month-old visual system. Since in this case the observers were infants between the ages of 4 and 5 months of age, we restructured the Fourier Amplitude Spectrum by removing all spatial frequency and contrast components which could not be transferred by the visual system of the infants we tested. Finally, once having obtained the contrast and spatial frequency parameters at the fundamental component, two separate descriptive analyses were conducted. The first looked at the contrast parameter of the fundamental component for each of the unfiltered and filtered stimuli across Experiment 1 and Experiment 2, while the second plotted spatial frequency at the fundamental component for each of the unfiltered and filtered stimuli.

8.1.2 Filtered Condition Stimulus Analysis The Fourier Amplitude Spectrum for the filtered Pairing 1, 2, 3, and 4 stimuli was constructed by multiplying the unfiltered Fourier Power Spectrum by the normalized CSF of a 1-month-old infant as discussed above. However, in order to obtain a true representation of the sine-wave components transferred through the optical system of a 6-month-old infant when the stimuli are filtered to mimic the visual system of a 1-month-old infant, the amplitude spectra of each stimulus was divided by a normalized 6-month-old CSF. Amplitude spectra for all patterns (including the unfiltered stimuli discussed in section 8.1.1 above) were obtained using a modified version of Visilog 4.0 software which was programmed in C language by Dr. Shaui Chen of The Brooklyn College Infant Study Center.

8.1.3 Plotting Contrast and Spatial Frequency Values Contrast at the fundamental component for each unfiltered and filtered stimulus was then calculated as Michelson Contrast and the spatial frequency at the fundamental component of each unfiltered and filtered stimulus was calculated as cycles per degree of visual angle. Figure 10a plots the Michelson contrast for unfiltered and filtered stimuli at the fundamental components, and Figure 10b plots the spatial frequency for the unfiltered and filtered stimuli at the fundamental components. Finally, it should be noted that in the following section when referring to "unfiltered" curvilinear and rectilinear stimuli we are referring to those stimuli filtered by a normalized 6-month-old CSF and when referring to "filtered" stimuli we mean those stimuli filtered by a normalized 1-month-old CSF and inversely filtered by a normalized 6-month-old CSF. This distinction was necessary so as not to confuse the term "unfiltered". By this usage of filtering

Figure 10a. Contrast values of the fundamental frequency for unfiltered and filtered Pairing 1, Pairing 2, Pairing 3, and Pairing 4 stimuli pairings. The data are presented as a line graph for purposes of clarity.

Figure 10b. Spatial frequency values of the fundamental component for unfiltered and filtered Pairing 1, Pairing 2, Pairing 3, and Pairing 4 stimuli. The data are presented as a line graph for purposes of clarity.

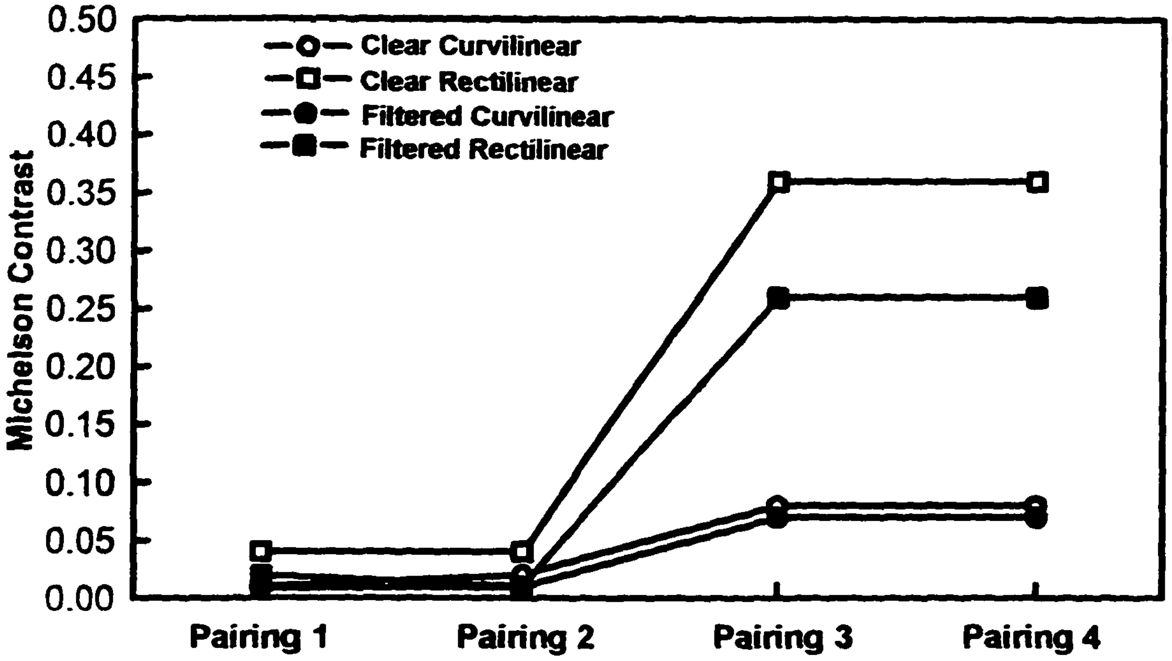
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
Michelson Contrast
Clear Curvilinear
Clear Rectilinear
Filtered Curvilinear
Filtered Rectilinear
Pairing 1
Pairing 2
Pairing 3
Pairing 4

Figure 10a

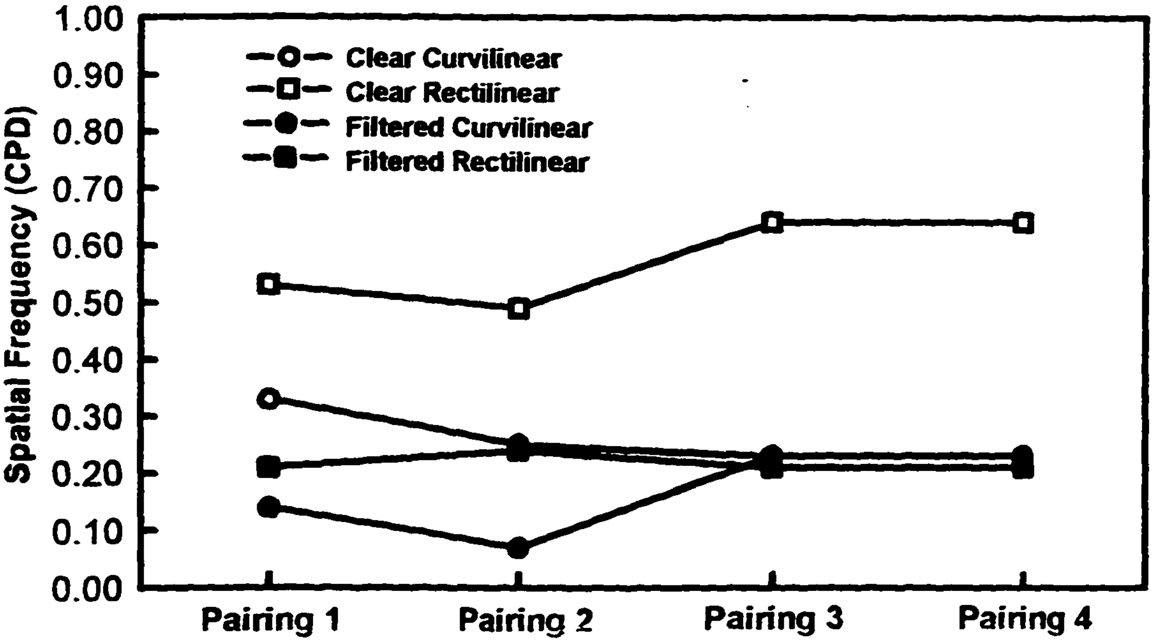
Spatial Frequency (CPD)
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
Clear Curvilinear
Clear Rectilinear
Filtered Curvilinear
Filtered Rectilinear
Pairing 1
Pairing 2
Pairing 3
Pairing 4

Figure 10b

we are referring to the fact that when the older infants in this study view the 1-month-old filtered stimulus pairings they are imposing a natural filter on the unfiltered images. Therefore in order for us to gage what contrast and spatial frequency will be passed through the older infant's visual system, it was necessary to filter the image by the CSF of the intended viewer; in this case the 4- and 5-month old infants.

8.1.4 Comparison of Unfiltered and Filtered Spatial Frequency and Contrast at the Fundamental Frequency Component When compared across the unfiltered and filtered Pairing 1 and Pairing 2 stimuli, contrast at the fundamental components were approximately the same. Therefore, if infant preference behavior for these stimulus pairs were motivated by contrast, no differential fixation response would have been predicted or expected since no apparent difference could be found between the unfiltered and filtered curvilinear/ rectilinear pairings.

An obvious difference between contrast could be observed in the case of the unfiltered and filtered Pairing 3 and Pairing 4 stimuli. But, if contrast were the parameter responsible for infant preference behavior, one would have expected the unfiltered C3 and C4 stimuli, the preferred stimuli, to contain higher contrast and not the R3 and R4 stimuli, which was the case.

Based on the examination of contrast across each of the Pairing 1, 2, 3, and 4 stimuli at the fundamental component, it was hypothesized that contrast was not likely to be the underlying variable responsible for the change in preference behavior of the older infants tested across Experiment 1 and Experiment 2. This hypothesis could be supported by the following observations of the contrast values obtained: First, if contrast were the variable responsible for the reported changes in preference behavior, then based on the characterizing information given by the CSF, it would have been expected that the curvilinear stimuli would contain the higher contrast. This was not the case across all stimulus pairings. In fact, the Pairing 1 and Pairing 2 stimuli each contained approximately the same contrast. Therefore if a prediction of infant preference were to be made based on contrast for the Pairing 1 and Pairing 2 stimuli, that prediction would be that infants between the ages of 1-and 6-months of age would show no preference. In addition, predictions based on contrast for the Pairing 3 and Pairing 4 stimuli would be that infants should have preferred the rectilinear stimulus, since both the unfiltered and filtered rectilinear stimuli contained higher contrast.

Unlike contrast, analysis of spatial frequency at the fundamental component revealed a pattern consistent with the mean percentage preference times we reported for the unfiltered and filtered conditions of Experiment 1 and Experiment 2. In all unfiltered stimulus pairing conditions, that is, stimuli filtered by a normalized 6-month-old CSF, the spatial frequency of the rectilinear stimulus is higher than its curvilinear counterpart in all cases. However, the difference between spatial frequency across filtered stimulus pairings varied. For example, little if any difference could be found between spatial frequency of the filtered Pairing 3 and Pairing 4 stimuli, whereas filtering rescaled spatial frequency for the Pairing 1 and Pairing 2 stimuli downward.

Further inspection of unfiltered curvilinear and rectilinear stimulus pairings also revealed that preferences might very well be driven by lower spatial frequency in general and not simply by spatial frequency corresponding to the peak of the 6-month-old CSF. For example, all of the unfiltered rectilinear stimuli are much closer to the peak of the 6-month-old CSF than their curvilinear counterparts. Therefore if pattern preference was toward those images which contained spatial frequencies at the fundamental component corresponding to the peak of the observer's CSF (in this case 4- and 5-month-olds) then one would expect the unfiltered rectilinear stimuli to have been preferred, which was not the case. Moreover, if preference was determined by the image that contained the lower spatial frequency at the fundamental component, this line of reasoning might explain the findings of the Pairing 2 stimuli. As can be observed in Figure 10b, filtering not only rescaled the spatial frequency of the clear C2 stimulus to a lower spatial frequency, it shifted the spatial frequency parameter of the filtered C2 stimulus to the lowest spatial frequency found across all of the stimulus pairings. Therefore if preference were determined by the lowest spatial frequency at the fundamental component of an image, it would then follow that across all stimulus pairing, filtering would have had the least effect on the C2 stimulus.

Finally, we observed that differences between spatial frequency became greatly reduced when the curvilinear and rectilinear images were restructured by a 1-month-old CSF. In fact, when filtered, spatial frequency at the fundamental component of the Pairing 3 and Pairing 4 stimuli became approximately equal. Since spatial frequency at the fundamental component of the filtered Pairing 3 and Pairing 4 stimuli were the same, and since the results of Experiment 2 revealed that infants did not prefer either stimulus of the pairings in approximately the same way, it was again believed possible that spatial frequency at the fundamental component appeared to influence infant preference behavior. Furthermore, based on the above preliminary analysis it was hypothesized that if the curvilinear stimulus were equated with their rectilinear stimulus counterparts for spatial frequency at the fundamental component, then the same return to no preference would be exhibited by infants as reported in the filtered conditions of Experiment 1 and Experiment 2.

[9]

Method

9.1 Subjects

Fifteen 4- and 5-month-old infants, 6 female and 9 male took part in this study. Subjects were selected using the same criteria as described in Experiment 1. Of these infants, 2 were excluded from analysis due to fussiness. The final sample of 13 infants (mean age = 156.8 days; SD = 29.4 days) were healthy (mean birth weight = 3229.6 grams; SD = 453.6), and full-term (mean gestation = 38.9 weeks; SD = 2.6 weeks).

9.2 Photorefraction

Either before or after taking part in the preferential looking task, each infant was "photorefracted" to determine his or her current measure of accommodation and convergence. The paraxial photorefraction system, method and technique were the same used in Experiment 1. Analysis of the photorefraction data revealed that all infants accommodated and converged appropriately for their age.

9.3 Unfiltered Stimuli

Unfiltered versions, as described in Experiments 1 and 2, of the Pairing 1,2, 3 and 4 rectilinear stimuli were utilized for display to the infant subjects who participated in this study. All parameter values with regard to size, visual angle and luminance were the same as reported in Experiment 1 and Experiment 2.

9.4 Filtered Stimuli

The filtered stimuli were constructed for this experiment in two phases: First, unfiltered curvilinear stimuli of the Pairing 1,2, 3 and 4 stimuli were modified by altering the spatial frequency at the fundamental so that spatial frequency at the fundamental of the curvilinear stimulus would be equated with its rectilinear counterpart. In other words spatial frequency at the fundamental of each curvilinear stimulus was adjusted upward so that the curvilinear stimulus of a pairing would equal spatial frequency at the fundamental of the rectilinear stimulus it was originally paired with. This was accomplished by using a modified version of Visilog 4.0 software programed in C language by Dr. Shaui Chen of the Brooklyn College Infant Study Center. Stimulus parameters (overall figure and ground measurements) for all curvilinear stimuli equated for spatial frequency at the fundamental remained the same as the unfiltered condition versions of stimuli C1, C2, C3, and C4. Since filtering did not affect the size of the stimuli, the visual angle subtended by each image remained the same.

The increased spatial frequency did however effect a change in the appearance of the stimuli. That is, increasing the spatial frequency of the fundamental created a fuzzy, grey field over each of the curvilinear stimuli, thereby affecting the mean average luminance of the images. Mean average luminance was calculated for each curvilinear stimulus equated for spatial frequency at the lightest and darkest area of the stimulus and the C1 stimulus contained a mean average luminance of approximately 110 cd/m^2, stimulus C2 contained a mean average luminance of approximately 100 cd/m^2, the C3 stimulus contained a mean average luminance of approximately 100 cd/m^2, and the C4 figure contained a mean average luminance of approximately 90 cd/m^2. Figure 11 illustrates the effects of equating spatial frequency at the fundamental for each curvilinear and rectilinear stimulus pairing.

9.5 Preferential Looking Procedure

The same preferential looking paradigm, apparatus, and timing procedures as described in Experiment 1 were used for Experiment 3.

Figure 11. Pairing 1, Pairing 2, Pairing 3, and Pairing 4 stimuli equated for spatial frequency. Across all stimulus pairings, the spatial frequency component at the fundamental frequency of the curvilinear stimuli was increased so that it matched the spatial frequency of its rectilinear counterpart.

Stimulus Pairings Equated for Spatial Frequency: Experiment 3

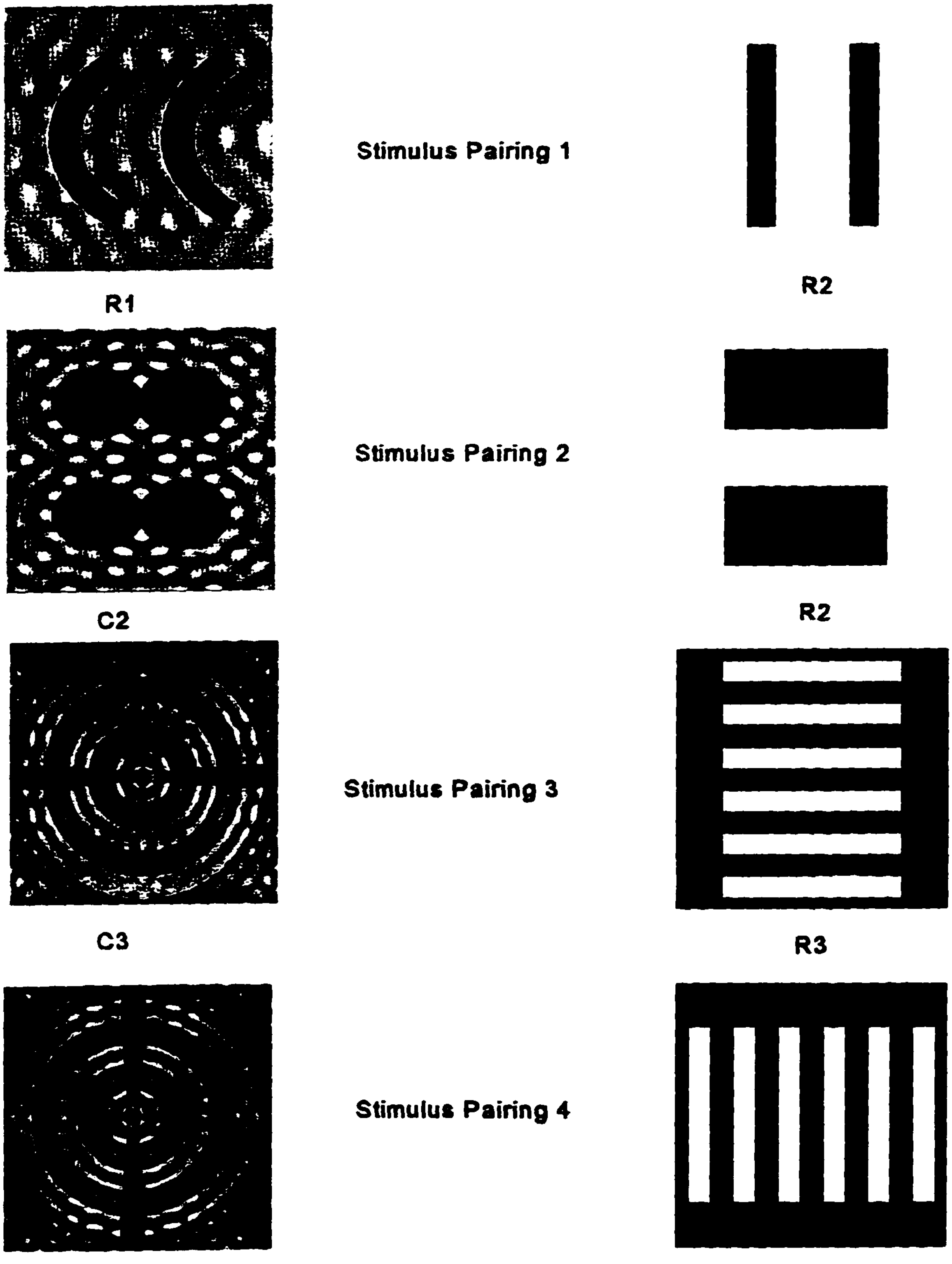

Figure 11

[10]

RESULTS

10.1 Overview of Mean Percentage Looking Time Analyses.

The amount of time infants fixated each stimulus was converted to percentage preference looking times and then analyzed in the same manner as reported in Experiment 1. Mean preference percentage looking times and standard errors obtained in this experiment are shown in Table 4.

10.1.1 ANOVA Analysis of Mean Percentage Looking Time. A 2 x 4, stimulus dimension (curvilinear versus rectilinear) by stimulus pairing (Pairings 1, 2, 3, and 4) within-subjects ANOVA was conducted. A main effect for stimulus dimension was found $F\ (1,12) = 16.13, p < .002$, whereas no main effect was

Table 4

Mean and Standard Errors: Infant Data Experiment 3, Pairing 1, 2, 3, & 4 Stimuli.

Mean percentage preference scores are given only for the curvilinear stimulus of the pairing. Rectilinear stimulus values can be calculated by subtracting the curvilinear value from 100%. Standard errors are the same for both curvilinear and rectilinear stimuli.

Stimulus Dimension	n	M	SE
C1 Stimulus	13	56.9	3.5
C2 Stimulus	13	65.6*	3.1
C3 Stimulus	13	54.2	1.5
C4 Stimulus	13	53.9	3.1

*$p < .004$ Indicates difference between curvilinear and rectilinear stimulus pair.

found for pairing of stimuli[27]. A significant interaction, $\underline{F}$ (3,36)= 4.71,$\underline{p}$ < .007 however was found between stimulus dimension and stimulus pairing, therefore, an analysis of simple effects was conducted[28].

10.1.2 Simple Effect Analysis. It was hypothesized that since a main effect was found between the curvilinear and rectilinear stimulus pairings, that at each level of pairing the mean percentage preference scores between the curvilinear and rectilinear stimuli would be different; therefore it was decided the appropriate simple effect tests should hold the stimulus pairing constant over the curvilinear and rectilinear stimulus dimensions.

To determine if the pairing of stimuli viewed by the infants influenced percentage preference looking time between curvilinear and rectilinear stimulus pairings, 4 paired t-tests were performed. Alpha levels for each paired t-test were adjusted to .0025 by dividing the alpha level of .01 by the number of tests performed (4) .

Both Pairing 1 and Pairing 4 stimuli were not significantly different from

---

[27] No significant main effect for stimulus type would be expected because when the marginal means for each curvilinear and rectilinear stimulus pairing are added together, the marginal means must equal 100%. An alternative way to analyze the percentage preference looking times would have been to perform 2, one-way ANOVAS: one in which the curvilinearity level of stimulus dimension was held constant and analyzed over each level of stimulus type and the other which held the rectilinearity level of stimulus dimension constant over each level of stimulus type. While the results of the 2, one-way ANOVAS would also reveal no difference between the curvilinear and rectilinear stimuli across type, this kind of analysis would not have given information regarding the effects across stimulus dimensions over type.

[28] The presence of an interaction simply indicates that the main effects do not sufficiently explain the data and an additional analysis is necessary. One way to analyze significant interactions is to divides the factorial design into subhypotheses, each focusing on only a specified part of the design.

each other. The Pairing 3 stimuli were also considered not significantly different although a .01 level of significance was found. The Pairing 2 curvilinear and rectilinear stimuli were found to significantly differ t (12)= 5.05,p < .0001. Figures 12a, 12b, 12c, and 12d plot the unfiltered, filtered and equated for spatial frequency stimulus pairings used in Experiment 1, Experiment 2, and Experiment 3.

10.1.3 Analysis of Mean Percentage Looking Time from 50%. Four paired t-tests were conducted to determine if mean percentage preference looking times were significantly different from 50%. Alpha levels for each of the paired t-tests were adjusted to account for the number of tests conducted, thus, the alpha level for each test was adjusted to .0025.

10.1.4 Results: Mean Percentage Looking Time Versus 50%. The Pairing 2 stimuli were significantly different, t (12)= 5.05,p < .0001. However, no difference was found for mean preference percentage looking times and 50% for the Pairing 1, Pairing 3, and Pairing 4.

Figure 12a. Mean percentage looking time of the Pairing 1 stimuli when equated for spatial frequency. Also shown are the results of the unfiltered and filtered Pairing 1 stimuli from Experiment 1. The asterisk indicates that the mean looking time was also significantly different when compared to a baseline of 50%. The data are presented as a line graph for purposes of clarity.

Figure 12b. Mean percentage looking time of the Pairing 2 stimuli when equated for spatial frequency. Also shown are the results of the unfiltered and filtered Pairing 2 stimuli from Experiment 1. The asterisk indicates that the mean looking time was also significantly different when compared to a baseline of 50%. The data are presented as a line graph for purposes of clarity.

Figure 12c. Mean percentage looking time of the Pairing 3 stimuli when equated for spatial frequency. Also shown are the results of the unfiltered and filtered Pairing 3 stimuli from Experiment 2. The asterisk indicates that the mean looking time was also significantly different when compared to a baseline of 50%. The data are presented as a line graph for purposes of clarity.

Figure 12d. Mean percentage looking time of the Pairing 4 stimuli when equated for spatial frequency. Also shown are the results of the unfiltered and filtered Pairing 4 stimuli from Experiment 2. The asterisk indicates that the mean looking time was also significantly different when compared to a baseline of 50%. The data are presented as a line graph for purposes of clarity.

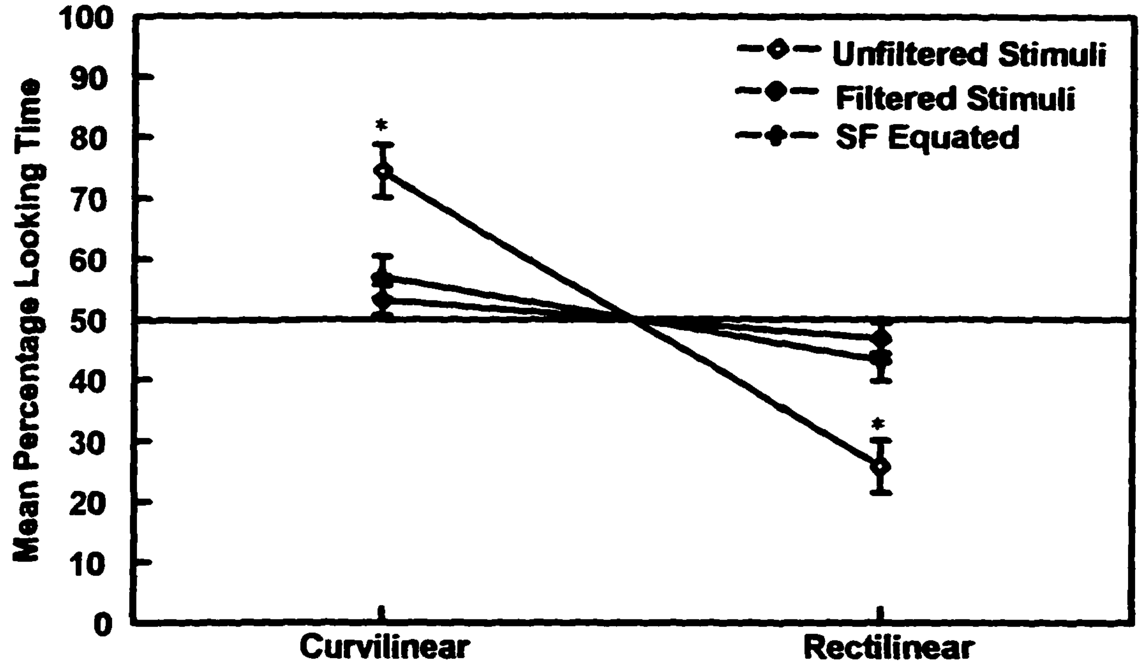
Mean Percentage Looking Time
100
90
80
70
60
50
40
30
20
10
0
Curvilinear
Rectilinear
Unfiltered Stimuli
Filtered Stimuli
SF Equated
*
*

Figure 12a

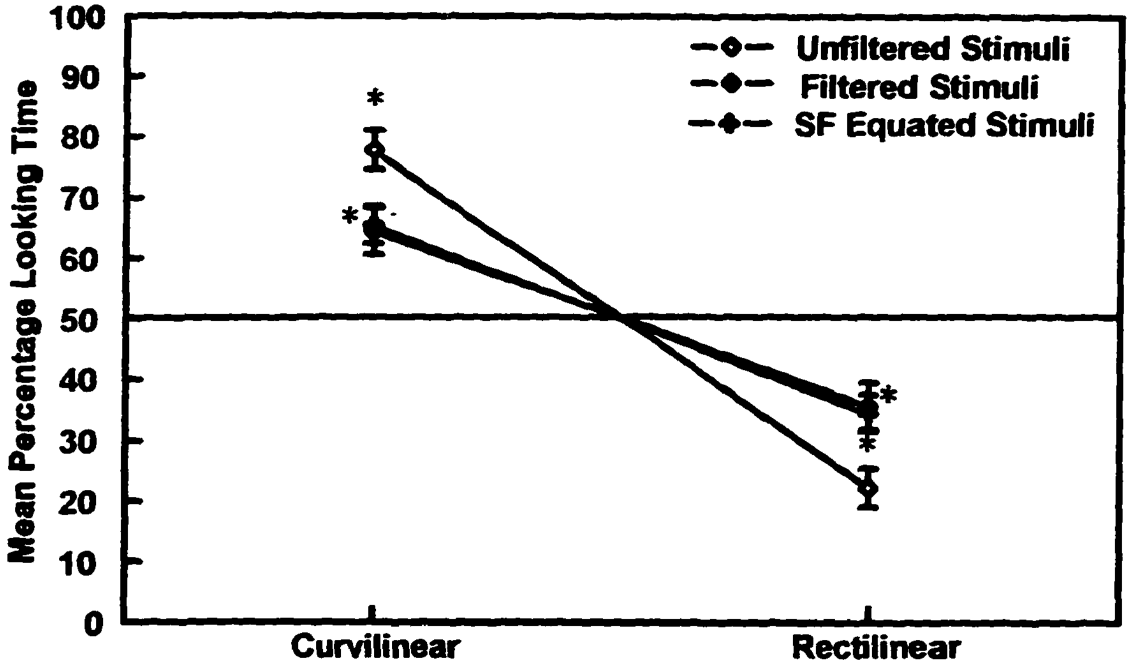
Mean Percentage Looking Time
100
90
80
70
60
50
40
30
20
10
0
Curvilinear
Rectilinear
Unfiltered Stimuli
Filtered Stimuli
SF Equated Stimuli
*
*
*
*

Figure 12b

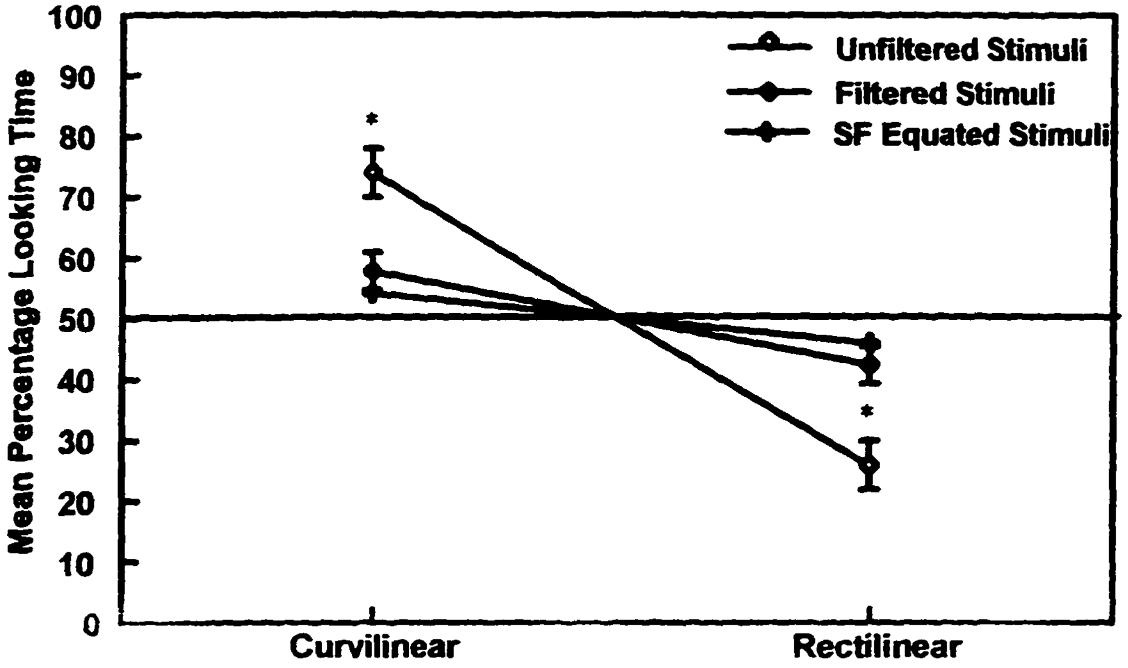
Mean Percentage Looking Time
100
90
80
70
60
50
40
30
20
10
0
Curvilinear
Rectilinear
Unfiltered Stimuli
Filtered Stimuli
SF Equated Stimuli
*
*

Figure 12c

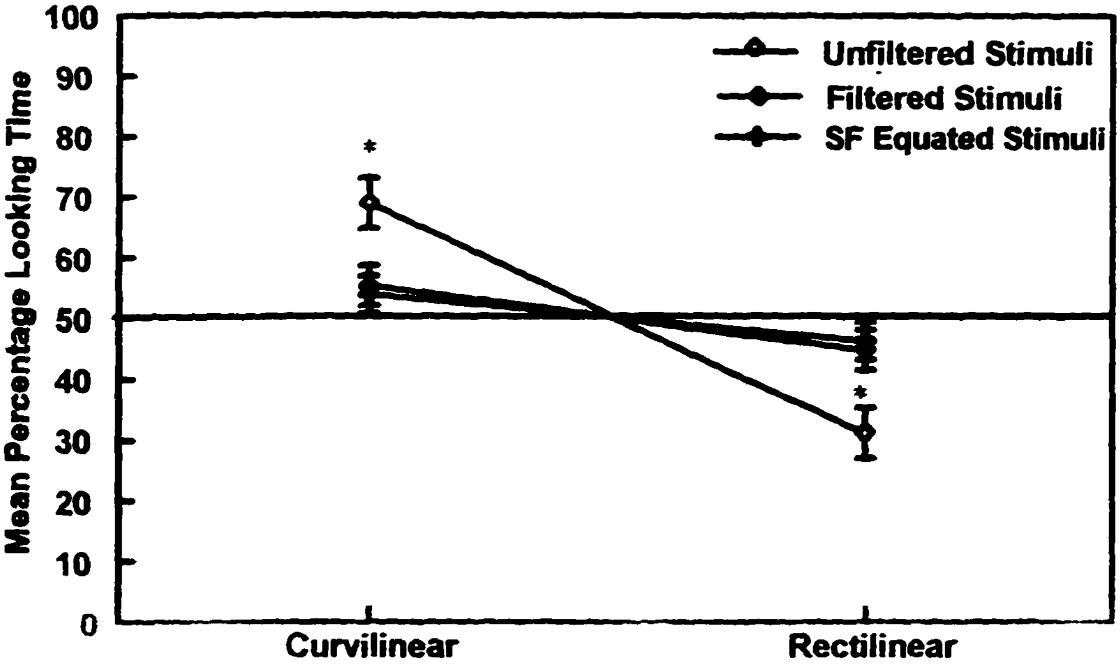
Mean Percentage Looking Time
100
90
80
70
60
50
40
30
20
10
0
Unfiltered Stimuli
Filtered Stimuli
SF Equated Stimuli
*
*
Curvilinear
Rectilinear

Figure 12d

[11]

DISCUSSION

11.1 Overview of Data Analysis and its Relationship to Experiment 1 and Experiment 2

Equating spatial frequency at the fundamental component for the curvilinear stimuli with spatial frequency at the fundamental component for the rectilinear stimuli resulted in a decrease of infant preferential looking behavior across all stimulus pairings. In fact, this finding is consistent with the results reported over the filtered conditions of Experiment 1 and Experiment 2. Consequently, when the findings of all three experiments are plotted, mean preference percentage looking times for infants who viewed filtered curvilinear and rectilinear stimulus pairings were approximately equal to the mean preference percentage times of infants who viewed the curvilinear stimuli equated for spatial frequency paired with its unfiltered rectilinear counterpart.

Additional comparisons between the infant preference behavior reported in the filtered conditions of Experiment 1 and Experiment 2 and the current experiment can also be made. For example, when the Pairing 3 and Pairing 4 stimuli are filtered, each curvilinear and rectilinear stimulus contains the same spatial frequency at the fundamental and therefore not only would we not expect a preference for either stimulus, but we would expect the looking time to each of these stimuli to be approximately the same. These are the same results that we obtained from Experiment 3 when equating spatial frequency at the fundamental for the curvilinear and rectilinear stimuli.

11.2 Conclusions and Additional Questions Resulting from Experiment 3

The findings across all the stimulus pairings tested in Experiment 3 not only support a Linear Systems Model of form perception but also support the hypothesis that the underlying mechanism responsible for infant pattern preference is spatial frequency at the fundamental component of that stimulus. Moreover it appears that infant preferences are determined by lower spatial frequency in general since spatial frequencies at the high end of the CSF are generally more difficult for the infant sensory system to analyze. Neural factors are believed to be responsible for this, beginning with photoreceptor immaturity and possibly extending to immaturities at higher cortical levels.

For how long does sensory processing influence form perception? Recall that Fantz et al. (1975) claimed that discrimination of form was more important for adults than for infants. Therefore, does preference for curvilinear stimuli over rectilinear stimuli continue into adulthood? If the curvilinear preference is found in adulthood, could similar results be produced when adults are presented with unfiltered and filtered, curvilinear and rectilinear stimulus pairings. That is do adults prefer curvilinear stimuli to rectilinear stimuli and if so, can filtering effect the preference behavior of adults in the manner filtering affected the 4-and 5-month-old infants who took part in this study.

The following section describes the results obtained from an adult experiment which was conducted using adult participants to examine the preceding questions. For example, if adults are presented with unfiltered versions of the stimulus pairings used in infant studies, would adults prefer the unfiltered curvilinear stimulus of the pairings to its rectilinear counterpart? In addition, would filtering those same stimulus pairings by a 1-month-old CSF revert adult preference behavior to that of a 1-month-old infant?

In the following experiment unfiltered and filtered versions of the Pairing 1, 2, 3, and 4 stimuli were analyzed to determine if adult preferences, like infants could be predicted based on spatial frequency at the fundamental component. In addition, adult subjects were given a preference task which produced percentage preference looking time data which could be directly compared with infant differential fixation percentages obtained from Experiment 1 and Experiment 2.

[12]

EXPERIMENT #4

EXPERIMENTAL DESIGN AND METHOD

12.1 Unfiltered and Filtered Condition Stimulus Analysis

All unfiltered Pairing 1, 2, 3, and 4 stimuli were analyzed to obtain spatial frequency and contrast parameters at the fundamental component of each stimulus. This was accomplished using the same two steps described in Experiment 3. First, the images were Fourier analyzed to obtain all spatial frequency and contrast components contained within the stimuli. Next, the Fourier Amplitude Spectrum of each unfiltered stimulus was multiplied by a normalized adult CSF to create the unfiltered version of the stimuli which is theoretically viewed by adults. Next in order to obtain the spatial frequency and contrast parameters at the fundamental when an adult views an image through the visual system of a 1-month-old, the unfiltered Fourier Amplitude Spectrum of the images were then divided by the normalized CSF of a 1-month-old. Plots of both spatial frequency and contrast at the fundamental component were then generated so that descriptive analyses could be performed in the same manner as described in Experiment 3.

Mathematical computations for all unfiltered and filtered Fourier Analysis were accomplished by using a modified version of Visilog 4.0 software, programmed in C language by Dr. Shaui Chen of The Brooklyn College Infant Study Center. Figure 13a plots the Michelson contrast and Figure 13b plots spatial frequency in cpd at the fundamental of the Pairing 1, 2, 3, and 4 stimuli.

12.2 Predictions based on Unfiltered and Filtered Spatial Frequency and Contrast at the Fundamental Component.

Inspection of the unfiltered and filtered adult amplitude spectra contrast parameter at the fundamental revealed an almost identical pattern to that of the unfiltered and filtered 6-month-old contrast parameters. While the adult contrast parameters are lower than that of the 6-month olds, contrast of the Pairing 3 and Pairing 4 stimuli were higher for the unfiltered rectilinear stimuli. Moreover, the contrast parameter for the Pairing 1 and Pairing 2 stimuli, like 6-month-old contrast were approximately equal. In fact, adult contrast parameters across stimulus pairings showed little variability. It was therefore hypothesized based on this information that if adults did show the same pattern of preference behavior as the infants tested in the unfiltered and filtered conditions of

Figure 13a. Contrast values at the fundamental component for unfiltered and adult filtered Pairing 1, Pairing 2, Pairing 3, and Pairing 4 stimuli. The data are presented as a line graph for purposes of clarity.

Figure 13b. Spatial frequency values at the fundamental component for unfiltered and adult filtered Pairing 1, Pairing 2, Pairing 3, and Pairing 4 stimuli. The data are presented as a line graph for purposes of clarity.

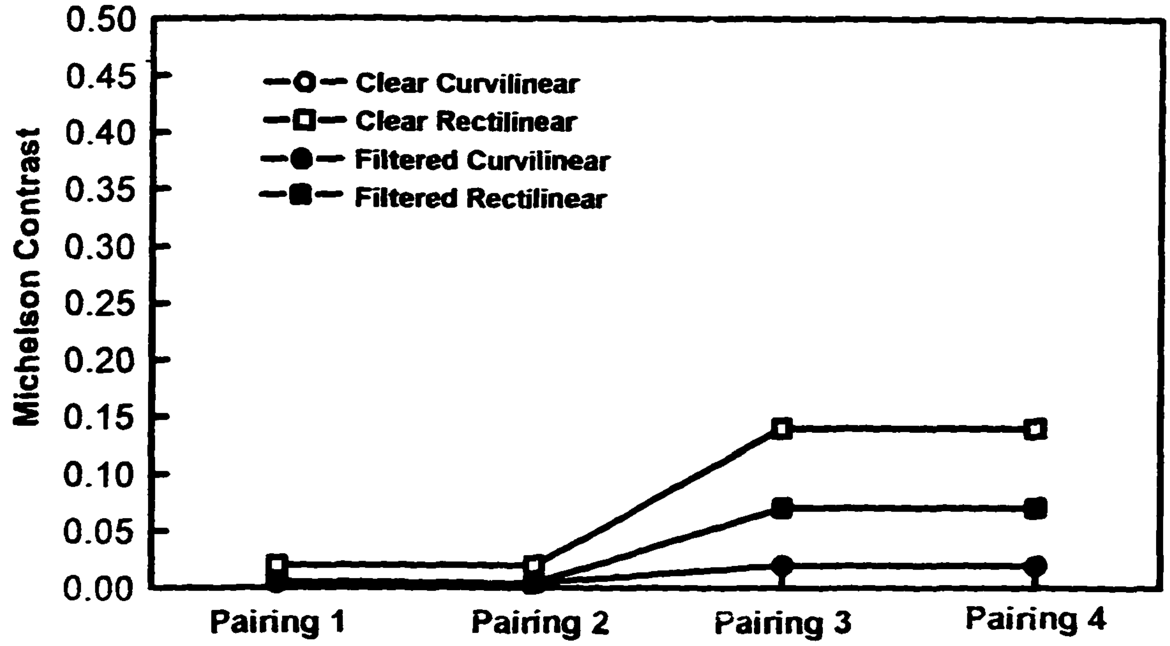
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
Michelson Contrast
Clear Curvilinear
Clear Rectilinear
Filtered Curvilinear
Filtered Rectilinear
Pairing 1
Pairing 2
Pairing 3
Pairing 4

Figure 13a

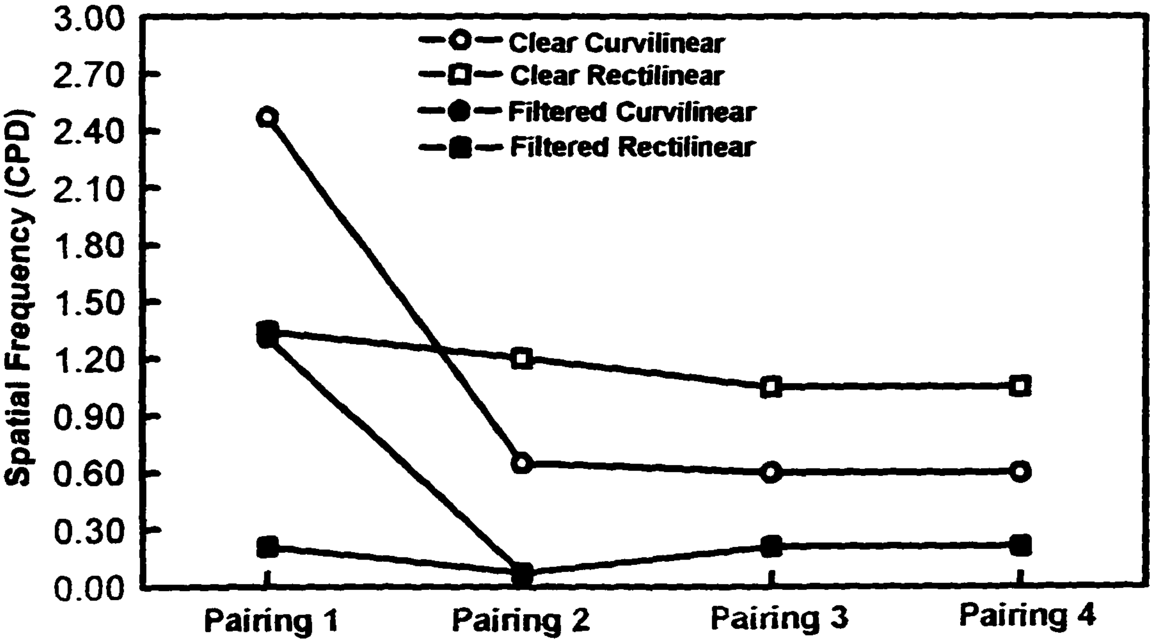
Spatial Frequency (CPD)
3.00
2.70
2.40
2.10
1.80
1.50
1.20
0.90
0.60
0.30
0.00
Clear Curvilinear
Clear Rectilinear
Filtered Curvilinear
Filtered Rectilinear
Pairing 1
Pairing 2
Pairing 3
Pairing 4

Figure 13b

Experiment 1 and Experiment 2 then this pattern of preference was not due to contrast at the fundamental.

Examination of spatial frequency at the unfiltered and filtered Pairing 3 and Pairing 4 stimuli at the fundamental also contained similar patterns when compared with the 6-month-old spatial frequency plot. For example, the unfiltered rectilinear stimuli of the Pairing 3 and Pairing 4 stimuli contained higher spatial frequency components than its curvilinear counterpart and when filtered, the curvilinear and rectilinear stimulus pairs each contained equal amounts of spatial frequency. Differences in the amount of spatial frequency between the unfiltered C3 and R3 stimulus pair and the unfiltered C4 and R4 stimulus pair were also similar when the adult spatial frequency at the fundamental and 6-month-old spatial frequency at the fundamental are compared.

On the other hand, a different pattern of results was found when the adult unfiltered and filtered Pairing 1 and Pairing 2 stimuli were compared with the infant unfiltered and filtered Pairing 1 and Pairing 2 stimuli. The most striking difference was found for the Pairing 1 stimuli. For example, the unfiltered C1 adult stimulus contained a higher spatial frequency component than its R1 counterpart. In contrast, the infant unfiltered R1 stimulus contained higher spatial frequency at the fundamental component than its curvilinear counterpart. Moreover, when the Pairing 1 stimuli were filtered, the spatial frequency content of the C1 stimulus remained high. This was not the case with the infant-filtered

C1 stimulus, where we found spatial frequency becomes lower as well as closer to the spatial frequency of its rectilinear counterpart at the fundamental component.

The unfiltered adult Pairing 2 stimuli showed a pattern consistent with the infant unfiltered Pairing 2 stimuli. That is, the unfiltered R2 stimulus contains a higher level of spatial frequency when compared to its curvilinear counterpart. Unlike the Pairing 2 stimuli which differed in spatial frequency content when infant filtered, the adult filtered Pairing 2 stimuli each contained the same low spatial frequency components.

Based on the adult unfiltered and filtered plots of spatial frequency at the fundamental component, it would be difficult to make predictions as to what patterns adult subjects would prefer. The major reason analysis of the adult unfiltered and filtered stimuli did not aid in prediction of adult preference is due to the fact that adults are sensitive to a much greater range of spatial frequencies than the infant. Banks and Salapatek (1981) found that adult peak contrast sensitivity is about 40 times greater than 1-month-olds. Therefore, the pattern information to which adults are sensitive is much greater than the amount of information infants can use. In addition, spatial frequency at the fundamental component in all cases of unfiltered and filtered stimuli are well within the range of visibility for the adult.

However, if we used the spatial frequency found at the fundamental frequency to predict adult preference behavior we could make the following predictions. First, a preference for the unfiltered rectilinear stimulus of a pairing would be found in the case of the Pairing 2, 3 and 4 stimuli. This hypotheses is based on the fact that spatial frequency at the fundamental component of the unfiltered R2, R3, and R4 stimuli are closer to the peak of the adult CSF. On the other hand, when the unfiltered Pairing 1 stimuli are compared along the dimension of spatial frequency, it would be predicted that adults should prefer the C1 stimulus since it is closer to the peak of the adult CSF than its rectilinear counterpart.

Adult subjects should show no preference to either of the Pairing 2, 3, and 4 stimuli when the stimuli are filtered by the CSF of a 1-month-old infant, because when filtered, each of the stimuli contains the same spatial frequency at the fundamental component. While filtering changed and simultaneously reduced the amount of spatial frequency at the fundamental component of the C1 and R1 stimuli, the filtered C1 stimulus continued to remain closer to the peak of the adult CSF. Therefore, it could be predicted from this preliminary analysis that adults would continue to prefer the filtered C1 stimulus to its rectilinear counterpart. Finally, if adult preferences were based on spatial frequency at the fundamental component then mean percentage preference scores for filtered Pairing 2, Pairing 3, and Pairing 4 stimuli should be approximately the same. Conversely, we should also find that the percentage preference score for the filtered Pairing 1 stimuli would differ from the percentage preference looking time obtained for the Pairing 2, 3, and 4 stimuli.

[13]

Method

13.1 Subjects

Twenty adult subjects, 11 female and 9 male between the ages of 16 and 52 (mean age =25.4 years; SD = 9.2 years) were recruited from staff members, and graduate students of the Brooklyn College Infant Study Center, the Brooklyn College Visual Research Lab and the Brooklyn College Feeding, Behavior and Nutrition Lab to take part in this study. All adult subjects who participated in this study were unaware of the hypotheses being tested in experiments 1, 2, and 3 and were also blind to the results obtained for those studies.

13.2 Unfiltered Stimuli

Unfiltered versions, as described in Experiments 1 and 2, of the Pairing 1,2, 3 and 4 curvilinear and rectilinear stimulus pairings were created for display to adult subjects. All parameter values used in the creation of the Pairing 1 and Pairing 2 unfiltered stimuli were the same as those reported in Experiment 1 and Experiment 2 except for a reduction in size of the white vertical background area of the Pairing 1 and Pairing 2 stimuli from 20 cm to 15.2 cm. Therefore all stimulus pairings measured 15.2 cm by 15.2 cm. The reduction in stimulus size was effected so that all stimulus pairings presented in this study would subtend the same visual angle and also to insure that adult preference and ranking would not be affected by the size of the stimulus. Stimulus size was a factor in this experiment because unlike infant subjects who only viewed either Pairing 1 and Pairing 2 or Pairing 3 and Pairing 4 stimuli, adults viewed all four sets of stimulus pairings in this experiment.

While the visual angle along the horizontal dimension of the Pairing 1 and Pairing 2 stimuli remained the same, the visual angle along the vertical dimension of the Pairing 1 and Pairing 2 stimuli subtended approximately 28.4° of visual angle at a viewing distance of 30 cm. Figure dimensions for all Pairing 1 and Pairing 2 stimuli remained the same, thus no change was affected with regard to visual angle from Experiment 1. All parameter values with regard to visual angle used in the creation of the Pairing 3 and Pairing 4 stimuli remained the same as reported in Experiment 2. Mean luminance values for each of the stimuli used in this are the same as those reported in Experiment 1 and Experiment 2.

13.3 <u>Filtered Stimuli</u>

Each Pairing 1, Pairing 2, Pairing 3 and Pairing 4 stimuli were analyzed in the same manner described in Experiment 1 in order to obtain its two-dimensional Fourier Amplitude Spectrum, and then multiplied by a normalized 1-month-old CSF in order to obtain the stimulus' filtered power spectrum. At the stage of inverse filtering, each stimulus was divided by the spatial contrast sensitivity function appropriate for the visual system of an adult since all stimulus pairings were presented to adult subjects in this portion of the experiment. Figure 14 illustrates the effects of filtering on the Pairing 1, Pairing 2, Pairing 3, and Pairing 4 stimuli.

The visual angle subtended by each of the filtered stimuli remained the same as reported for the unfiltered stimulus pairings of this experiment. Average luminance for lightest and darkest area, on the other hand, are effected and the changes are approximately as follows: (C1) 170 cd/m^2, (R1) 140 cd/m^2, (C2) 150 cd/m^2, (R2) 160 cd/m^2, (C3) 170 cd/m^2, (R3) 170 cd/m^2, (C4) 140 cd/m^2, (R4) 140 cd/m^2.

13.4 <u>Adult Preference to Look Procedure</u>

Adult subjects participated in a modified version of an infant preferential looking task, where adults reported their preference to "look at" a specific stimulus. Testing conditions were the same as those described in Experiment 1 except that stimuli were placed on a table instead of presented through the viewing theater used for infants. Subjects were randomly presented unfiltered and filtered Pairing 1, 2, 3, and 4 stimuli in counterbalanced order and were

Figure 14. Filtered stimuli used for presentation to adult subjects. Unfiltered stimuli were filtered using a normalized 1-month-old CSF and then inversely filtered by the CSF of an adult observer.

Adult Filtered Stimulus Pairings: Experiment 4

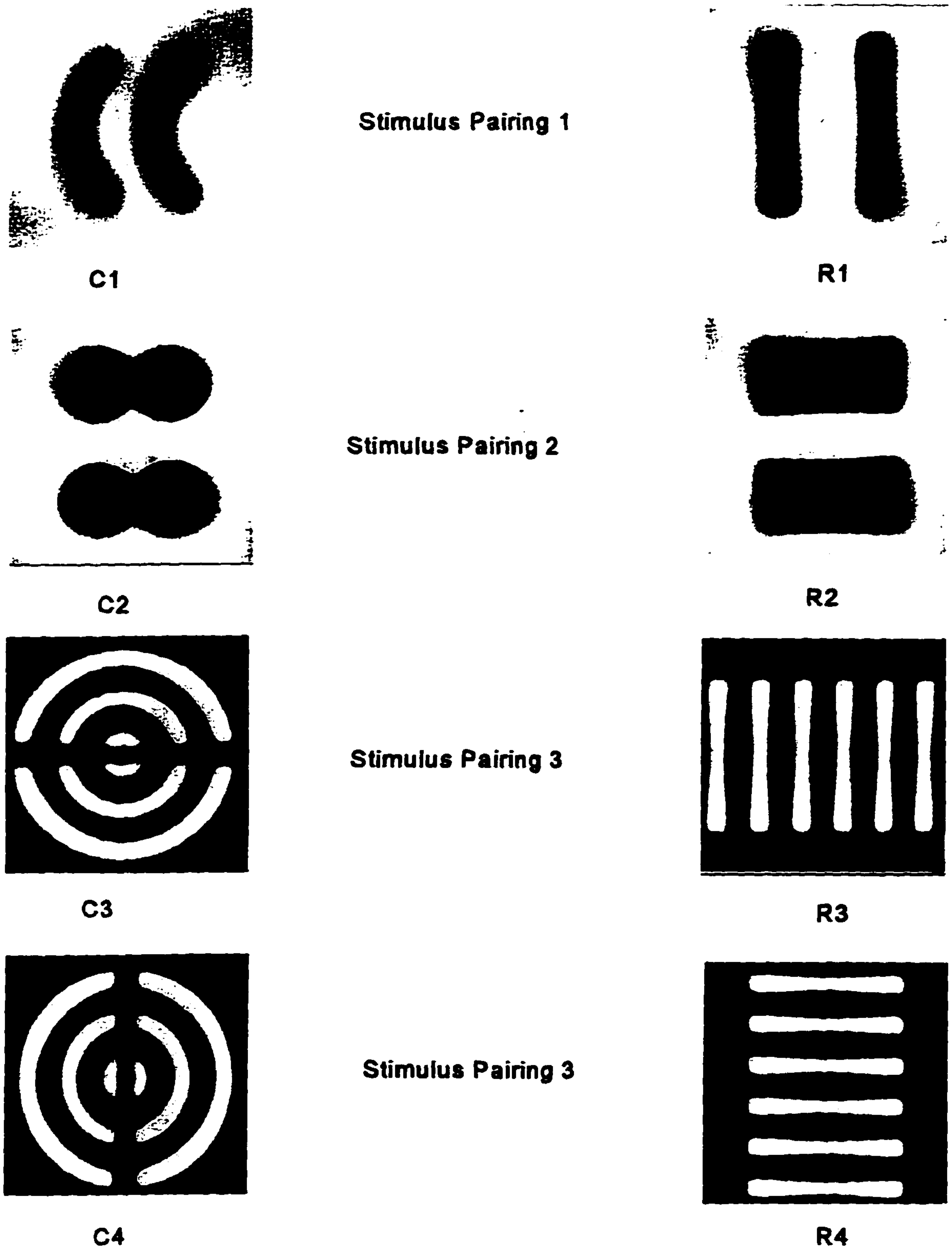

Figure 14

instructed where to view the stimuli so that the distance from observer to stimulus pairing would be approximately 30 cm. Each subject was then asked the following question regarding the stimulus pairings: Having only these two objects present in a room to look at, would you prefer to look at one object over the other? Subjects who responded "yes" were then presented with the follow-up question, "On a scale of one to ten, approximately how much more would you prefer to look at the image you chose over the image you did not choose?" In other words, if a subject decided that he or she preferred the unfiltered C1 stimulus over the R1 stimulus the subject was then required to quantify the preference by assigning the stimulus a number between 1 and 10. Consequently, a preference was considered any stimulus assigned a number higher than 5. Subjects who responded "no preference" had their preference scores recorded as a 5 for each stimulus of the pairing.

[14]

RESULTS

14.1 Overview of Adult Preference Response: Procedures and Analysis

The purpose of the preference portion of this study was to determine if preference for a curvilinear over rectilinear stimulus, known to be present by the third month of development continued through adulthood. Moreover, if this preference behavior was found to occur into adulthood, could filtering the curvilinear and rectilinear stimulus pairs revert adult preference behavior to the behavior consistent with 1-month-old infants? Adult preference was measured in this case by simply asking adults which stimulus they preferred to look at. Further analysis of the data obtained from this study focused on determining if a relationship could be found between the underlying mechanism believed to cause infant preference behavior; in this case the development of the infant

CSF.

The ratings given by adults for each curvilinear and rectilinear stimulus of a pairing were transformed into percentage preference looking times so that the preferences reported by adults could be directly related to the infant differential fixation times from Experiment 1 and Experiment 2. For each adult subject, the preference scores across presentations were added. Next these scores were converted into a percentage preference looking time score by dividing them by 20. For example, if a subject responded that he or she preferred the curvilinear stimulus over the rectilinear stimulus by a score of 7 for the first viewing and by a score of 8 for the second viewing , the curvilinear stimulus was then scored as a preference for the curvilinear stimulus by a score of 15 to 5 or 75% preference. Consequently the score for the rectilinear stimulus was scored as 25% preference. Mean preference percentage looking scores and standard errors for the adult sample are reported in Table 5.

14.2 Overview of Adult Preference Score Analysis

The percentage preference looking times for this experiment were examined using the same analysis as described in Experiment 1 and Experiment 2. However since adult participants were shown all of the curvilinear/rectilinear stimulus pairs across one experiment the factor of stimulus pairing was consequently increased. Therefore a, 2 x 4, filtering (unfiltered and filtered) by stimulus pairing (1, 2, 3, 4) ANOVA was conducted where the level of stimulus dimension curvilinearity, was held constant across each ANOVA. In addition,

Table 5

Mean and Standard Errors: Adult Data, Pairing 1, 2, 3, & 4.

Mean percentage preference scores are given only for the curvilinear stimulus of the pairing. Rectilinear stimulus values can be calculated by subtracting the curvilinear value from 100%. Standard errors are the same for both curvilinear and rectilinear stimuli.

Stimulus Dimension	n	M	SE
Unfiltered			
C1 Stimulus	20	61.0	3.3
C2 Stimulus	20	60.1	3.4
C3 Stimulus	20	65.1	3.9
C4 Stimulus	20	66.3	3.9
Filtered			
C1 Stimulus	20	60.5	3.0
C2 Stimulus	20	53.6	4.9
C3 Stimulus	20	68.2	2.8
C4 Stimulus	20	69.0	3.8

the mean preference percentage scores obtained for this study were also tested against a baseline of 50% by performing 8 separate paired t-tests for each of the unfiltered and filtered, curvilinear stimuli.

14.2.1 <u>ANOVA Analysis of Mean Preference to Look Scores.</u> No main effect for level of filtering was found, whereas a significant main effect was found for pairing of stimuli, $\underline{F}$ (3,57)= 5.02, $\underline{p} < .004$. No significant interaction was found between level of filtering and stimulus pairing. Adult mean percentage preference data for the unfiltered and filtered stimulus pairs are plotted in Figure 15a for the Pairing 1 stimuli, Figure 15b for the Pairing 2 stimuli, Figure 15c for the Pairing 3 stimuli and Figure 15d for the Pairing 4 stimuli.

14.2.2 <u>Results of ANOVA Analysis.</u> While preference response given by adults moderately decreased with filtering across the unfiltered C2 and filtered C2 stimuli, adult preference behavior overall did not appear to change as a function of filtering. In fact, the preference response given by adults while not significant, were found to be slightly higher in the filtered Pairing 3 and Pairing 4 conditions. Furthermore, when the mean percentage preference looking time data were compared with the descriptive analysis of spatial frequency and contrast at the fundamental frequency, no relationship between the two could be found.

14.2.3 <u>Analysis of Adult Scores from 50% Baseline.</u> Eight paired t-tests were performed to determine if the mean percentage preference looking times for each of the unfiltered and filtered, curvilinear stimuli differed from a

Figure 15a. Mean percentage preference time of unfiltered and filtered Pairing 1 stimuli when presented to adult observers. The data are presented as a line graph for purposes of clarity.

Figure 15b. Mean percentage preference time of unfiltered and filtered Pairing 2 stimuli when presented to adult observers. The data are presented as a line graph for purposes of clarity.

Figure 15c. Mean percentage preference time of unfiltered and filtered Pairing 3 stimuli when presented to adult observers. The asterisk indicates that the mean looking time was also significantly different when compared to a baseline of 50%. The data are presented as a line graph for purposes of clarity.

Figure 15d. Mean percentage preference time of unfiltered and filtered Pairing 4 stimuli when presented to adult observers. The asterisk indicates that the mean looking time was also significantly different when compared to a baseline of 50%. The data are presented as a line graph for purposes of clarity.

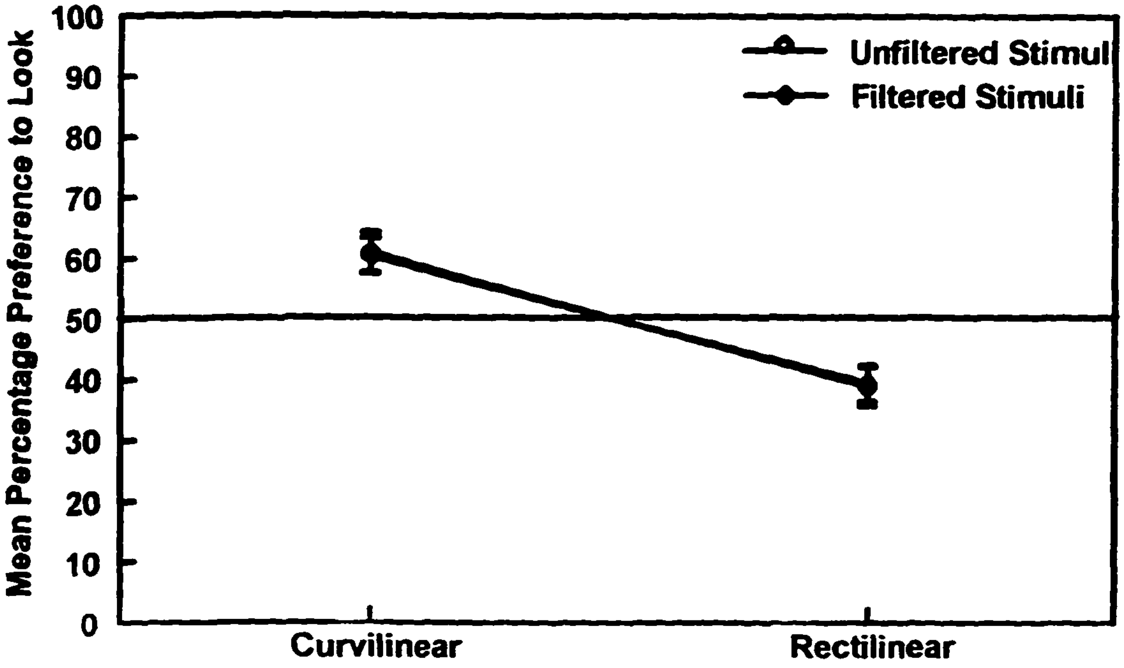
Mean Percentage Preference to Look
100
90
80
70
60
50
40
30
20
10
0
Unfiltered Stimul
Filtered Stimuli
Curvilinear
Rectilinear

Figure 15a

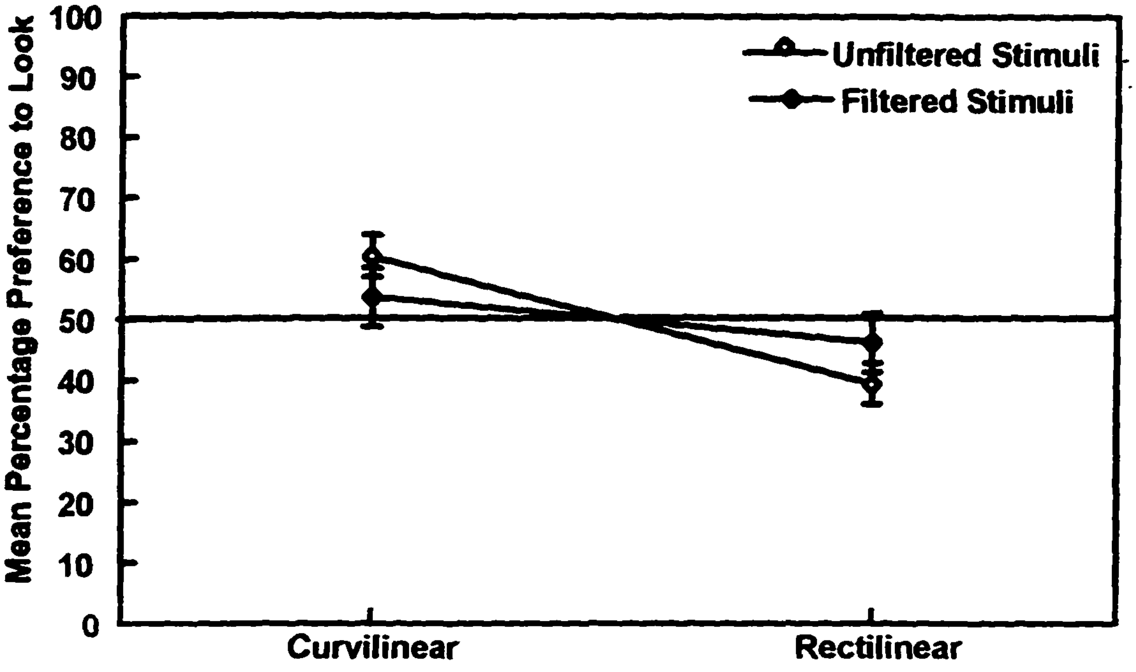
Mean Percentage Preference to Look
100
90
80
70
60
50
40
30
20
10
0
Unfiltered Stimuli
Filtered Stimuli
Curvilinear
Rectilinear

Figure 15b

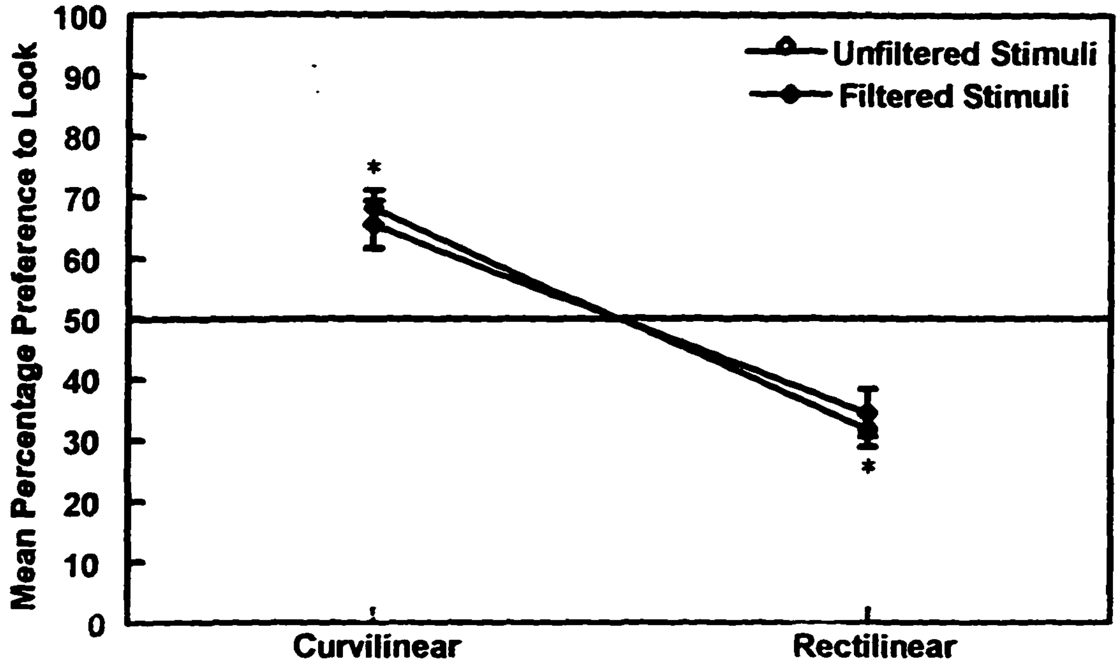
Mean Percentage Preference to Look
100
90
80
70
60
50
40
30
20
10
0
Unfiltered Stimuli
Filtered Stimuli
*
*
Curvilinear
Rectilinear

Figure 15c

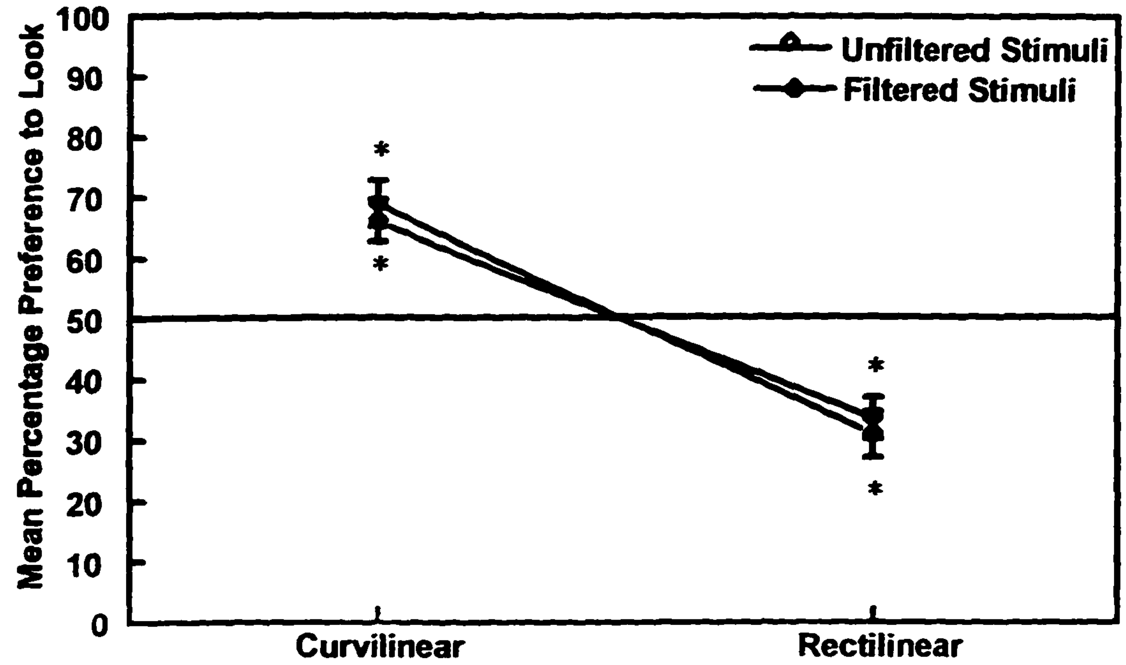
Mean Percentage Preference to Look
100
90
80
70
60
50
40
30
20
10
0
Unfiltered Stimuli
Filtered Stimuli
*
*
*
*
Curvilinear
Rectilinear

Figure 15d

baseline of 50%. Alpha levels for each paired t-test were adjusted to .001 to compensate for the number of tests conducted. It should be noted that the following results were interpreted with caution based on the necessary reduction of the alpha level from .01 to .001 which might increase the possibility of a Type II error.

14.2.4 Results: Adult Preference to Look Scores Versus 50% Baseline.

Three clearly distinct differences emerged from the paired t-test results. First, there were those stimuli that significantly differed from 50%; the unfiltered C3 stimulus, $t\,(19)= 3.99, p < .001$, the filtered C3 stimulus, $t\,(19)= 6.43, p < .001$, the unfiltered C4 stimulus, $t\,(19)= 4.73, p < .001$ and the filtered C4 stimulus, $t\,(19)= 5.09, p < .001$. Next, those stimulus pairs which clearly did not significantly differ from baseline at the adjusted alpha level of .001. Only one set of stimulus pairings met this criterion; the filtered C2 stimulus, $t\,(19)= -.77, p = .45$. Finally, the unfiltered and filtered C1 stimuli and the unfiltered C2 stimuli while considered not significant according to the defined alpha level, none the less returned probability levels no greater than .006.

[15]

DISCUSSION

15.1 Adult Mean Preferential Looking Scores

Mean percentage preferential looking score results obtained from the adult preference section of this study using unfiltered stimulus pairings ostensibly replicated the preference behavior found in infants older than 3 months of age, particulary in the case of the unfiltered Pairing 3 and Pairing 4 stimuli. Support for this conclusion is provided by the results of comparing the unfiltered C3 and C4 stimuli to 50% baseline. That is, while the omnibus test of significance revealed no difference between the level of filtering for the C3 and C4 stimuli, comparison of the C3 and C4 means to baseline did show that adult's preference to look at these stimuli was significantly greater than 50% of the overall time. Conversely, the preference to look at the R3 and R4 stimuli was significantly less than 50% of the overall time. This finding is quite interesting, since while Fantz et al. (1975) report preference behavior based on the dimension of pattern configuration as being essential to object recognition, spatial orientation, and social responsiveness later in life, they never investigated if the preference for curvilinear configuration continued from infancy into childhood and across, into adulthood.

While the unfiltered C1 and C2 stimuli were found to not significantly differ at an adjusted alpha level of .001, inspection of the individual means does reveal much higher preference to look scores for the unfiltered C1 and C2 when compared to the unfiltered R1 and R2 stimuli. It is possible in this case, given the necessary adjustment to our level of significance, that had we run more subjects, both the unfiltered Pairing 1 and Pairing 2 stimuli would also differ from 50% baseline.

Filtering appears to have no effect on adult preference to look, except in the case of the filtered C2 stimulus. In fact, mean preference to look scores are actually somewhat higher in the case of the filtered C3 and C4 when compared to the unfiltered C3 and C4 stimuli. We are again at a loss to explain why filtering had a different effect on the filtered C2 stimulus. That is, we have yet to determine why mean preference to look scores were lower when the C2 stimulus was filtered.

15.2 Comparison of Adult and Infant Preference Scores

It seems quite apparent from the adult preference data we collected that while infant preference behavior is influenced by manipulating the contrast and spatial frequency components of an image, adult preference behavior is not affected by such filtering. Based on the data we collected in this study we believe the following line of reasoning supports this conclusion. First, unlike the infant subjects who took part in Experiment 1 and Experiment 2, adult subjects, when presented with filtered versions of the Pairing 1, Pairing 2, Pairing 3 and Pairing 4 stimuli, did not reverse their preference behavior in the manner that the infant subjects had. In fact, we were quite surprised to find that filtering had even a small effect on the Pairing 2 stimuli and examination across all mean adult preference to look scores reveals that it is the Pairing 2 stimuli that are responsible for the main effect of pairing. These results were even more interesting given the case that it was this same stimulus pairing which presented the least level of reduction in looking time when presented to infants in Experiment 1.

15.3 Can Adult Preference Behavior be Predicted? When we consider that filtering had little to no effect on adult preference to look behavior we could conclude that the Linear Systems Model cannot explain preference behavior in adulthood. Yet, adults did prefer to look at the unfiltered curvilinear stimulus over its rectilinear counterpart. Given these two findings it appears therefore that adult preference behavior is motivated by something other than the characteristics of the CSF. The direction of further inquiry now apparent becomes to uncover what that "something" is. To hypothesize advanced cognitive development on the part of the adult subject as the mechanism responsible for adult behavior in the unfiltered and filtered conditions is not sufficient. Several areas within the realm of cognition could be responsible. For example, during debriefing of the adult subjects, reasons for preference ranged from, "The curved stimuli reveal more completeness in their pattern", to "The rectilinear stimuli reminded me of difficult times." Therefore it is possible that aesthetics might have been the basis for the former subject's preference whereas past associations might have been the basis for the latter preference.

When combined with the preference results across all three infant experiments, the adult preference to look results do give us some insight into the development of curvilinear preference behavior. That is, at some point in development, the characteristics of the CSF, which in turn are thought to describe the characteristics of the visual system, fail to interfere with preference behavior. The question at hand now becomes; when during development does front-end processing no longer influence preference behaviors?

[16]

GENERAL DISCUSSION

16.1 Overview of Infant Experiment 1, Experiment 2, and Experiment 3

The utility of The Linear Systems Model to predict differential fixation by infants to pattern when using a preferential looking paradigm was tested across Experiment 1, Experiment 2, and Experiment 3 of this study. By presenting infants with pairs of stimuli known to elicit definitive preference behaviors at different times during the course of development, we have provided sufficient evidence which demonstrates that changes in preference behavior over the first 6 months of life can be related to changes that are known to occur across the infant CSF during the same time period. That is, when older infants are presented stimulus pairs that substitute what is transferred by the visual system of a younger infant we were able to manipulate and change the older infant's behavior to reflect an earlier form of behavior. Namely, no preference, for either the curvilinear or rectilinear stimulus of a pairing.

When the 4- and 5-month old participants of Experiment 1 and Experiment 2 were presented with unfiltered curvilinear and rectilinear pairings, infants not only fixated the unfiltered curvilinear stimulus for significantly longer periods of time but also significantly "preferred" the curvilinear stimulus of the pairing to its rectilinear counterpart from a hypothetical baseline of 50%. Conversely and in agreement with our predicted hypothesis, when those same infants were shown filtered curvilinear and rectilinear stimulus pairings, infants did not differentially fixate either of the stimuli and consequently no significant preference response was found between stimulus pairs. Additionally, the results of the unfiltered condition pairings across both experiments are consistent with the results reported by Fantz et al. (1975) for infants over the age of 3 months. Moreover, the mean preference response data of the filtered stimulus pairs used in Experiment 1 and Experiment 2 also replicated the findings of Fantz et al. (1975) for infants under the age of 2 months.

16.2 Comparison of the Linear Systems Model to Other Models Used to Explain Infant Preference

Based on many years of empirical research, Fantz et al. (1975) constructed a Hierarchical Model of stimulus preference in order to explain the changes in differential fixation found across infant development. While other models, like Karmel's (1975) Contour Density Model followed, paradigms such as these could only provide evidence of developmental shifts in preference within specific confined parameters. That is, each model could only account for preference behavior when applied to those pattern dimensions which were well studied. For example, patterns consisting only of curvilinear or rectilinear patterns and patterns containing clear boundaries and sharp contrasts. The Linear Systems Model, on other hand, is not limited to the study of specific patterns and not only provides a quantifiable measure of the sine-wave properties contained in "any" two-dimensional image but moreover accounts for the sensitivity of an individual observer to the spatial frequency and contrast contained in that image.

It was further hypothesized by Fantz et al. (1975) that the underlying mechanisms responsible for shifts in preference could be explained by the various immaturities found in the young infant's visual system. For example, the infant's lack of accommodation for different distances and high acuity threshold were believed responsible for the initial restriction of infant preference to stimuli high along the criterion of pattern definition. Fantz et al. (1975) went on to further note the importance of visual selectivity in early infancy and stated that if differentiation was not shown among the unlimited features of a natural environment, and all the features of an image were equally resolvable to the infant during the early weeks of life then the infant would indeed be faced with a "great blooming buzzing confusion".

16.3 The Underlying Mechanisms Responsible for Infant Preference.

Recent findings however, dispute the limiting effects of accommodation (Braddick, Atkinson, French, & Howland, 1979; Banks, 1980; Hainline, Riddell, Grose-Fifer, & Abramov, 1992) and it is now generally agreed that the quality of the retinal image exceeds the resolution performance of the young visual system. However, morphological immaturities apparent in the fovea of the neonate, particularly the photoreceptors, are currently believed to be responsible for many of the deficits found in infant visual processing. Abramov, Gordon, Hendrickson, Hainline, Dobson, & LaBossiere 1982 noted "the paucity of cones in the foveal region" and "the very immature appearance of the retina as compared to the adult fovea" (pg. 267).

16.3.1 Linear Systems and the *Ideal Observer.* Banks and Bennett (1988) used an "Ideal Observer Model"[29] to further elaborate on the influence of immature foveal receptoral factors[30] on the infant CSF, and its connection with poor visual performance of neonates. They concluded that a substantial fraction of the spatial contrast sensitivity deficit found early in life could be accounted for by immaturities in the morphology of foveal cones, which results in poor quantum catching and isomerization of the newborn's foveal cone lattice. Furthermore,

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[29] The Ideal-Observer theory measures information available at chosen processing stages of a visual system. By definition the performance of an ideal observer is optimal, given the physical and physiological constraints that are built in.

[30] Banks and Bennett (1988) examined how inefficient the newborn's cones are at capturing and guiding photons in the inner and outer segment of the foveal receptors, funneling it to the outer segment and producing an isomerization. They found that the cones of the neonate do not act as effective waveguides, therefore a major constraint would expected to be observed in the spatial vision properties of the infant.

Banks and Bennett (1988) also point out the relationship between development of the infant visual system over the first year of life, and the development of improvements to the CSF.

16.3.2 Conclusions Derived from Experiment 1 and Experiment 2. Given our current knowledge of how the neonatal visual system develops and also our current understanding of the component properties contained within an image we can use that information with the results of the infant data we obtained across Experiment 1, Experiment 2, and Experiment 3 to draw the following conclusions. Firstly, given the fovea is the area of the retina responsible for detecting fine spatial detail in an image, and such fineness of detail within an image is accompanied by high spatial frequency components then the development of preference in the early months of life would be expected to coincide more with the development of the infant CSF rather than the development of cognitive abilities as suggested by Fantz et al. (1975). Furthermore, the underlying mechanism responsible for developmental changes and shifts in preference would be due to the maturation of foveal receptors and not by the limitations of accommodation.

While the results of Experiment 1 and Experiment 2 were able to link development of the infant CSF to changes in preference behavior, it is still unclear how much of an influence development of the CSF has on infant preference at 4- and 5-months of age. It is possible that the older infants tested in these studies might be using some advanced form of cognitive ability in response to the unfiltered stimulus pairings and therefore we cannot rule out cognitive influence entirely with regard to the development of infant preference. On the other hand our results do show that the development of front-end processing, which coincides with the development of the CSF, appears to play a much larger role in preference behavior for the younger infant. It could therefore be concluded on the basis of our findings that if cognitive factors are responsible for preference behavior at later periods in infancy, then such cognitive abilities, at least early on, are immature and can be disrupted easily. In other words, if the visual system of 4- and 5-month-old infants can readily process the appropriate sensory information from the stimulus, then cognitive factors might be the determining factor in preference. However, as appears to be the case with the filtered images, when the appropriate information is not "transferred" through the visual system of the observer from the stimulus, knowledge from cognitive factors may not be readily accessed, and therefore the infant can only respond in terms of what limited information is available from the stimulus. It would therefore be important to examine when cognition supercedes preference behavior over sensory input.

While Fantz et al. (1975) also hypothesized that early in infancy stimuli containing high contrast contributed to newborn infant fixations to stimuli, it appears that contrast does not play the same role as spatial frequency in preference. When the unfiltered and filtered stimulus pairs used across Experiment 1 and Experiment 2 were analyzed to obtain their Fourier components, preference based on the amount of contrast would predict that the rectilinear stimulus would be preferred if high contrast were the factor. Contrary results were found. The curvilinear stimulus contained less contrast than the rectilinear stimulus and was significantly preferred in all unfiltered conditions.

16.3.3 Discussion and Comparisons of Results found in Experiment 3.

The third experiment equated spatial frequency at the fundamental component of the unfiltered curvilinear stimulus with its unfiltered rectilinear counterpart, as viewed by the visual system of a 1-month-old infant when observed by 4- and 5-month old infants. As hypothesized, a significant preference was not found for the curvilinear stimulus. Therefore, Experiment 3 not only supported the assumptions put forth by the Linear Systems Model, but also found evidence that the development of sensitivity to higher spatial frequency was the underlying factor responsible for the shift from preference to non preference.

Unlike the results reported by Banks and Salapatek, we did not find that infant preference behavior was motivated by those stimuli that contained contrast and spatial frequency components within the peak of the infant CSF. The infants we tested preferred those stimuli which contained lower spatial frequency, in general, at the fundamental component. However upon inspection of the Fourier Amplitude Spectrum of the sine-wave and rectangular wave gratings used by Banks and Salapatek (1985) (see Figure 2.), we find that while spatial frequency at the fundamental component happened to be located at the peak of the infant CSF, spatial frequency at the fundamental component was also the lower spatial frequency of the pairings preferred by infants. Therefore, it would be important to determine which component is more central to infant preference: that stimulus which contains spatial frequency components at the fundamental of the stimulus which is closest to or at the peak of the infant CSF or that stimulus which contains the lowest spatial frequency at the fundamental in general. Furthermore, just how different do these components have to be in order to ascertain a preference response for one stimulus over the other?

Finally, it could be argued that the results we obtained from Experiment 3 were due to a lack of visibility of the curvilinear stimulus. That is, when the curvilinear stimulus was filtered to equate its spatial frequency with the rectilinear stimulus, the curvilinear stimulus was not fixated because it simply could not be "seen" by the infant. If this were the case then one could also reasonably assume that the effects of filtering across Experiment 1 and Experiment 2 were obtained for the same reason. However, if filtering the curvilinear stimulus from Experiment 3 resulted in making the curvilinear stimulus less visible, then we would have expected the rectilinear stimulus to be preferred, since it has been well documented that infants prefer "something" over "nothing". In addition, when we compare mean preference looking times for the Pairing 1, 2, 3, and 4 filtered stimuli from Experiment 1 and Experiment 2 to its pairing results from Experiment 3, looking times across experiments are almost identical. This finding gives further support for the conclusion that spatial frequency at the fundamental component is the variable responsible for changes across filtering in preference behavior.

16.4 Applications of Results from Experiment 1, Experiment 2, and Experiment 3.

When taken together the overall results of infant testing across each of the experiments we conducted not only support a Linear Systems model, but more importantly allow researchers the opportunity to study and manipulate how the processes resulting in preference behavior develop over the first six months of life. In addition, we believe that the findings we have reported might also have significance for other studies which use Forced-Choice Preferential and Novelty Preference Techniques. For example, The Fagan Test of Infant Intelligence uses a novelty preference paradigm to determine an infant's current level of intelligence, but does not consider the effects that visual abnormalities could have on preference behavior. Appropriate preference behavior might not be observed under these conditions since spatial frequency and contrast information transmitted to the visual system might be further effected or "filtered" by visual abnormalities. For example, it is well-documented that infants are less sensitive to higher spatial frequencies than adults and an infant who is severely myopic would be even less sensitive to higher spatial frequencies. If the images used in the Fagan Test of Infant Intelligence were constructed of high spatial frequency components at the fundamental then it is possible that "incorrect" preference behavior would be observed. Consequently, that infant would be labeled as less intelligent when the problem is simply poor eyesight. Given the current findings of this research it would seem that visual tests of this type need to consider the effects of sensory processing.

16.5 The Nature of Adult and Infant Preference Behavior

The results of Experiment 4 revealed both interesting similarities and complicated differences when compared to the infant data across Experiment 1 and Experiment 2. Under unfiltered condition testing, adult preference behavior for the curvilinear stimulus, while not as strong as the infant preference was none the less significant. However, while conclusions regarding the underlying preference behavior in infancy are well supported by the research in this paper, the mechanisms which could possibly account for the adult preference remain unclear, since simply positing cognitive factors leaves many questions unanswered.

Unlike the infant results found in Experiment 1 and Experiment 2, filtering did not reduce preference for the curvilinear stimulus across the adult Pairing 1, 3, and 4 stimuli. In fact the percentage preference increased when adult viewed the filtered Pairing 3 and Pairing 4 stimuli. Therefore it seems that limiting the information available to the visual system of an adult by removing certain spatial frequencies and contrast did not affect adult preference behavior in the cases we tested. This however was not the finding for the filtered Pairing 2.

Similar, yet contrary to the results found across infant preference behavior, the filtered Pairing 2 appears to be somewhat of a "special" case in terms of adult preference behavior. The filtered C2 stimulus showed only a modest decrease in infant preference behavior when compared to the other curvilinear stimuli, however when the C2 stimulus was presented to adults it was the “only” stimulus preference time to decrease. Interesting as this result may seem, it is unclear why filtering would have an effect on this particular set of stimuli and not the others. Moreover, we are also at disadvantage to explain why the C2 stimulus had the least effect on infant preference and the greatest effect on adult preference.

16.6 Future Areas of Study

There are a number of potential studies which can be done to further the knowledge we have gained thus far. Firstly, this research is only a subset of the kinds of testing which one could propose using the Linear Systems Model. Replication studies using different “pairings” of stimuli should be further conducted since there is the possibility that the results which were originally obtained might be based on the kinds of stimuli selected. Fantz and Fagan (1975) have tested numerous stimulus pairings, along several dimensions and while our results are consistent with the findings for curvilinear and rectilinear stimuli, this may not be the case when stimulus quantity is the stimulus dimension under investigation. It is further suggested that longitudinal studies be proposed to track the course of preference development. These studies should focus on when sensory processing no longer effects infant preference behavior and is driven by cognitive factors like selective attention and long-term memory. While it is impossible for a single series of studies to address all the questions we have, or provide definitive answers on these issues, investigating the relationship between the development of the CSF and the development of preference behavior in infancy by using the Linear Systems Model has advanced our knowledge of early preference behavior.

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