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Manipulating Spatial Frequency to Examine

Global and Local Information Processing

in 7-Month-Old Infants.

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Manipulating Spatial Frequency to Examine Global and Local Information Processing in 7-Month-Old Infants.

by

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Dedication

To parents who want their children to have a better life.

To Angie who arrived late in the project but made it all possible.

It's going to be a beautiful partnership.

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Manipulating Spatial Frequency to Understand

Global and Local Information Processing

in 7-Month-Old Infants.

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The University of Texas at Austin, 2009

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It has been shown that infants build representations of their visual world by forming relations among its parts. However little is know about how they select the parts to relate. One possibility is that while constructing their visual world part by part they are also decomposing it, using finer and finer parts. One way to test this theory is to simply control the parts infants see. This easiest way to do this is to filter real life objects of their high and low spatial frequencies. High spatial frequencies provide information about the smaller parts where as low spatial frequencies provide information about the larger ones. By removing high or low spatial frequency we can control the coarseness of their representation and ultimately determine the level at which they function best. The present study examined infants' ability to use high and low spatial frequencies to discriminate between objects. Infants were habituated and tested using a combination of high and low

spatial frequency images. Only infants experiencing a consistent spatial frequency across habituation and test were able to discriminate between objects. Infants were also better at discriminating between objects containing high spatial frequencies. In a second study designed to be more true to life, infants were habituated to broadband images and tested using high or low spatial frequencies. This time infants did not discriminate between objects but they did look longer at low spatial frequency information than at the high. From these findings we can conclude that infants use both high and low spatial frequency information when discriminating objects, and that in certain cases one frequency may become more important than the other. The spatial frequency they use may be dependent on the context of the task. Numerous studies have shown that adults prioritize high and low spatial frequency information depending on how fast they want to process the object, the amount of detail they require, and whether they used high or low spatial frequency information during previous experiences. Infants may be similar. At times they may emphasize low spatial frequency information and the big picture. At other times they may emphasize high spatial frequency information and the detail. More studies examining how infants select information for processing are necessary and spatial frequency will likely to be an important tool in the investigation.

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Chapter 1

Introduction

Information processing theory has become one of the most influential theories for understanding cognition in the last 20 years. Its appeal stems from its similarity to the way a computer functions. Computers are designed to manage an extraordinary number of inputs using a distinct set of processes. As people invent increasingly better ways to surround themselves with information, finding a theory that suitably explains how we manage it becomes paramount. While it has been adopted by many researchers to explain numerous cognitive phenomena, Palmer and Kimchi (1986) proposed a framework of five assumptions that are universally held by all of them.

The first assumption describes the three central components that are its basis. Subsequent assumptions describe how the components form a system. Assumption 1 is *information description*. It assumes that all theories share the same three central components. They are inputs contributed by the environment, operations enacted on them, and outputs that are the result. Assumption 2 is *recursive decomposition*. It states that any input can be made more informative by decomposing it into its elements. Assumption 3 is *flow continuity*. It states that all information contained in the input must also be contained in some form in the output. Assumption 4 is *flow dynamics*. It states that the system always progresses in one direction from input to output. Finally, assumption 5 is *physical embodiment*, in which inputs and outputs are represented by specific states of the brain and processes are the operations used to change those states.

This study will specifically explore the nature of the first assumption, that information processing theory uses inputs, operations, and outputs. It will first attempt to organize what we already know about these components using both adult and infant literature. It will then argue that we can further our understanding of them by adapting adult techniques to younger populations.

Infants process information just as adults do. That is to say, both infants and adults use inputs, processes and outputs to learn from and interact with their environment. However, depending on the origin of these components and if they are acquired over time or are provided at birth, they may use them very differently. While information processing has been studied in great detail in adults, studying it successfully in infants has proven to be more difficult. Furthermore, a review of the infant literature suggests that the majority of what we know focuses primarily on *how* infants process information as opposed to *what* they process. Gibson (1955) commented that understanding someone's behavior must begin with studying the content of their perceptions. Without knowing what infants process, knowing how they process it is of little use. Gibson's observation demonstrates well how the focus of infant research has changed over the years, once emphasizing content over mechanism and now emphasizing mechanism over content.

What is sorely needed in the field is a developmental model of information processing that brings together our understanding of all three of its central components. The model must accomplish two things. First it must predict the parts of the environment an infant will acquire at any given moment. As in adults, infants' representations are not faithful depictions of their environment, but rather abstractions of its most important parts. Ideally the prediction should follow a perceptual hierarchy in which the environment's content is arranged into multiple levels. Palmer (1977) offered an example of such a hierarchy. In his hierarchy, the highest level is a single perceptual unit that represents the entire object. At the lowest level reside the smallest perceptual units that make up the object. A complete infant information processing model should predict where infants enter the hierarchy. It should predict when an infant will take in *face* as opposed to *eyes, nose* and *mouth* or *eyelid, lash and iris*. To be complete, the model must consider factors such as prior experience with the object, the complexity of the object, and exposure time to the object.

The second thing the model must provide is a mechanism for how infants use the parts they acquire. More specifically, once infants have inputs, what operations do they perform on them? For example, if an infant perceives eyes, a nose and a mouth and arrives at *John*, the model must say how the infant arrived at *John*. Primarily, two possibilities exist (Gibson, 2000). Enrichment theories suggest that infants integrate parts in a building up process, searching for commonalities among them. For example, with inputs of eyes, nose, and mouth an infant might relate them and build a face. Differentiation theories on the other hand suggest that infants break objects into their parts as a way of distinguishing among them. They search for differences. With inputs of eyes, nose and mouth, an infant would not relate them into a face, but would break them down to get information about the individual parts. In this case, an infant may decide if the eyes are blue, brown or green and the nose pointy or curved.

These two theories have most commonly been portrayed as being in conflict with one another. How could an infant simultaneously build up an event while breaking it down? The answer may be simple. Each theory may speak to a different aspect of information processing. More specifically, differentiation theories may describe well how infants acquire information and enrichment theories may describe how they process it. In effect, infant information processing may require a simultaneous breaking down and a building up. They may look at an object in increasing detail all while processing those details into larger parts.

First, prior work by Kimchi (1994) offers subtle support for the information and processing components being independent. She found that adults' ability to operate on the parts of an object was not dependent on the part's hierarchical position within the object. In other words, elements located near the top of the perceptual hierarchy were processed just as easily as those near the bottom. No evidence of this yet exists in infants.

Second, little is known about how infants may begin this simultaneous breaking down and building up of their representations, the main questions being what do they process and how do they process it. Numerous researchers have studied this in adults. Researchers such as Palmer (1977) and Pomerantz (1983) have proposed different ways of describing information, but in adults. Furthermore, Kinchla and Wolfe (1979), Martin ((1979) and Ward (1982) among others have proposed how adults select information for processing. Only Vurpillot, Reul and Castrec (1977), Ghim and Eimas(1988), Colombo(1993) and Macchi Cassia et al. (2002) have pursued anything similar in infants.

The purpose of this study is to work toward a more complete model of infant information processing. Prior models have stressed mostly operations and ignored input. This study will focus on the latter. It will bring together facets of both differentiation-type theories as well as enrichment-types in an effort to explain how information processing requires both a breaking down and building up of information. The first step will be proposing a way of understanding information in terms of its parts.

Chapter 2

Inputs

Palmer's Perceptual Hierarchy

Palmer (1977) said any object can be perceived both as a whole object and a series of parts in a relation. He proposed a perceptual map for organizing the parts of an object. He noted that each part of an object is its own whole as well as a series of elements. The result is a hierarchical structure that maps an object from its largest part to its smallest. For example, here is how Palmer's hierarchy would map a person. At the very top of the hierarchy, the person is a blob. At the next lowest level, the person is perceived as a head, torso, two arms and two legs. Each of these parts can then be described at yet another lower level; the head has a set of eyes, a nose and a mouth and the arms have a shoulder, elbow and hand. It could be said then that the eyes have a lid, iris, and pupil and the hands have a palm, four fingers and a thumb. Each level contains one or more parts that are each constructed of their own smaller parts.

In his work, Palmer (1977) noticed that some parts of objects seemed naturally to go together while others seemed unconnected. He described this phenomenon as selective organization. A good example is Palmer's map of a person. As one moves through the hierarchy, the head and arm are at approximately the same level. Palmer points out, though, that parts of the head are not usually configured with parts of the arm. In other words, one's tendency is to avoid forming configurations from elements of two different features. In this way, the hierarchy does not configure all parts to all other parts, rather only to a selective few. The result is a tree structure that rapidly grows in breadth.

The base of each branch is a feature and its offshoots are its elements. Palmer tested this idea using four experiments.

Testing Palmers Hierarchy.

Any object can be parsed into an infinite combination of parts, yet Palmer showed that different viewers often parse along similar lines. In his first experiment, Palmer asked participants to parse a series of line figures “into their natural parts.” Each figure was composed of six line segments and participants were instructed to parse each into two three-segment parts. Mathematically, each figure could be parsed 10 possible ways with each way being equally probable. Results indicated that participants parsed each of the figures relatively similarly. Of 16 participants and 10 figures, all participants parsed five of the figures in the same way, three figures two different ways, and two figures three different ways. Palmer argued that Gestalt principles cannot explain the outcome because they do not distinguish any of the parsings as being more likely than the others. He proposed that a new system of guidelines is needed to explain why viewers parse objects as they do.

While the result of Experiment 1 suggested that viewers parse objects according to seemingly natural lines, it does not speak to how they draw those lines. Palmer believed that parts of an object were rated as more natural than other parts because the part’s naturalness is dependent on the other parts within the whole. In other words, one reason certain parts go together is because they do not go with other parts. This idea led Palmer to Experiment 2. Because how well parts go together is dependent on all parts within the object, participants could rate a parsing shared by two objects as being more natural in one object than in another depending on how their other parts are parsed.

Participants were presented with six-segment line figures each paired with five possible was of parsing it. Additionally, half of six-segment figures shared the same parts but in different orientations. They were instructed to rate each of the five parsings on how natural it appeared within the figure. With this design, Palmer determined 1) if some parsings within a figure would be rated as more natural than other parsings and 2) if a parsing would be rated as more natural for one figure than for another. The results supported his predictions. Some parsings were rated as more natural. Also, parsings were rated more natural for some figures than for others. Furthermore, none of the parsings for a figure received equal ratings. (no overlap).

While Experiments 1 and 2 strongly suggested that figures are parsed along natural lines, Palmer argued that his experiments did not test true automatic perceptual processing. In Experiment 3, participants were shown a 6-segment line figure and a three-segment line figure and were asked to respond as quickly as possible whether the 3-segment figure was part of the 6-segment figure. He predicted that more natural parts would be responded to faster than less natural parts. His results again supported his prediction. Parts that were rated most highly on naturalness were responded to the fastest. It is thought that parts with moderate and low level naturalness levels required additional subtle comparisons, which slowed the process.

Palmer's Experiment 4 was the most telling of all. Palmer predicted that parts with high naturalness are also more easily manipulated than parts with moderate and low naturalness. Participants were given sets of two 3-segment line figures and were asked to mentally fit them together. They were then tested with a picture showing the parts either correctly or incorrectly put together. They were to respond as fast as they could whether the test stimulus was the same as or different from the probe. Results indicated that parts with high naturalness were easier to manipulate than others.

From his experiments Palmer concluded that objects can be broken down into natural parts and that how those parts are formed depends on all parts within the objects. Furthermore, his results support at least three levels of structure within an object. The first level is the whole object, because a part's naturalness depends on all parts within the whole. The second level is defined by groups of parts, because some parts go together more naturally than others. Finally, the third level is the independent part. Even parts that do not naturally go together could be compared by parsing their individual parts.

Palmer's Hierarchy In Practice

If Palmer is correct and all parts of an object are selectively organized, not all information in the hierarchy is processed at any given time. For example, when comparing the ears of two dogs, information about the dogs' noses is seldom included. If not all parts are processed at the same time, the question becomes which parts are processed first and why. There are at least two answers to this question. The first says the factors are task dependent. Someone requiring only gross detail to perform their task may enter the hierarchy near the top, where as those requiring finer detail may enter at the bottom. For example, if someone were looking for a man among a sea of people, that person would likely enter the hierarchy near the top searching for someone with male parts. On the other hand, if the person were looking for "John" that person would likely enter near the bottom searching for John features. Additionally, in the case of the later, the person may best perform the task by entering the hierarchy more than once. Perhaps the most efficient way to find John would be to first find a man and then determine if he is John.

The second answer to the question says it is dependent on low-level sensory mechanisms. All objects have parts. Each part has a certain amount of detail. Parts processed at the bottom of their hierarchy have finer detail than those processed at the top. As a result, parts near the bottom require more effort and thus take longer to process than those it at the top. If where one enters the hierarchy were dependent on low level sensory mechanisms it is possible one may work simultaneously to perceive all parts of the hierarchy only to have the parts near the top be processed before the ones at the bottom.

Both of the above answers are possible. The first suggests that some parts have a perceptual dominance over other parts where as the second suggests that some parts have a temporal precedence over other parts. The first is based on what one does with parts once they have them and the second is based on how one selects the parts. Both are probably true to equal degree.

Navigating the Hierarchy

Navon (1977) offers numerous reasons why a viewer would begin at very top of the hierarchy and progress downward. One reason is that objects contain an infinite amount of information and in order to efficiently choose which information to process the information must be pared down. By starting near the top, a viewer can reduce the amount of information that must processed by locating significant features, which tend to lead to significant elements. In other words, it is more efficient to follow a single feature to a limited number of elements, than to start with an infinite number of elements (some of which may or may not be related) in the hopes of finding a significant feature.

According to Navon, the most rudimentary part of an object is its location. Navon depicts this idea as *blob*. Blob is the highest level of the hierarchy and corresponds to the region containing the figure. If more information is needed beyond location, one may enter at a lower level, to the elements that make up blob. If still greater detail is needed, one could enter at a third level identifying the elements themselves. The key to Navon's understanding of Palmer's (1977) hierarchy is that viewers enter the hierarchy at its highest level. Then as they need more detail, they progress down to lower levels. Navon described this process as decomposing the object for clarity.

I have already noted that all parts of an object can be mapped onto a perceptual hierarchy. At the very top of the hierarchy is the object itself. As one moves away from the object toward the bottom of the hierarchy, the object's parts become more evident as object detail becomes finer and finer. Navon (1979) may have explained it best when he described the process as a "focusing in." The terms global and local are relative terms that describe the amount of detail available. Parts near the top of the hierarchy will be considered more global than parts near the bottom because their potential for detail is greater, meaning they contain more subparts. Conversely, parts near the bottom will be considered more local than parts near the top because the potential for detail is less.

A common misbelief is that global describes only the very top of the object's hierarchy and local all parts below it. This is incorrect. The global verses local distinction can be made at an infinite number of locations within the hierarchy. It is a sliding scale in which a configuration is global to its features while its features are global to their elements. Inversely, elements are local to their features, which are local to their configuration. For example, a face has feature eye, which has the element lash. While face is global to eye, eye is global to lash. The global verses local distinction can be made at any point within the hierarchy as long as a viewer can distinguish among an object's parts.

A second misbelief is that one must know the local elements in order to know the global form. From a perceptual hierarchy standpoint, this is untrue. If a part acts simply as a placeholder or blob in space that contributes to the perception of a larger object, its identity need not be known. A perfect example is how two objects can be perceived similarly even though they are made up of different elements. A compound letter such as those used by Navon and others is an excellent example. The letter H is no less an H when it is made up of Zs than of Ss. An H is an H no matter what its elements. However, over the years a second definition of global has seen use in the cognition and perception literature. It holds with the colloquial definition of global. That definition states that global describes any representation consisting of many separable parts. In the view of this study, this latter definition does not apply to issues of perceptual hierarchy, but rather issues of processing, which will be covered in detail in the next chapter.

Navon and the Inevitability of Global Processing

Navon conducted a series of landmark studies investigating how viewers use perceptual hierarchies. His stimuli were compound stimuli consisting of letters of the alphabet made from much smaller letters. In some versions the large and small letters were the same (consistent) and in others they were not (inconsistent). Navon was most interested in determining if adults perceived the large letter or the small letters first. By adding interference to one or the other and comparing response time he could identify which letter they were processing. If by directing interference at the small letter he slowed the participant's response time, he could assume the participant was processing the small. If he saw no change then the participant was processing only the large.

In his most telling study Navon presented a single compound stimulus and asked participants to identify as fast as possible either the small letter or the large letter. Some of the stimuli contained consistent small and large letters while others contained inconsistent. While participants typically responded more slowly when identifying the small letter, they responded significantly so when the small letter did not match the large. There was no change when they were asked to name the large, no matter if it matched the small. Navon argues that since no delay was evident when participants were asked to identify the large letter, the delay when naming the small when the large and small were inconsistent was the result of the participant processing the large letter before the small. Navon referred to this phenomenon as the inevitability of global processing. It states that a viewer must first process the global form before processing the local elements. It would later come to be referred to as the global precedence effect.

Navon used his finding as evidence that information processing does indeed involve decomposing scenes, moving from gross to fine detail from the global form to the local elements. Referring to his blob example provided earlier, Navon argues that his finding aligns well with the idea that we must first understand that something exists before we can know its identity.

Alternate Explanations of Navon

Martin (1979) argued that Navon (1977) was making rich interpretations from a limited amount of data. She felt that the temporal precedence of global information Navon observed may be due to his stimuli and not a universal information processing principle. She theorized that by manipulating the stimulus she could show a temporal precedence for local information. She investigated Navon's findings by controlling for the sparsity of the local elements in the global form. She suggested that the global precedence effect was not absolute, but rather reliant on the conspicuousness of one level over another. She proposed that where one enters the perceptual hierarchy might actually be an effect of the stimulus itself. One would begin with the level that is most obvious.

By controlling stimulus scarcity and using a paradigm very similar to Navon's, Martin (1979) observed that participants entered at a more local level when local elements were sparsely spaced. However, when local elements were densely spaced they tended to enter at a more global level. Her findings therefore suggest that Navon's global precedence effect is not universal. Where one enters the hierarchy depends on the stimulus itself. The most conspicuous parts take precedence.

Kinchla (1979) also conducted several studies investigating how viewers enter the perceptual hierarchy. He too felt that the level one enters is dependent on the stimulus. He argues that our visual field instills an upper limit on how global we can start. When processing small scenes we may enter the hierarchy at the most global level. However, when processing large scenes we may start at a more moderate level. He points out that Navon used only one size of stimuli (all smaller than 6 degrees of visual angle). Had he tested larger stimuli his results may have been different.

As Navon argues for a global precedence, Kinchla argues for a “middle out” precedence. He conducted a simple study investigating this theory. His procedure and stimuli were much like that of Navon, however he varied the visual angle size of the stimuli. He found that participants who viewed scenes at greater than 9 degrees of visual angle processed the local stimuli before the global, where as participants who viewed stimuli at less than 9 degrees processed the global first. Kinchla referred to this finding as the optimal size effect. Viewers do not necessarily enter the hierarchy at the most global level, but rather start at the level that works optimally with the visual field. Since participants responded accurately to both global and local parts, Kinchla further concluded that movement through the hierarchy was not limited to global then local, but could conceivably travel in both directions.

Much more recently, Gyonneau, Kirchner and Thorpe (2007) tested the effect of object rotation on the processing of global form and local elements. In their task, participants were asked to identify which of two scenes presented simultaneously contained an animal. The scenes were rotated to 16 different degrees. There was no difference in response time to any of the 16 orientations, suggesting that participants were not attending to the global form of the animal but rather the local elements that could be indicative of an animal. Again, it is evidence that processing begins not at the top of the hierarchy or the bottom but somewhere in the middle.

Ward (1982) also investigated stimulus effects on how a viewer enters the hierarchy. He noted that globality, conspicuity, and optimal size all seem to influence where one enters. He also noted that all of these factors are related to the stimulus. He theorized that factors related to the state of the individual could also influence how a viewer enters the hierarchy. Might the last instance of processing affect future instances? He used stimuli similar to those of Navon (1977), Ward (1982), and Kinchla (1979), but presented them in a novel way. He showed participants compound stimuli in pairs, one presented after the other. In some pairs, the global forms and local parts were the same. In others they were different. Both members of the pairs had either consistent global form and elements, inconsistent, or a mix of the two. In each case, they were asked to identify either the global form or the local elements of the stimuli as fast as they could.

The results show response times for the second stimulus were faster than for the first. They were also faster when both stimuli had the same letter at the target level. Ward referred to this finding as his level readiness effect. It describes information processing not as an effect of global precedence, but rather an effect of attention allocation.

The Whole as a Sum of Unknown Parts.

While it is evident that a viewer can enter the hierarchy at one of many levels, it is still unclear as to how a viewer can enter at a global level without knowing the parts that make up the local level. In other words, it has been demonstrated that a viewer can move from global to local, but the question is still how is t possible to know the whole before the parts?

One possibility is that the identity of the local elements is not contained in the whole. Pomerantz (1983) suggested that local level elements contribute to the global level in two main ways. First, they might act as placeholders. They would contribute to the processing of the global form simply by existing. For example, in the compound stimuli Navon (1977) and others have used, a global H is still recognizable as an H whether it is made up of S's or Z's. In this case the identity of the elements is not as important as their existence.

The second way Pomerantz (1983) suggests local elements contribute to a global form is by the nature of the element. In this case, the local element must be known in order to see the global form. The classic example is the human face. On one hand, one does not need to know the local elements to recognize something as a face. Three well placed dots and a line will often do. However, if one wishes to recognize a face as a specific face, the nature of the elements must be known, that is to say the type of eye, nose and mouth. Someone could then move readily from global form to local element (a general global form made up of unknown elements taking up space) or local element to global form (specific elements arranged to define a specific global form) depending on the desired output.

Love, Rouder, and Wisniewski (1999) provided a counter explanation for how a viewer could know the global form without knowing the local elements. They argue in favor of equivalencies. Equivalencies are groups of objects that become clustered together because they share similar rudimentary features. For example squares may be grouped together they have recognizably straight sides. Circles may be grouped together because they have rounded. The presence of consistent information may act to tie the elements together. Each group forms its own equivalence, which is then treated as a single unit. These units take on a global form without need for independent local elements. In this way, local elements also define the global form without having their own definition.

While both explain how it is possible to know the global form without first knowing the local elements, the ideas of Pomerantz (1983) suggest it is based on low-level sensory information where as Love et al. (1999) suggest it is dependent on higher level perceptual information. This contradiction is similar to the one brought to light earlier, that where one enters the hierarchy is dependent both on the task at hand and on low-level sensory mechanisms. I argue that the solution is also similar. Low level sensory information determines which parts are taken in, but equivalences determine how they are used, in this case as a single unit.

The role of spatial frequency

Hughes (1986) showed that the asymmetrical interference observed by Navon (1977) and others is related to the availability of certain spatial frequencies. He found low frequencies were available for processing more quickly than high frequencies. Hence, most often the global form is evident before the local elements because the global form is perceived at lower frequencies than the local elements. Hughes found that by hindering participants' perception of low frequencies, he could get them to respond to a local target as fast as a global target even when the two were inconsistent with each other. In other words, he could lessen the global dominance effect. In a follow up study, Hughes (1990) completely removed an object's low frequencies. He again found that when high and low frequencies were present a global precedent existed, but once low frequencies were removed, a local precedence was observed. Both studies offer strong support that the global precedence effect may be driven by the availability of low frequencies.

According to Robertson (1996) low frequencies may also be driving the level readiness effect observed by Ward (1982). In his study, Robertson observed a level readiness effect for both the local and global levels when he showed broadband stimuli - that is stimuli containing both high and low frequencies - even when the kind of target or location on the screen changed. However, once low frequencies were removed from the stimulus, the level readiness effect lessened and a target readiness effect appeared.

While not directly testing the level readiness affect, Schynes and Oliva (1994) suggested that prior experience with objects and scenes makes identifying familiar ones faster in the future- that all one needs to identify an object or scene are low spatial frequencies and a schema. By taking in blobs, which are visible at lower frequencies, and comparing their organization to existing schemata, viewers may be able to recognize them from a previous object or prior scene.

While spatial frequency may account for how a viewer enters a hierarchy, it may not explain everything. For example, Lamb and Yund (1996a) demonstrated that participants were fastest in an object identification task when both low and high frequencies were included in the stimulus, compared to either low or high alone. They also showed that stimuli containing high frequencies alone slowed responses to the global level but not the local level. These two findings support the findings of Hughes (1990, 1996), that spatial frequencies dictate the availability of global form and local elements. However a third finding directly refutes the findings of Robertson (1996) that the absence of low spatial frequencies eliminate repetition effects. Lamb and Yund found no such effect. Furthermore, Lamb and Yund (1996b) failed to find an effect of spatial frequency on asymmetrical interference once stimuli were balanced for contrast, and that also contradicts the findings of Hughes (1996) who observed global interference when responding to the local level with unbalanced stimuli. These findings suggest that while spatial frequency does seem to contribute to a global precedence effect and perhaps even level repetition or asymmetrical interference effects, more factors must contribute to how objects are perceived.

Lamb and Yund (1996a) suggested that level repetition effects might be the result of neural mechanisms more complicated than simple frequency detection. They indicate findings by Previc (1990) suggest that areas of the visual field may be allocated to detecting global forms and other areas to local elements. Lamb and Yund (2000) conducted perhaps the most comprehensive test of how spatial frequency and attention dictate how a viewer navigates the hierarchy. Participants saw compound letter stimuli that were either broadband or contrast balanced. Contrast balanced stimuli were stimuli with low frequencies removed and contrast adjusted to that of the broadband stimuli. For each trial participants had to indicate as fast as possible the identity of the target letter which could be at either the global or local level. At the start of each trial a lighted box cued participants to the target level. On some trials these cues were valid but on others they were not. Target level was repeated for some successive trials but not for others.

Their results indicated that spatial frequency alone cannot account for processing dominance. They found that participants responded to global form faster than local elements but also the global form in broadband faster than contrast balanced. This finding is in line with many past findings that suggest global form experiences a temporal precedence over local elements, mostly due to the faster availability of low frequencies, the faster availability due to larger receptive fields. A second finding was that cuing participants to the target level decreased their response times. Valid cues helped more than invalid. However, when the interaction of cue and frequency was tested it was found to be not significant. Participants did not perform best when a cue was valid and spatial frequency was low. Therefore, spatial frequency had no significant effect on a cue's effectiveness.

Lamb and Yund also tested for a repetition effect and found participants responded fastest when target levels were repeated. This effect was not tied to cueing nor to spatial frequency. Taken as a whole, Lamb and Yund concluded that cueing and repetition effects are independent phenomena and that it is unlikely that spatial frequency contributes to either. Furthermore, they suggest that cuing requires participants to utilize a controlled shift of attention while level repetition utilizes an automatic shift, again neither being guided by spatial frequency. Similar work by Hubner (2000) in which participants attempted to override repetition effects using controlled shifts of attention substantiates these conclusions. Neural mechanisms, like those proposed by Previc (1990) in which specific areas of the visual field are allocated to detecting either global form or local elements, were cited as being one explanation for the latter.

Also investigating the role of attentional shift were Hibi, Takeda, and Yagi (2002) who showed that it might influence where one enters the hierarchy. Hibi et al presented participants with compound stimuli much like Navon (1977) and others have done but manipulated their exposure duration. In one experiment exposure duration from trial to trial was either long or short at random. In a second experiment, trial duration (either long or short) was held constant. In the first experiment Hibi et al observed the global interference effect in both the short and long duration conditions. They saw this in the second experiment as well. However, also evident in the second experiment was a local interference effect, but only when trial duration was long.

Findings by Paquet and Merikle (1984) suggest that the results of the second experiment can be explained by the immediacy of low frequency processing, that at shorter exposure durations high frequency information contained in the local elements is not available. However their findings cannot explain the results from the first experiment. Hibi et al suggest that global interference must not be dependent on the physical properties of the stimulus since the stimuli in the first experiment were identical to the stimuli in the second. Furthermore exposure duration must serve to direct attention toward one level or the other, and the random shifts that were required in the first experiment offset this effect.

While it has been shown that multiple factors might contribute to determining how one navigates the hierarchy, spatial frequency still may play a large role. Hughes (1996) provided many reasons why low frequency information may dominate high for evolutionary reasons. Low frequencies are less susceptible to image degradation from poor vision. Being less susceptible to degradation means being able to survive difficult environmental conditions such as mesopic and scotopic eye conditions or even fog glare. Low frequencies also allow us to see objects moving at high velocities, use larger receptive fields and therefore fewer neurons. He further states that numerous mechanisms contribute to processing precedent, but spatial frequency seems to be related to many of them.

If it is true that spatial frequency is one of the factors that determines which parts of an object become available for processing, it would be easy to see how this information could have applications in specific areas of cognition such as categorization. Collin and McMullen (2005) reasoned that if global information becomes available first and that categorization usually begins at the basic level, than perhaps the two could be connected. Perhaps basic level categorization uses low frequencies where as subordinate level categorization requires high in order to acquire enough detail to distinguish among its members.

Using a category verification task in which participants received a name of a category followed by an object that either belonged or did not belong to that category, Collins and McMullen tested the effect of low pass, high pass, and 50% phase randomization (noise) on participants ability to categorize. Low pass, high pass, and phase randomization did not affect categorization at the basic level. However, low pass filtering but not high pass or phase randomization hindered categorization at the subordinate level.

A follow up study by Collin (2006) supports these findings. Collin provided participants with a picture of an object and a label for its category. The label corresponded to the basic level sometimes and the subordinate level other times. He then asked participants to adjust either a low pass or high pass filter to the threshold at which they could just barely assign category membership. He found participants placed the threshold at a lower frequency when assigning basic level membership than when assigning subordinate level membership. Both findings suggest that low pass filters allow for only some features to come through, specifically features that allow for categorization at a basic level but not those that allow for categorization at the subordinate level.

One issue that is raised by findings like Collin's is how does one reconcile the effects of special frequency with those of other factors that affect how we take in information, like prior experience with the object or expertise with the category. Continuing in the realm of categorization, experts categorize their field of expertise differently than novices. They are more efficient categorizers, readily differentiating among objects that typical novices cannot. The first thought is that they must work at a more subordinate level of categorization than novices, suggesting they must also enter the hierarchy more locally. However, if spatial frequency dictates where one enters and everyone perceives spatial frequency the same way this cannot be the case. Perhaps the difference between experts and novices is not the parts they begin with or the level at which they enter but rather the way they process them. If it is true that spatial frequency determines the input, perhaps experts simply develop more intricate mechanisms for utilizing them. Perhaps they are more attuned to relationships among the object's parts or the prior experiences that tie them together.

Goldstone (1998) explored in detail how through perceptual learning we become better processes of our environment. By his definition perceptual learning involves "relatively long –lasting changes to an organism's perceptual system that improve its ability to respond to its environment and are caused by this environment." (p586). He suggests four different mechanisms that a viewer may utilize to streamline the processing of inputs. They are attentional weighting in which resources are directed to more important parts and less to unimportant, stimulus imprinting in which one develops feature detectors for identifying important parts more rapidly, differentiation in which parts undistinguishable to novices become distinguishable, and unitization in which multiple associated parts become treated as one single part. If one buys into these mechanisms and the fact that information processing involves both inputs and operations it is only a small leap to understanding how spatial frequency dictates where we enter the hierarchy and expertise what we do once we are there.

The above evidence strongly suggests that adults use a perceptual hierarchy when organizing parts within their environment. It also suggests that spatial frequency and attentional shift may determine the level at which adults enter that hierarchy. At times they may enter near the top of the hierarchy and at other times near the bottom. With low spatial frequencies being available first, parts near the top of the hierarchy can be processed before parts near the bottom, which are processed later as higher frequencies become available.

Additionally, attention seems to influence where we enter the hierarchy. While certain sensory mechanisms allow some parts to be processed before other parts, attention may still drive which of those parts actually see processing. What this means is that on one hand the level at which one enters the hierarchy is determined automatically while on the other it is determined by intention. The most obvious question that stems from this conundrum is how do these two factors work together in information processing theory? The most common approach to solving this problem is to study the theory from a developmental perspective.

Infants Use a Perceptual Hierarchy

For more than thirty years researchers have been mirroring adult information processing studies in infants. Numerous studies have investigated whether infants use a perceptual hierarchy when organizing parts within their environment and whether this hierarchy is learned or innate. Additional studies have investigated how infants navigate this hierarchy, specifically how different stimulus attributes affect the level at which they enter. This includes the dominance of certain levels over others. Vurpillot, Ruel, and Castrec (1977) were the first address these questions.

While their interests were similar to those of Palmer (1977), Vurpillot et al (1977) addressed them from a developmental perspective. They began by investigating infants' earliest ability to differentiate objects using global forms and local elements. Their stimuli were similar to those used by adult researchers. They consisted of drawings in which a global form was created from local elements (For example, a cross made of squares). Likewise, in some cases the global form was identical to the local elements and in other cases it differed.

To study the effect of stimulus size on infants' ability to differentiate, they created two stimuli sets - one small and one large. They familiarized 2 and 4 month old infants to a single stimulus and then tested them using that stimulus paired with a second stimulus that contained either a novel global form or a novel local element. They found that when the stimuli were small, infants could differentiate them using global form but not local elements. When they were large, the reverse was true. Infants used the local elements but not global form.

Vurpillot et al (1977) concluded that by two months of age infants are able differentiate among objects using both global form and local elements. Additionally, they stated that the attribute that was most salient dominated processing. This could be either the global form or local elements depending on the size of the stimulus. They received much criticism for this conclusion because it was not clear that infants had perceived both the global form and the local elements during a single stimulus. Another interpretation suggests that infants simply processed either the global form or the local elements of the stimulus. Perceptual dominance did not have to occur.

At the forefront of this criticism were Ghim and Eimas (1988) who said that because Vurpillot et al did not show that infants attended to both global form and local elements in a single stimulus, they cannot claim that infants follow a perceptual hierarchy. They could only claim infants attend to parts of a particular size. They conducted their own study addressing this issue.

Ghim and Eimas (1988) began with a replication of Vurpillot et al (1977). Like Vurpillot et al, they familiarized 3 and 4-month old infants to a single compound stimulus and then tested them using that stimulus paired with a second stimulus that varied either at the global or local level. They too found that infants could differentiate stimuli using either global form or local elements independent of their size. The question of ideal size verses perceptual dominance still remained. To test to test this, Ghim and Eimas conducted a second study.

In their second study Ghim and Eimas used a procedure that they likened to the interference procedure used by Navon (1977). In this procedure, two bits of information are put in direct competition with each other. For Navon, adding a distracter auditory stimulus to compete with the target visual stimulus slowed participant response times. Similarly, Ghim and Eimas decided to pit novelty at one level of the hierarchy against novelty at another. If an infant were given a stimulus that is novel at one level but familiar at another, the dominant level will guide their preference. For example, assume that a stimulus is novel at the global level, and that the global level dominates the local level.   if given a choice, infants should prefer that stimulus over one that is familiar at the global level but novel at the local.

As in their first study, Ghim and Eimas (1988) familiarized infants to a single stimulus but this time tested them using two new stimuli in a paired comparisons format. One stimulus was novel at either the global or local level but familiar at the other. The second stimulus was novel at both levels. Their prediction was that if the global level is dominant, infants will prefer equally a stimulus that is completely novel and one that is novel only at the global level. Their findings confirmed their prediction. This suggests that the global level does have some perceptual dominance over the local. While this study is informative, it does have at least one common shortcoming. It draws broad conclusions from a very narrow set of stimuli.

The study by Ghim and Eimas (1988) tested specifically for a perceptual dominance of one level over another. Their results suggest that infants perceive both the global form and local elements but choose to respond in terms of the global form. In a series of studies, Colombo and colleagues tested for a perceptual precedence of one level before another. It was another approach to understanding how infants function within the perceptual hierarchy. It seeks to show that one level will be made available for processing before another.

Information processing is slower in infants than adults. Because it is slower, it is more easily interrupted at specific stages - the windows for those stages being larger. Colombo takes advantage of this and uses a procedure with infants that would not be possible in adults. Rather than adding interference as Ghim and Eimas (1988) and Navon (1977) did to determine the level of the hierarchy at which infants work, he simply interrupted infants' processing at specific times. He then tested what they knew. To make his approach work, Colombo had to consider individual differences in processing time. His earlier findings suggested that separating infants by according to processing efficiency was necessary when investigating development.

Freesman, Colombo, and Coldren (1993) found that at four months of age short lookers are more efficient processors than long lookers in visual habituation paradigms. If given the same amount of familiarization time short lookers will process a stimulus more thoroughly than long lookers. By classifying infants as either short lookers or long lookers Freesman et al could control for thoroughness of processing when entering the test phase. Freesman, et al. used this technique to look for a perceptual precedence effect in infants.

Freesman et al (1993) sorted four-month olds into short and long lookers. They then provided each with either a short familiarization period (20s) or a long one (40s). During the test phase they changed either the global form or the local elements and noted their preference. After 20s of familiarization, short lookers showed a preference for new global forms and new local elements. Long lookers showed no preference for either. Long lookers given 40s of familiarization showed a preference for new global forms but not new local elements. When familiarization time was decreased to 10s for short lookers, they preferred only new global forms and not local elements. These findings suggest that with limited familiarization time infants will process the global form before its local elements. It also suggests that infants utilize a perceptual hierarchy much like adults.

Macchi Cassai (2002) extended the findings of Vurpillot et al (1977), Ghim and Eimas (1988) and Freesman, et al. (1993). She asked if the ability to use a perceptual hierarchy is innate or learned, and if infants navigate the hierarchy similarly to adults. Macchi Cassai noted that with research from Kimchi (1979) and Ward(1982), Navon's (1977) idea of processing precedence has been replaced by the idea of processing dominance. While she does not discount Navon, she argues that his research tells only part of the story. Further research varying stimulus attributes must be done to understand why certain levels tend to dominate processing over others.

Macchi Cassai predicts that spatial frequency plays a primary role, at least in adults. The newborn visual system is quite different from the adult system. First newborns are not as good at sensing contrast (about 30 times less). Second, their acuity is worse (about 40 times worse). Finally infants are more sensitive to lower frequencies. These factors, Macchi Cassia predicts, suggest that infants may find processing the global form easier than the local elements.

While the reason for infants' showing a global dominance effect (underdeveloped visual system) would be different than adult's (limited viewing time), they are both tied to spatial frequency. Thus the focus of Macchi Cassai's work is two-fold. First, she sought to explore the origins of the perceptual hierarchy. It had been noted that infants as young as 4 months of age have shown some use of a perceptual hierarchy. Her goal was to find evidence of its use in newborns. Second, she sought to better understand why certain parts of a stimulus are dominant over other parts during viewing. She conducted a series of six experiments to answer these questions.

Macchi Cassia's (2002) first sought to extend earlier studies to include newborns. Using a paradigm similar to Vurpillot et al (1977) she showed that infants as young as 23-hours old can discriminate between stimuli using either the global form or local elements. A subsequent study looked for a perceptual dominance effect similar to the one observed in older infants and in adults. Using an interference paradigm similar to Ghim and Eimas (1988) Macchi Cassia showed that newborns indeed display the same global dominance they found. Once it had been determined that newborns behave much like older infants and adults, She sought to determine why they display a perceptual dominance for the global form. She began by varying the spatial frequency of the stimulus.

Much evidence suggests that the global dominance effect is the result of sensory mechanisms enacted early on during processing. In her next series of studies Macchi Cassia (2002) sought support for this idea in newborns. As mentioned, newborns are more sensitive to low frequencies than adults. According to Hughes et al. (1996) the global dominance effect may stem from low level sensory and perception mechanisms, particularly low frequency detection. If the global dominance effect were the result of efficient low frequency detection paired with inefficient high frequency detection then eliminating low frequencies would cancel out the effect. Logically, eliminating high frequencies would have no effect.

Using the Ghim and Eimas (1988) interference paradigm, Macchi Cassia tested newborns using stimuli subjected to either a high pass or a low pass filter. While the results for newborns looking at low frequency stimuli were identical to her previous results (support for a global dominance effect) infants looking at high frequency stimuli showed no global dominance effect. This indicated that the effect may indeed have it's origin within sensory mechanisms enacted early on in processing.

Summary

The evidence provided above strongly suggests that at least one aspect of information processing does involve some breaking down of our visual world. It offers ample support that the role of differentiation theories is to provide an explanation for how information is acquired for processing. While early work by Navon (1977) suggests that information is first taken from the most global level, more recent work suggests that viewers, including newborns, begin not at the most global level but rather at some perceptually ideal level. This level is probably determined by low-level sensory mechanisms. Furthermore, while viewers may not begin with the most global level when selecting parts to process, they do seem to progress from gross to finer detail or from a global level to a more local level when acquiring information for processing. This trend is most likely driven by the tendency to process certain spatial frequencies before others. While this chapter was predominantly about what we process, the next section will be about how we process.

Chapter 3

Operations

As mentioned, Information Processing Theory is a two-component theory. One component is the input. It embodies information coming in. The second part is operations and it embodies the processes applied to the input. This chapter will begin with an overview of terminology.

Nomenclature

Over the years numerous terms have been used to describe the operations component of information processing. Certain terms have become synonymous. Wholistic-configural and featural-analytic are good examples. The goal of this chapter is to add clarity to the terminology we see when discussing processing mechanisms. The terms it will address are top down, bottom up, wholistic, configural, featural and analytic.

When these operations are discussed, they are most often mentioned in pairs. For example, the terms top down and bottom up are usually considered antitheses of each other. A necker cube is usually discussed as being processed either top down or bottom up. Likewise, the terms wholistic, configural, featural, and analytic are often used as contrasts for each other. Face processing is considered either wholistic, configural, featural, or analytic. Having so many terms, that are not well defined, that are often used interchangeably has created a mess. I suggest changing this convention and argue that all of these terms should be viewed as simple extensions of analytic processing. The following is an explanation of this proposal.

The three major operations are top down, bottom up, and analytic. Analytic is the simplest of the three. I refer to it as data based because it uses no information beyond the input. It should not be confused with data driven which pairs the input with prior experience. This will be discussed shortly. The result of analytic processing, simply put, is an inventory of the parts contained within an object. This inventory can be large or small depending on the amount of time spent breaking down the stimulus. Thus, analytic processing involves entering the perceptual hierarchy at a specific level and acquiring all of the inputs at that level. For example processing of dog may result in nose, ears, legs, and tail. It contains no information about how these parts fit together or the identity of the object they belong to. One could say that analytic processing is a precursor to top down or bottom up processing in a sense that it provides those operations with inputs upon which to work. Analytic is the simplest form of information processing, but it is where others types of processing start

The two other major types of operations are top down and bottom up. Both operations begin with a set of inputs corresponding to the parts of an object. Furthermore, both operations use their own version of cognitive/perceptual "glue" to bring those parts together. In the case of top down processing, that glue comes in the form of cognitive schemas created over time from prior experience. Top down involves entering the perceptual hierarchy at a specific level and taking in all of the contents at that level (analytic). The schema that best fits the contents is then applied. The purpose of the schema is to amend the inputs, which can be considerably sparse. By applying a schema, a viewer can make inferences about the object and all of its parts by using just a few inputs. The output after top down information processing is then 1) the information contained in the input, 2) the information contained within the schema, and 3) a single representation of the two combined (the whole).

Since schema contain information about past operations performed on previous inputs, amending them with new inputs from time to time allows the viewer to make richer inferences about objects and their parts. For example, a viewer sees a set of eyes, a nose, and hairstyle and attempts to fit a schema formed from prior inputs. The scheme of best fit is *Jen*. It accounts for the eyes and nose but not the hair, which happens to be too short. By amending the existing schema *Jen* (a certain set of eyes, nose, chin and cheek structure, height, age, unique marks, etc.) with the novel input (short hair) the viewer will be able to make an additional inference about *Jen* in the future. Jen can have short hair.

The third and final operation that can be performed is bottom up processing. As mentioned, top down processing uses prior experience to glue together current inputs. Like top down processing, bottom up processing involves entering the perceptual hierarchy at a specific level and acquiring the contents. However, rather than using prior experience to build a detailed representation, bottom up processing uses perceptual relations. The result is a representation that is more accurate than one formed by top down processing, but also less detailed. It contains precise information taken from the environment, void of inferences, helpful or not. It does however lead to object specificity well beyond analytic processing. For example, all objects that contain eyes, a nose, and mouth may be a face, but it is the relations among these parts that make them a specific face. The output after bottom up processing is then 1) the information contained in the input, 2) the relations among them, and 3) a single representation of the two combined (the whole).

In summary both top down and bottom up processing begin with a set of inputs, which they use to build a representation of the object. The output contains three bits of information: 1) the inputs, 2) the schema or relations organizing them and 3) the whole object. Since information processing must proceed from input to operations to output, the bits must come in this order. In theory, if one were to interrupt this chain one would see three stages of processing. The first stage is at the level of the feature (featural processing). The second stage is at the level of either the schema or relations (configural processing). The third and final level is at the level of the complete representation including its features, the schema or perceptual relations that bring them together, and the combination of the two (wholistic processing).

As has been shown, top down and bottom up processing are more similar than not. Both should be considered contributors to enrichment theories because they both result in building representations from inputs. One uses schemas to drive the process. The other uses perceptual relations. It is thought that adults use a balance of these two. This observation begs an interesting question. What happens if someone has no schemas? Or if someone cannot perceive relations in space? These questions are being addressed by infant researchers.

Infants' Use of Bottom Up Processing

Numerous studies have shown that infants use bottom up processing to build their representations. Cohen, Chaput, and Cashon (2001), Johnson (2003), Johnson (2004) and most recently Westermann, Mareschal, Johnson, Sirois, Spratling and Thomas (2007) all argue in favor of a constructivist approach to understanding cognitive development. Cohen et al in particular states that through a combination of maturation and experience infants are able to process progressively more complex figures and scenes. They start with rudimentary attributes like color and shape and advance to more complicated features like those in faces and toys. They succeed on some occasions and fail on others. It is these successes and failures that help infants develop the cognitive operations they use as adults.

Numerous studies have explored principles of constructivism. For example, evidence that infants use increasingly more complex operations can be found in Cohen and Younger (1984). They habituated 2 and 3-month-olds to two lines placed in a specific angled relation to each other. They found that at two months of age infants processed the lines separately, failing to detect any relation between the two. However, by 3 months of age this trend changed and they were readily detecting the relation as well.

Using slightly older infants and more complex stimuli, Younger and Cohen (1983) presented 4, 7 and 10 month olds with line drawings of animals belonging to an artificial category. At 4 and 7 months of age, infants were processing the animals analytically as a set of independent features, but by 10 months of age shifted to also finding relations among those features. By noting these relations they were able to form simple categories.

In a later study Younger and Fearing (2000) demonstrated that early categories were more widely inclusive than later ones. More experience with forming categories helped infants make narrower categories. French, Mareschal, Mermillod, and Quinn (2004) took this finding one step further. Infants could be taught to form specific categories by controlling the types of experience they receive. Infants naturally exclude dogs from the category cat, but include cats in the category of dog. Mareschal, Quinn, and French (2002) created a connectionist model that predicts this asymmetry). By controlling the type of experiences used to form their categories of dog and cat, French et al helped 3 and 4-month-olds acquire a new category for dog that contained only dogs, and cat that contained both dogs and cats. This is yet more evidence that infants use progressively more complex inputs and operations to process information.

Studies in face processing offer further evidence. Work done by Cashon and Cohen (2004) demonstrated that at three months of age infants process faces analytically as a set of independent features, but by 7 months as a set of features in a relationship. Kelly et al (2007) then demonstrated that while infants may become better at finding relationships among parts of with age and experience, they are also learning which ones less important. In a study testing the effect of experience with race within and outside infants own race, Kelly et al found that infants at 3 months of age could easily recognize faces of many different races, but by 9 months were more limited to faces within their own racial category. This developmental shift in particular suggests that experience shapes the inputs infants take in as well as the operations they perform.

As a final example, Johnson (2003) pitted constructivist principles against those of nativism in a perceptual completion task in infants. Objects often become occluded by other objects. Even though occluded, infants as young as two months usually perceive the parts as a unitary whole. It is thought that attributes like common motion often help. A nativist approach suggests that infants at birth know that objects moving together must be solid and persistent. Numerous studies have provided evidence for this argument. Most stem from Kellman and Spelke (1983) who found infants were consistently surprised by two parts when one solid unit was expected.

A constructivist approach, on the other hand, suggests common motion is an advanced principle that is learned through age and experience. It is applied only after the individual parts are understood. Johnson (2003) presented 2-month-old infants with a picture of a square. Extending from the top and bottom of the square was a short bar. The bars moved left and right in a sliding motion along the top and bottom edges of the square. In two conditions the bars were aligned. In a third and fourth they were misaligned. In two conditions the bars moved together. In a third and fourth they moved separately. He found infants perceived the motion of the bars, but only perceived them as a unitary whole when they were aligned. This finding is evidence against the nativist argument because it shows infants processing objects separate from their motions.

According to Cohen and Cashon (2006) the biggest weakness of the nativist argument is that it makes the assumption infants of all ages behave similarly given similar circumstances. The type of rod, its length, how it moves, and the attending infant's age all seem to dictate the response to a stimulus. While object unity may be evident in four month olds using very simple stimuli, it often does not show in older infants using more complex stimuli. This observation, suggest Cohen and Cashon, is evidence that infants' understanding of objects is something they build over time. Common motion, while often telling, does not automatically suggest a unitary whole.

A New Approach to Infant Processing

One criticism of studies examining infant processing is that few document short term processing. Most studies comment on how infant processing changes over weeks and months. For example, six month olds process the whole car, where as 3 month olds process only its parts. Few attempt to explain how processing proceeds over minutes or seconds. This must change if we want to truly understand how infants process information.

The next chapter suggests a way of thinking about how infants process information over the short term. Its focus is not theorizing about what infants might do in their first months of life. Rather, it attempts to explain what they do in the first minutes or even seconds of the task at hand. It ties together the findings presented in Chapters 1 and 2 into a, hopefully, coherent theory.

Chapter 4

Breaking Down and Building Up

As mentioned in previous chapters, information processing theory has been studied widely in adults but less so in infants. Researchers often focus on the processing component and less on the information component. More needs to be learned about how infants select the inputs upon which they operate. While it is well known that infants build their representations from parts to whole, there is a strong possibility they often select finer and finer parts, thus simultaneously breaking down and building up their environment.

As will be shown in this chapter, there may be a developmental trend that suggests young infants select inputs using different criteria than older infants and especially adults. There are two areas of research that may contribute to a better understanding of why this is. One is spatial frequency literature in adults as covered in Chapter 2. The second is object-scanning literature in infants. To understand cognitive development, that is to say how infants become adults, the theories of the two areas must be reconciled.

Bronson (1994) suggests that infants' early scanning is predominantly unguided and often unrelated to any target in the visual field. When they do fixate a target, they seem to do so at a single feature. With time, usually by 3 or 4 months of age, scanning becomes more volitional and quite adult-like. They begin moving readily from feature to feature and have most of the speed and accuracy of adults. There is much research that supports these statements. Possibly the earliest is by Salapatek and Kessen (1966). In their seminal study of infant scanning with and without targets, they found infants scan much less when a target is present. This suggests that even though their scanning appears unguided they know when a target is present. They are simply unable to direct their fixations to it.

Salapatek and Kessen (1966) further suggest that infants might scan according to a different set of principles than adults. They seem to prefer high contour densities, brightness and interesting shapes instead of discrepant targets. Infant information processing may be directed by brightness transitions, angle detectors, or optimal levels of brightness like those found near vertices. Pip and Haith (1977) noticed this as well and explained it in very simple terms. Before eight weeks of age infants scan the parts they find the most attractive. Furthermore, they scan the most attractive parts using the smallest movements- the more attractive the tighter the fixation.

Another set of studies conducted by Maurer (1975) and Maurer and Salapatek (1985) explored why infants fixate 1) a single feature sometimes and the whole object other times, and 2) interior features sometimes and exterior ones. When Maurer showed newborns a picture of a face she noticed they looked primarily at its exterior features. Not until two-months of age did they move to they interiors. She found a similar pattern using a very different stimulus- a square surrounded by a frame. She conducted a third test, this time using schematic faces. Unlike real faces and squares surrounded by frames, schematic faces have their most salient features at the interior, as oppose to the exterior. She saw the reverse of her original finding. Newborns began with the interior features and moved to the exteriors by two months of age. This suggests that infants' scanning, and as a consequence infant information processing, may begin with the most salient features of a stimulus, at least at 2 months of age.

Bronson (1991) conducted one of the few studies that have compared the highly variable scanning patterns of newborns to the more stable ones of 3 month olds. He found that the least advanced 3 month olds often looked much like the most advanced newborns. He noted that the advanced ones seem to scan more efficiently. Their scanning was more deliberate and more target oriented. They could not say definitively, however, if the improvement was due to being better at taking in information or better at processing it.

While this question has yet to be answered, studies suggest the infant's visual system itself can be the most limiting factor. Hunnius and Geuze (2004) conducted scanning studies with infants up to 18 weeks of age, but using dynamic stimuli instead of the usual static. When using moving stimuli they observed a chronological shift in infants' scanning efficiency. It was not until 3 months that infants readily moved to the less salient features and almost 5 months before their scanning appeared adult-like. These ages are 1 to 2 months later than those observed using static images. This suggests that improvements in scanning efficiency may be due to being able to locate and stay with a target better. Moreover, Colombo, Ruther, Frick, and Gifford (1995) as well as Adler and Orprecio (2006) show that infants do not show evidence of pre-attentive search and pop-out until at least 3 months of age, further suggesting that an underdeveloped visual system may be infants greatest handicap.

The differences between the adult visual system and infants' are quite great. Mercuri, Baranello, Romeo, Cesarini, and Ricci (2007) state that infant visual acuity appears to increase by about 1 cycle/degree in the first months of life and continues to do so through first year. Additionally, an infant's visual field is approximately 30 degrees at birth and only 60 degrees by 5 months. Not until the end of the first year will their field be 90 degrees as it is in adults. To understand the importance of these differences, revisit the theories discussed earlier in this paper regarding how adults select information for processing. The majority of them are based on optimal size within the visual field or spatial frequency or both. With infants having poorer acuity and a smaller visual field, the theories gathered in the adult literature may apply, but how we approach testing them must be different.

The above studies are evidence that the youngest infants do not begin processing at the most global level of the stimulus. They appear to be starting somewhere lower on the hierarchy. The first hurdle that must be overcome is how to test for where they enter. First and foremost, a better understanding of infant acuity and individual differences must be had.

Dobson, Teller and Belgum (1978) developed a simple procedure for measuring the highest and lowest spatial frequencies an infant can detect. They created a series of cards each with a line grating of a specific frequency printed on it. Each card was paired with a second card containing a solid gray field. Infant looking behavior toward the pair of cards was observed. Infants who detected the individual lines of the frequency grating preferred to fixate that card to the solid colored card. Infants who could not detect the individual lines showed no preference. Since tremendous variability in the infant visual system exists during the first months of development, a test such as this, used as a pretest, will be important for identifying infants whose vision is outside the developmental norm. A computer-based test would be particularly helpful.

A second hurdle will be developing an accurate way of controlling for the amount of familiarization infants receive and its content. For example, while infants might begin processing an object at a certain level of detail, it is unknown when they will make a shift to another level. To assume infants are attending to one level, or more specifically to one feature or set of features, throughout the familiarization period is dangerous. Two procedures have been developed to this end. The first captures how infant information processing progresses from stimulus onset to the end of a trial. Several brief presentations of a stimulus lasting from 250 ms to more than a few seconds are shown. Each presentation is followed by a masking stimulus. Two 10-second test trials are then shown pairing the familiarized stimulus with a novel one. The infant's looking preference was measured. This procedure would be excellent for understanding information processing that occurs within a single presentation (Catherwood, 1994).

The second procedure captures how infant information processing progresses cumulatively across several trials. In this procedure infants are provided with either a long, medium, or short familiarization period, each containing multiple presentations of the stimulus using a traditional infant control procedure. The familiarization period is similarly followed by two test trials measuring the infant's looking preference (Colombo, 1993). This procedure would be excellent for understanding information processing that occurs long term across multiple trials.

Schyns and Oliva (1994) offer a third procedure that may be helpful in studying infant information processing. They have used it successfully in adults, but no one has yet to apply it to infants. For their study, they frequency filtered a series of happy, angry, and neutral faces. They then overlaid the high spatial frequencies of one type of face onto the low spatial frequencies of another. Experimenters asked participants to identify the expression of the stimulus as fast as they could. Their assumption was that the face participants responded to is also the first one they processed. This procedure could easily be adapted to infants when combined with the Catherwood (1994) or Colombo (1993) procedure mentioned above. Faces could be replaced with objects, infants could be familiarized to a low spatial frequency filtered object overlaying a high spatial frequency filtered object, and their preference for either the high or low spatial frequency object alone could be tested. Their preference would indicate which they had processed.

Regardless of the procedure used, the first experiment conducted should investigate the effect of spatial frequency on infant information processing. Spatial frequency has been widely shown to influence the information component of information processing. At least in adults it often dictates which parts of the object are processed and in what order. Schyns and Oliva offer a novel way of getting at these questions.

It is true that infant information processing is about inputs and operations. Much is known about the latter- it has been shown that infants build their representations from the bottom up. Very little, however, is known about the former. It has been shown that adults begin at a global level and move rapidly to more local ones, decomposing the stimulus into finer and finer parts. It is uncertain if infants behave the same way. Evidence suggests that newborns may do something entirely different. No data exists in infants beyond 5 months of age. The purpose of the present study is to begin filling in these holes. It will explore how infants acquire information for their representations. It will begin by testing the role of spatial frequency.

Chapter 5

Present Study

The present study tests how infants use high and low spatial frequency information when discriminating between objects.[1] It has been proposed that infants follow a perceptual hierarchy when selecting parts to process. Starting at the top, they begin with the most global information and work their way to the bottom to the most local. Spatial frequency offers an excellent opportunity to test this.

The human eye has dedicated low and high spatial frequency detectors. These detectors determine the amount and type of information perceived during processing. Certain information is evident only at high spatial frequencies while other information only at low. Low spatial frequency detectors work faster than high, primarily because the information they transmit is coarser. Hence, it is possible to say that low spatial detectors may be responsible for providing information near the top of the hierarchy and high spatial frequency detectors for providing information near the bottom. By manipulating the spatial frequency information contained in the experiment we are able to test if a hierarchy exists.

The first experiment tests how well infants use high and low spatial frequency information independent of each other. The second study tests how well they use them together combined in a single stimulus as would happen in real life. The third study is a control study that teases out the effect of background shade. Seven-month-olds were chosen for this study because their visual system is just beginning to detect a significant amount of high spatial frequency. At an estimated level of 6 cycles/degree visual angle, its upper limit is still a fraction of what it is in adults. However the high frequency information it provides should be significantly different from the low spatial frequency information for the first time in the infant's life.

Experiment 1

This experiment tested infants' ability to use spatial frequency to discriminate between objects. More specifically, it tested whether they are able to use both high and low spatial frequency information independent of each other, are able to generalize that information from one spatial frequency to another, and have a preference for one spatial frequency of information over another.

From birth, infants are able to detect low spatial frequencies. Evolutionary theory provides numerous reasons for why we use low spatial frequency developmentally before high. Most suggest that being proficient at processing low spatial frequency information helps us avoid the things that can hurt us, like predators and falling objects. Speed of processing, in these cases, is a priority. For these reasons, infants in the present experiment should be better at responding to low spatial frequency information.

However, by seven months of age infants are proficient at detecting high spatial frequencies. While not at the level of adult function, the frequencies they detect still provide ample information about objects. This is important as they begin to explore their visual world in greater and greater detail. While low spatial frequencies provide quick information, high spatial frequencies provide more information. If the later is infants' priority than they should be better at responding to high spatial frequencies.

Infants have limited experience with objects compared to adults. Because of this they are best at processing them when context stays consistent. For example, infants process upright faces well but struggle with upside down ones. Its thought that infants are simply poor at generalizing what they know about upright faces to upside down ones. It is possible that something similar will happen the present experiment. Infants habituated to one spatial frequency and tested using another may not be able to transfer information from the first to the second. The change of spatial frequency would be too disruptive and infants would respond to the spatial frequency change itself rather then the object change.

Method

Participants – Sixty-seven infants 6.5 -7.5 months of age participated in this study. Parents were contacted by phone and invited to participate in a study on infant perception. Those who participated received a bib or sippy cup as a gift of appreciation. Of those participating, some were excluded for fussiness (n=3), parent interference (n=1) or for not habituating (n=15). The final sample included both males (n=20) and females (n=27).

Stimuli - Four objects were selected from Vigianno, Vannucci, & Righi, S. (2004). The objects were chosen specifically for their novelty to infants and their discriminabilty from each other at both high and low frequencies. The objects were a camel, dragonfly, hamburger, and pineapple.

Stimuli were of three types: broadband, low frequency and high frequency. Broadband and low frequency versions were taken from Vigianno, et al (2004). They were grayscale images and spanned approximately 9 degrees of visual angle at their longest side. Low frequency images contained frequencies of 1 cyle perdegree of visual angle or less. Both versions were on a white background.

To obtain high frequency images, low frequency versions containing six cycles per degrees of visual angle and less were subtracted from their broadband versions. This was done using Photoshop by making a negative of the low frequency version and blending it with the broadband version. The result was a high frequency version containing frequencies of 6 cycles per degrees of visual angle or greater on a gray background. See Figure 5.1 for an example of the three versions of stimuli and Appendix for the full set.

Figure 5.1

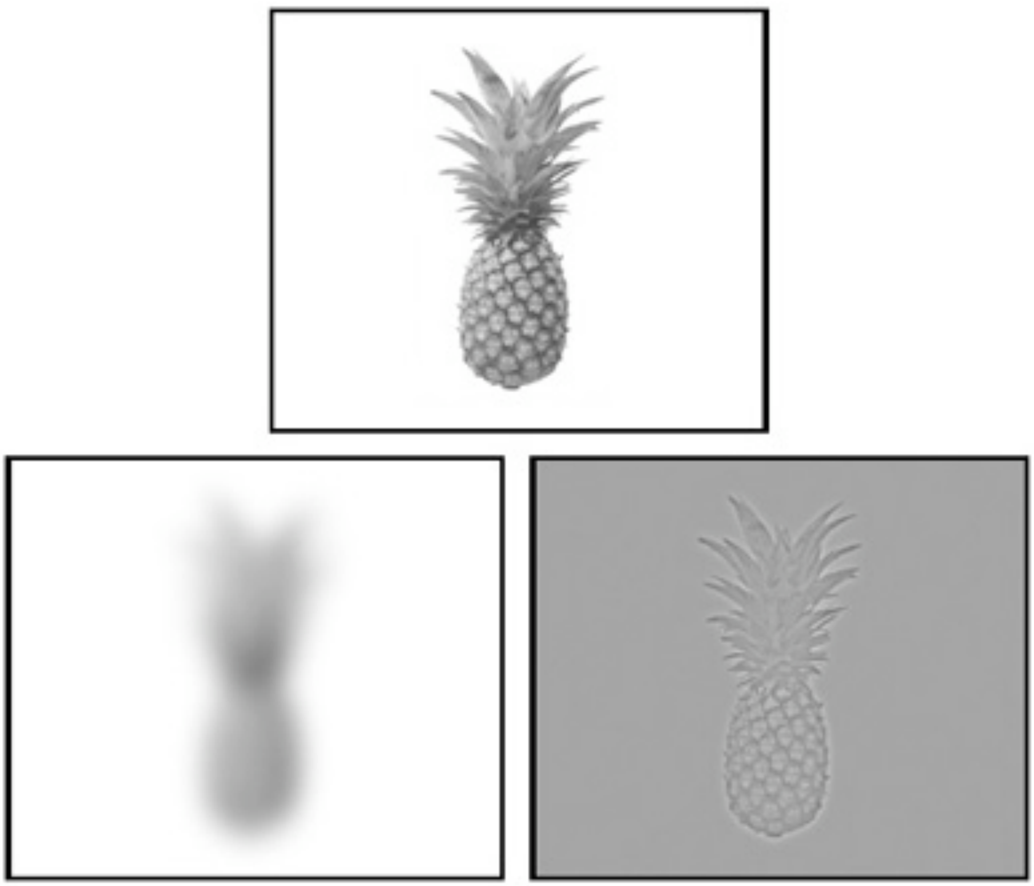

Figure 5.1 Example of the three types of stimuli used in the present study

Apparatus - Visual stimuli were presented on a 17" computer monitor resting on a table. The height of the monitor was adjusted so that it would be at the infant's eye level when seated on the parent's lap. To the left and right of the monitor were small speakers used to play the audio for an attention getter. Ten inches below the monitor was a low light camera used to monitor the infant's looking behavior. A black floor-to-ceiling curtain with cutouts for the camera and monitor hid the table from view. The curtain wrapped around the room creating a three-sided fabric recording booth approximately 8' x 6'. Lights in the room were dimmed to a very low level.

Stimulus presentation and data collection were controlled by a single experimenter from an adjoining room. Stimuli were presented using a Mac G4 with HABIT X presentation software (Cohen, Atkinson, & Chaput, 2004). A key strike by the experimenter signaled when the infant was looking at the presentation monitor. All sessions were recorded on DVD.

Procedure - Participants were also randomly assigned three or four objects to view. One was for the pretest, one for the habituation phase and one to act as the novel stimulus during the test phase. Infants were seated on the parent's lap approximately 36" from the presentation monitor. Parents were instructed to limit their interaction with their infant as much as possible. Once the parent indicated they were ready to begin, the experimenter started the experiment. The session began with an attention getter played on the presentation monitor. The attention getter was a blinking green circle synchronized with a recording of a ringing bell. Once the child fixated the attention getter the first stimulus was presented.

Presentations were infant-controlled. Once the infant fixated the stimulus, the experimenter depressed a key to indicate that the infant was looking. When the infant looked away the key was released. If the infant looked away for longer than 1 second the trial automatically ended and the attention getter was re-presented. Once the infant fixated the attention getter the experimenter depressed a key and another stimulus was presented. The infant could look for a maximum of 20 seconds per presentation. If the infant looked longer than 20 seconds the trial automatically ended and the attention getter was presented.

The first presentation was a pretest. Its purpose was to familiarize the infant with the apparatus and procedure prior to starting the habituation phase. It was always a broadband version and was always a different object than the habitation object or test object.

After the pretest, the habituation phase began. Stimuli were high frequency versions for half of the infants and low frequency versions for the other half. The habituation phase continued until a 50% decrement in looking time was observed. This was calculated by computer by first summing the infant's looking time to the first three habituation trials and then dividing by two. The 50% criterion was met once an infant looked for three consecutive trials that when summed were less than half of the first three. Infants could view a maximum of 20 trials. If they did not reach criterion within 20 trials the computer ended the habituation phase and automatically moved the infant to the test phase.

The test phase consisted of two trials. One trial was the familiar object from habituation. The other trial was a novel object. These trials were counterbalanced for order. For half of the participants, the trials contained high spatial frequency stimuli and for half it contained low spatial frequency stimuli. In half of the conditions the frequency of the test stimuli matched the frequency of the habituation stimuli. In all cases, the frequency of the familiar test stimulus matched the frequency of the novel test stimulus. See Table 5.1 for an overview of the design.

TABLE 5.1

Design Experiment 1

Condition	Habituate (SPFQ)	Test (SPFQ)	
High-High	Object A (high)	Object A (high)	Object B (high)
Low-Low	Object A (low)	Object A (low)	Object B (low)
High-Low	Object A (high)	Object A (low)	Object B (low)
Low-High	Object A (low)	Object A (high)	Object B (high)

Results

To determine if infants can discriminate between two objects using high or only low spatial frequency information, a 2(spatial frequency: consistent, inconsistent) x 2(test stimulus type: familiar, novel) ANOVA with repeated measures on the latter factor was conducted. No main effect of test stimulus type was found. However, a significant effect of spatial frequency was identified, $F(1,45)=6.93$, $p = .01$. When spatial frequency was consistent across habituation and test phases, infants looked significantly longer at the novel object than the familiar. When spatial frequency was inconsistent, infants showed no preference. See Figure 5.2. There was no significant interaction between spatial frequency and test stimulus type.

Figure 5.2

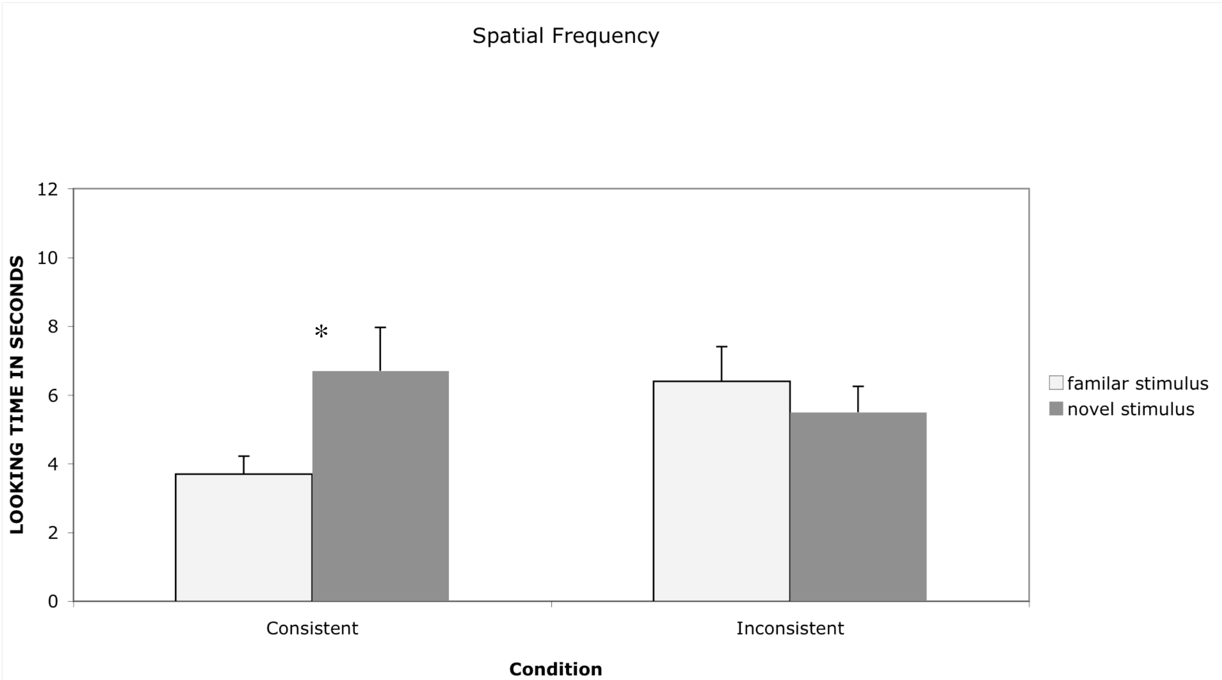

Figure 5.2 Mean looking time to the familiar and novel test stimulus. Infants in the Consistent condition experienced the same spatial frequency during the test as they did during habituation. Infants in the Inconsistent condition experienced different frequencies.

* $p < .01$

For infants in the Inconsistent condition, the familiar object had been presented in a more novel form than in the Consistent condition. It was presented in a new spatial frequency and on a new background. To determine if infants in the Inconsistent condition treated the familiar test stimulus as a novel stimulus, a 2(habituation spatial frequency: high, low) x 2(trial: mean of last three habituation trials, familiar test stimulus) ANOVA with repeated measures on the latter factor was conducted. A significant main effect of trial was found, F(1, 22)=14.71, p=.001. Infants looked significantly longer at the familiar test stimulus (X=6.39, SD=4.9) than the last three habituation trials (X=3.10, SD=1.45). This suggests that infants treated the familiar test stimulus as novel even though the object was familiar and responded to either the change of spatial frequency or the change in background shade ahead of the object. No significant effect of habituation spatial frequency was found nor a significant interaction.

Since the visual system processes high and low spatial frequency information independently, it will be helpful to understand how infants use them separately. The purpose of this analysis was to determine how infants use high vs. low spatial frequency information when discriminating objects. A 2(habituation spatial frequency: high, low) x 2(test spatial frequency: high, low) x 2(test stimulus type: familiar, novel) ANOVA was conducted with repeated measures on the latter factor. It revealed no significant main effect of habituation spatial frequency, test spatial frequency, or test stimulus type, but it did show a significant three-way interaction, F(1,43) = 6.93, p = .01. See Figure 5.3.

Figure 5.3

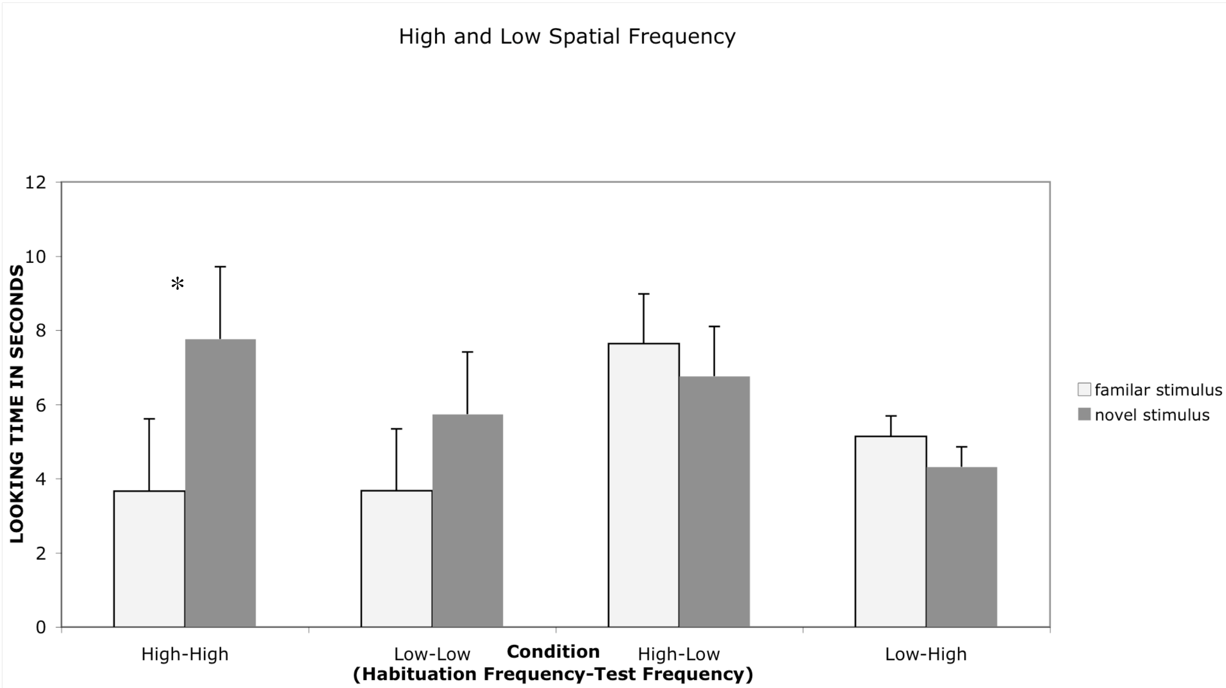

Figure 5.3 Mean looking time to the familiar and novel test stimuli for each of the four conditions.

* $p < .05$

To more easily compute the effects of habituation spatial frequency, test spatial frequency and test stimulus type, infants were grouped by habituation spatial frequency and analyzed separately. For both groups, a 2(test spatial frequency: high, low) x 2(test stimulus type: familiar, novel) ANOVA with repeated measures on the latter factor was performed. In the Habituation Spatial Frequency High group there was no significant main effect of test spatial frequency or test stimulus type, but there was a significant interaction of the two, $F(1,21)=4.73$, $p=.04$. Infants who saw high spatial frequency information during the test phase looked longer at the novel test stimulus than the familiar test stimulus, t(10) = 2.19, p = .05. In the Habituation Spatial Frequency Low group no significant main effects or interactions were found.

Discussion

Infants' ability to discriminate objects using high and low spatial frequency information was tested. It was found that infants were able to use high spatial frequency information to discriminate a familiar object from a novel one and possibly low spatial frequency as well. This suggests that they probably process both the global forms of the objects as well as their local elements. The ability does however appear to be fragile. When spatial frequency and background shade change, such as when some infants moved from habituation to the test, infants were no longer able to discriminate.

Infants who saw a consistent spatial frequency through habituation and test were able to discriminate between objects while infants who saw an inconsistent frequency were not. This could be due to at least two factors. First, changing an object's spatial frequency may act as a type of interference. During habituation, infants learned about an object using a specific set of spatial frequencies. Some were then asked to identify that object using the same spatial frequencies while others were asked to use different spatial frequencies. Infants who experienced the same spatial frequencies had access to the same information they saw during habituation. Infants who experienced new spatial frequencies had new in information that may have competed with old information. Simply put, infants who saw the same spatial frequency through habituation and test were asked to make a *same* or *different* judgment where as infants who saw a different spatial frequency during test than habituation were asked to make a *similar* or *different* judgment. Given infants limited experience with object constancy, the latter would be arguably more difficult.

The second factor is the change in background shade. If infants attended to it, it too may have acted as a kind of interference. If infants experienced one shade of background during habituation and then tested using another, it would be another case of new information competing with old. To tease apart if infants' inability to discriminate between objects is due to changes in spatial frequency or background shade, the two factors would have to be put in competition with each other. If it can be shown that infants respond to one ahead of the other, it could be assumed that infants were responding it instead of the object. This will be explored in Experiment 3.

The second finding was that infants were able to discriminate objects with high spatial frequency information better than objects with low spatial frequency information. In this case, the effect cannot be due to background color since background color was consistent within both conditions. More likely, it is due to how infants processed the information. There are two possibilities. First, high spatial frequency may contain more information than low frequency. More information equates to more ways in which objects can differ. Infants may have been better at discriminating familiar objects from novel ones with high spatial frequency simply because they could more easily find differences between the two.

Another possibility is that Infants may be assigning a processing precedence to high spatial frequency information over low spatial frequency information. If they value quantity of information over speed of processing this would make sense. There is much evidence contained in the literature that explains how and why a processing precedence may exist in adults. This would be one of the few examples demonstrating a precedence in infants and the only one arguing local before global. To say with any certainty that a precedence exists in infants numerous follow up studies would have to be performed.

Experiment 2

Although it demonstrated that infants are able to detect and spatial frequency information to discriminate objects, Experiment 1 was not an accurate test of everyday life. All objects viewed naturally contain both high and low spatial frequency information. Experiment 2 addresses this issue. Infants were habituated to an image of an object shown just as they would see the object in everyday life, in broadband. They were then tested using either high or low spatial frequency information.

One possibility is that infants will respond in terms of one set of spatial frequencies more readily than the other. The results from Experiment 1 suggest that infants may make processing high spatial frequency information a priority. On the other hand, infants have more real life experience processing low spatial frequencies. Since this is a complicated task that requires infants to perform a generalization from broadband to individual frequencies, a fall back to processing low frequencies may be observed. A second possibility is that they will respond to both equally. This would require that they attend completely to both high and low spatial frequency information and respond only in terms of one or the other. Responding to them equally would suggest that infants clearly and easily process both high and low spatial frequency information and do so without preference.

Method

Participants - Thirty infants 6.5 -7.5 months of age participated in this study. Infants were recruited as in Experiment 1. A few were excluded for parent interference (n=2) or for not habituating (n=4). The final sample included both males (n=13) and females (n=11).

Stimuli – Stimuli were identical to those used in Experiment 1

Procedure – The procedure was identical to Experiment 1 except that infants were habituated to a broadband version instead of a high or low spatial frequency version. Infants were randomly assigned to one of two conditions. As in Experiment 1, half received high spatial frequency versions during the test phase and half received low spatial frequency versions. See Table 5.2. Also as in Experiment 1, infants were randomly assigned three or four objects. One object was for the pretest, one for the habituation phase and one to serve as the novel object in the test phase. The frequency of the familiar and novel objects always matched.

TABLE 5.2

Design Experiment 2

Condition	Habituate (SPFQ)	Test (SPFQ)	
Broadband-High	Object A (broadband)	Object A (high)	Object B (high)
Broadband-Low	Object A (broadband)	Object A (low)	Object B (low)

Results

To determine if infants were able to generalize from a broadband stimulus to a high or low spatial frequency version, a 2(test spatial frequency: high, low) x 2(test stimulus type: familiar, novel) ANOVA was conducted with repeated measures on the last factor. The main effect of test spatial frequency was significant, F(1,22)=6.27, p=.02. Infants who saw low spatial frequency stimuli during the test phase looked significantly longer at the test stimuli than those who saw high spatial frequency stimuli. See Figure 5.4. No significant effect of test stimulus type was found nor a significant interaction.

Figure 5.4

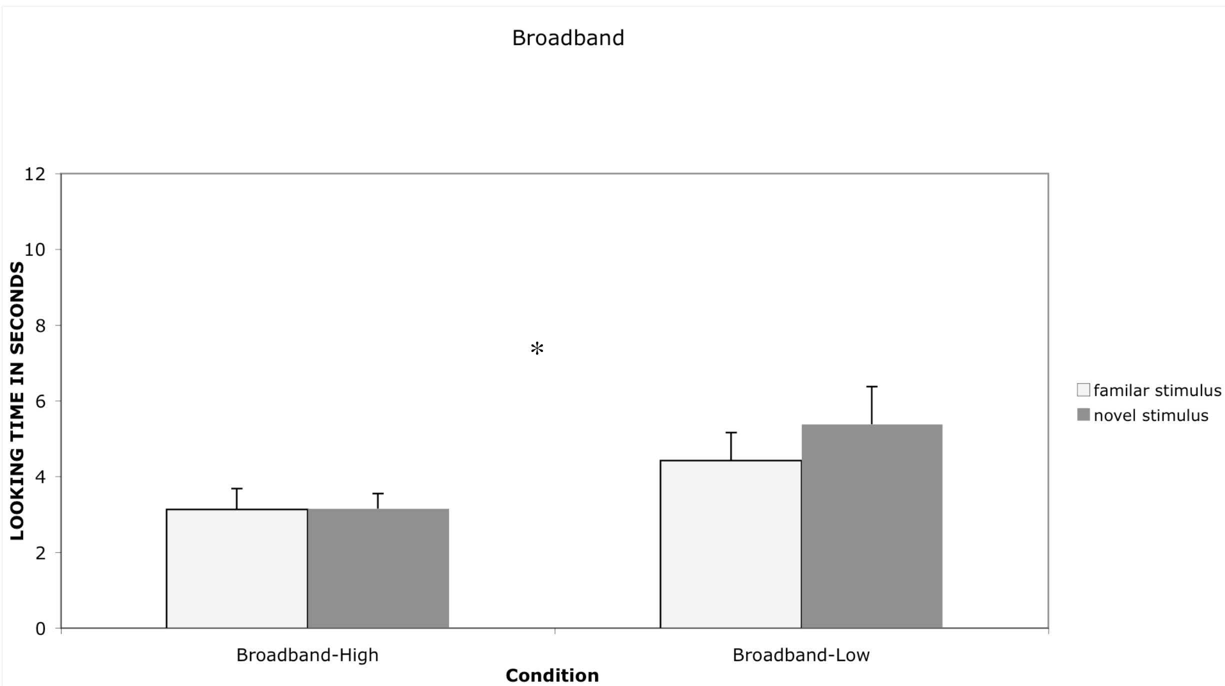

Figure 5.4 Mean looking time to the familiar and novel test stimulus when habituated to a broadband stimulus and tested using the same object at high or low spatial frequency and a novel object at the same spatial frequency.

* p < .05

Discussion

The results of Experiment 2 suggest that infants who are habituated to an object with broadband information did not discriminate that object from a novel object using just high or just low spatial frequency information. However, infants were found to have a significant preference for low spatial frequency information over high during the test. Evolutionary theory provides numerous explanations for why low spatial frequencies may be more important than high. Even though infants are able to process high spatial frequencies, processing low spatial frequencies during times of change may be more natural.

There are two important factors to consider when explaining this finding. First, during habituation infants experienced both high and low spatial frequency information when they saw the broadband stimulus. This is different from infants in Experiment 1 who saw only high spatial frequency information or only low spatial frequency information. Infants in the present study experienced more of a subtraction of information than a change. Furthermore, the present study was designed to fit with experiences that infants have in everyday life. For these reasons, comparisons between infants' performance in Experiment 1 and those in Experiment 2 should be made with caution.

Second, the change in background shade may have influenced infants' looking. As in Experiment 1, infants who experienced a consistent background shade showed an effect of longer looking. However, unlike Experiment 1 the effect was tied to an unshaded background. Because the effect in Experiment 1 was tied to a shaded background while the effect in Experiment 2 was tied to an unshaded background it can be assumed that the background itself does not influence infants' looking. The remaining possibility is that it is the change in background from shaded to unshaded or vice versa that contributed to infants' looking. Experiment 3 tests this possibility.

Experiment 3

The purpose of this experiment is to determine if a change in background shade affects infants' preference for novelty. In Experiments 1 and 2 infants could respond to three main characteristics of the stimulus. They could respond to the object as a whole, the spatial frequency or the background shade. Evidence from Experiment 1 suggests that when background shade and spatial frequency are held constant infants respond in terms of the object. Evidence from Experiment 2 suggests that when background shade is held constant but the spatial frequency and object are changed, they respond in terms of spatial frequency (i.e. they look longer at low spatial frequencies than at high ones). Experiment 3 is designed to determine if when the object is held constant and the background shade and spatial frequency change infants respond to the change in background shade or the change in spatial frequency.

Infants were habituated to a broadband version on either a shaded or unshaded background. They were then tested using that stimulus and a low spatial frequency version of it on an unshaded background. If infants respond to background shade over frequency, infants in the shaded condition should look longer at the novel test stimulus since it is on a novel background while infants in the unshaded condition should show no preference, both test stimuli being on unshaded backgrounds. If infants in both the shaded and unshaded conditions look equally long at the novel test stimulus it can be assumed that infants respond to spatial frequency more than background shade.

Method

Participants – Twenty-seven infants 6.5 -7.5 months of age participated in this study. Infants were recruited as in Experiments 1 and 2. Of those participating, some were excluded for fussiness (n=1), parent interference (n=2) or for not habituating (n=5). The final sample included both males (n=14) and females (n=8).

Stimuli – Stimuli were the same used in Experiments 1 and 2 with the addition of a broadband version placed on a shaded background. The background was identical to the background on the high spatial frequency version.

Procedure – The procedure was identical to Experiments 1 and 2 with the following exceptions. Half of the infants were habituated to the same broadband version used in previous experiments and half were habituated to the broadband version on a shaded background. Infants were then tested using the same broadband version they saw during habituation - shaded or unshaded - and a low frequency-unshaded version of the same object. See Table 5.3.

TABLE 5.3

Design of Experiment 3

Condition	Habituate (SPFQ - background)	Test (SPFQ - background)	
Broadband - Shaded	Object A (broadband - shaded)	Object A (broadband - shaded)	Object A (low - unshaded)
Broadband - Unshaded	Object A (broadband - unshaded)	Object A (broadband - unshaded)	Object A (low - unshaded)

Results

To determine if a change in background shade affects novelty preference, a 2(background shade: shaded, unshaded) x 2(test stimulus type: familiar, novel) was conducted. A main effect of stimulus type was found, F(1,20)=15.20. p=.001. Infants in the shaded condition looked significantly longer at the novel object than the familiar (t(11)= 2.56, p=.03) as did infants in the unshaded condition (t(9)= 2.94, p=.02). No main effect of background shade was found nor any interaction. See Figure 5.5.

Figure 5.5

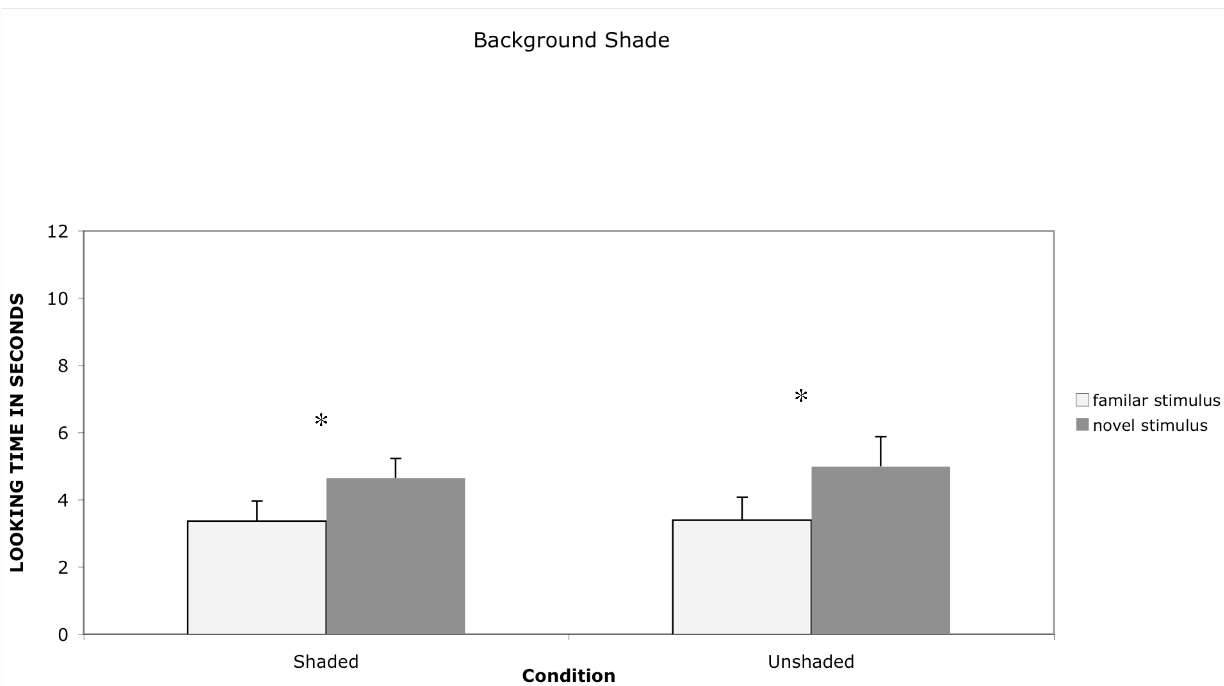

Figure 5.5 Mean looking time to the familiar and test stimulus. Infants in the Shaded and Unshaded conditions looked equally long at the novel stimulus even though infants in the Unshaded condition experienced the novel stimulus on a familiar background.

* $p < .05$

Discussion

The present experiment tested the effect of background shade on infants' preference for novel spatial frequencies. Although infants appeared to discriminate between familiar and novel frequencies, no evidence was found to suggest the change in background shade had an effect on infants' looking time. In both conditions infants responded in terms of spatial frequency more than background shade. It can therefore be assumed that background shade had little effect on infants' preference for novel objects and spatial frequency in Experiments 1 and 2.

Chapter 6

General Discussion

The results of this study suggest that infants use spatial frequency information to discriminate objects. However the finding only holds when infants are habituated and tested using a consistent spatial frequency. The results also suggest that infants discriminate objects more easily with high spatial frequency information than with low. Finally, infants look longer at low spatial frequency than high frequency information after being habituated to broadband images that simulate real life. These results fit with many findings in both the infant and adult literature

Verpilllot et al (1977) and Ghim and Eimas (1988) found that infants as young as 3-4 months of age attend to both the local elements and the global form of an object. They further found that infants attend to the global form before its local elements. This is very similar to what the present study found in 7-month olds. It was found that Infants attended to both global (high spatial frequency) and local (low spatial frequency) information and were able to use that information to discriminate between objects. Additionally, after habituating to a combination of global and local (broadband), they attended to global (low spatial frequency) over local (high spatial frequency). While they did not attend to the global information itself in the second study, they did attend to the factor that would provide it, that is low spatial frequency.

While the above two studies and the present study arrived at similar findings, they did so using two very different types of stimuli. Verpilllot et al (1977) and Ghim and Eimas (1988) used compound stimuli that consisted of large shapes made up of much smaller embedded shapes. These stimuli were analogous to the broadband stimuli used in the present study since they contain both local elements and a global form. There are two drawbacks to using this type of stimuli. The first is that they are artificial. They are not actual objects but rather a group of elements related in space. The second is that they provide no way of habituating infants to local elements or global forms separately. The stimuli in the present study are an improvement on both issues. First, the stimuli are images of everyday objects that are similar to objects they have seen and processed before. Second, they allow the infant to be habituated the smallest element to the largest form and everything in between, depending on the range of spatial frequencies the experimenter provides. Furthermore, they can be habituated to forms and elements simultaneously by using broadband stimuli or independently using high or low spatial frequency stimuli. The present stimuli are much more versatile than the compound stimuli used in previous studies.

The results of the present study are also supported by findings in the adult literature. Ward (1982) found that adults responded best when they experienced a consistent local element or global form. The present study found evidence of something very similar. Infants performed best when they experienced a consistent spatial frequency and worse when they experienced an inconsistent one. Ward credited his finding to the work of attentional mechanisms. Adults - and now infants - may respond best to information to which they are already attending. Unlike Navon (1977) and others who argue that global processing always precedes local processing, Ward suggests that attention can be directed variably to either the local elements or the global form.

As has been found in adults, how infants select information for processing does seem to be related to both spatial frequency and attentional shift. The present study demonstrated that infants can use both high and low spatial frequency information but start with one or the other based on what they saw prior. When shown just high or low spatial frequency information they attend to the object and are able to use the limited range of information to discriminate it from a second object. However when shown broadband information that contains both high and low spatial frequency information they attend to the spatial frequency itself, preferring to look at the low spatial frequency information more than the high, ignoring the object all together.

The present results also fit with Freesman et al (1993) who found that infants at four months of age proceed from processing the global form to processing the local elements. Their approach was very different from the present study. Rather than allowing infants to acquire both global and local information and testing which one they use, they limited the amount of familiarization time infants received before testing, hoping to catch infants after they acquire one but before they acquire the other. After as little as 10 seconds, infants were acquiring an object's global form. Not until 20 seconds did infants acquire it's local elements.

The above evidence paired with the results of the present study establishes the groundwork for understanding how infants use a perceptual hierarchy when selecting information for processing. It appears that infants do attend to information both near the top the hierarchy as well as information near the bottom. However the results of the present study cannot speak well to how infants enter the hierarchy. Infants were observed favoring low spatial frequency to high, however they were not attending to the object when doing so. Most correctly, they were showing a natural preference for one spatial frequency over another rather than providing evidence for use of a perceptual hierarchy.

It is possible that a natural preference for low spatial frequency information could lead infants to enter the hierarchy near the top, but future studies will be needed to determine this. In summary, it is still unclear whether infants begin at the top of the hierarchy, at the bottom, or somewhere in between.

Controlling familiarization time as Freesman et al (1993) did in conjunction with spatial frequency information would be an informative next step for the present study. One immediate improvement that could be made would be to provide a better test of infants' use of global and local information. Presentations of broadband, high, and low frequency information could be made and infants' ability to process them could be compared. Most interestingly, infants processing time of broadband stimuli could be compared to infants processing of high and low spatial frequency information separately. Infants could be habituated to a single object in broadband or a single object shown in both high and low spatial frequency. Does providing spatial frequency as part of a conjunction help or hinder processing? Furthermore, how separable are individual frequencies?

There are many other future directions the present study could take. First, different age groups could be tested. As infants become more proficient with high spatial frequency will they use it more or less? On one hand, they may use it more because it provides the best way to learn about the world in detail. On the other hand, they may use it less, since as they gain more experience with their world they may begin to prioritize speed and efficiency over detail. At the other end, younger infants who cannot process any high spatial frequency may show object discrimination at low spatial frequencies better than infants at 7 months of age.

A third direction is to investigate infants' processing of global and local information within trials as opposed to across them. Most studies do the latter, testing how infants process global forms and local elements across a habituation phase. Using a procedure similar to one used by Catherwood (1994), one could test how infants process local and global information within individual presentations. Catherwood used brief presentations of just a few hundred milliseconds. Infants' ability to recognize the object was then tested using longer trials of 10 to 20 seconds. Any preference observed during the test phase would indicate some recognition on the infant's part from habituation. This procedure would be excellent for studying temporal precedence effects in infants. While many studies have studied processing precedence in infants - that is, tested to which level infants respond having acquired information about both - few have looked at temporal precedence and none have done it on a scale of milliseconds in infants. A study such as this one would be analogous to the studies conducted by Navon (1977) in adults. To compare infants and adults in nearly identical tasks would be very informative.

Another procedure that could be used to clarify how infants may use a perceptual hierarchy is one used by Schyns and Oliva (1994). They used hybrid stimuli composed of one face displayed at high spatial frequency overlaid with another face of a different spatial frequency. They tested which face adults attend to and how spatial frequency and prior experience influenced their preference. Something similar could be performed in infants using objects.

Finally, the results of the present study could be adapted to an infant vision test. It has been shown that infants use high spatial frequencies to discriminate objects. Since high spatial frequency detectors develop after low spatial frequency detectors, the present procedure could be used to identify developmental delays in high spatial frequency processing. Using age appropriate spatial frequency stimuli a doctor could determine if an infant is detecting normal levels of high spatial frequency.

In sum, the goal of the present study was to investigate how infants use spatial frequency information to discriminate between objects and then use that information to shed light on how infants select information for processing. It was found that infants at seven months of age are able to use both global and local information, but no evidence was found that would suggest they use one before the other. More studies must be conducted. Better control of the amount of familiarization infants receive must be had. Additionally, new procedures should be employed that offer more accuracy and better temporal resolution of processing.

Appendix

Figure A1

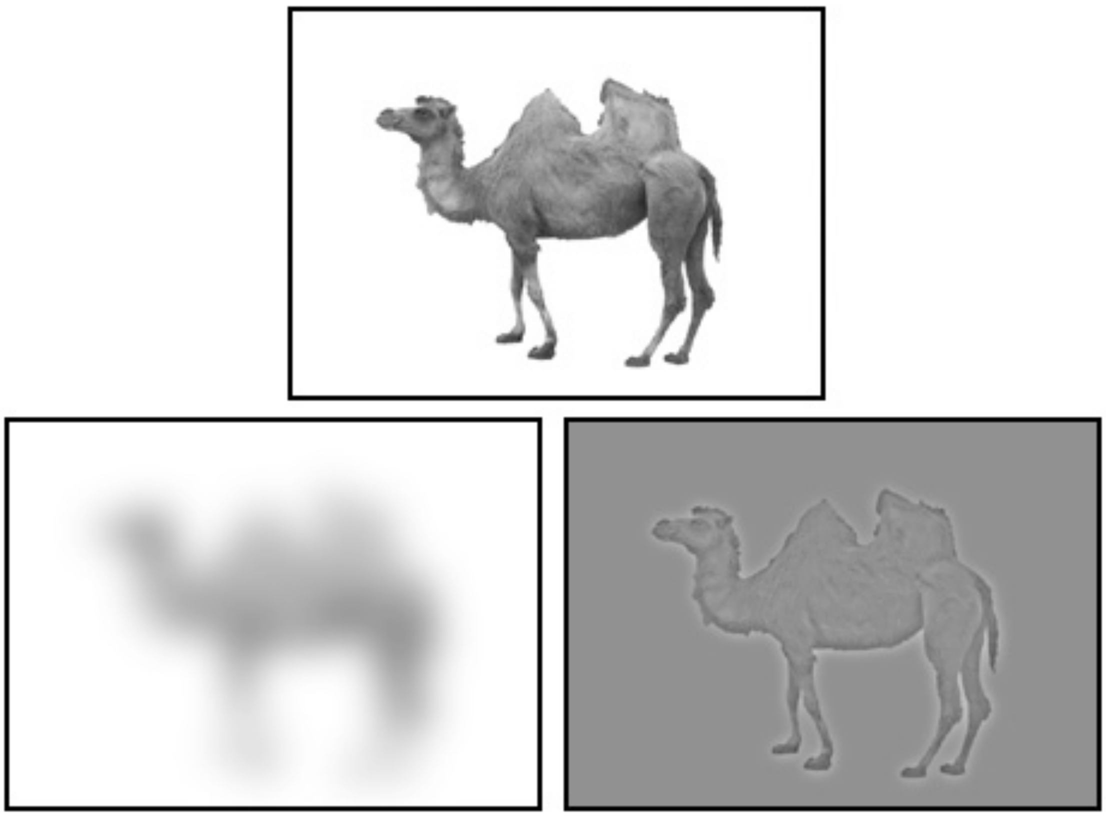

Figure A1. Camel in broadband, low spatial frequency and high spatial frequency.

Figure A2

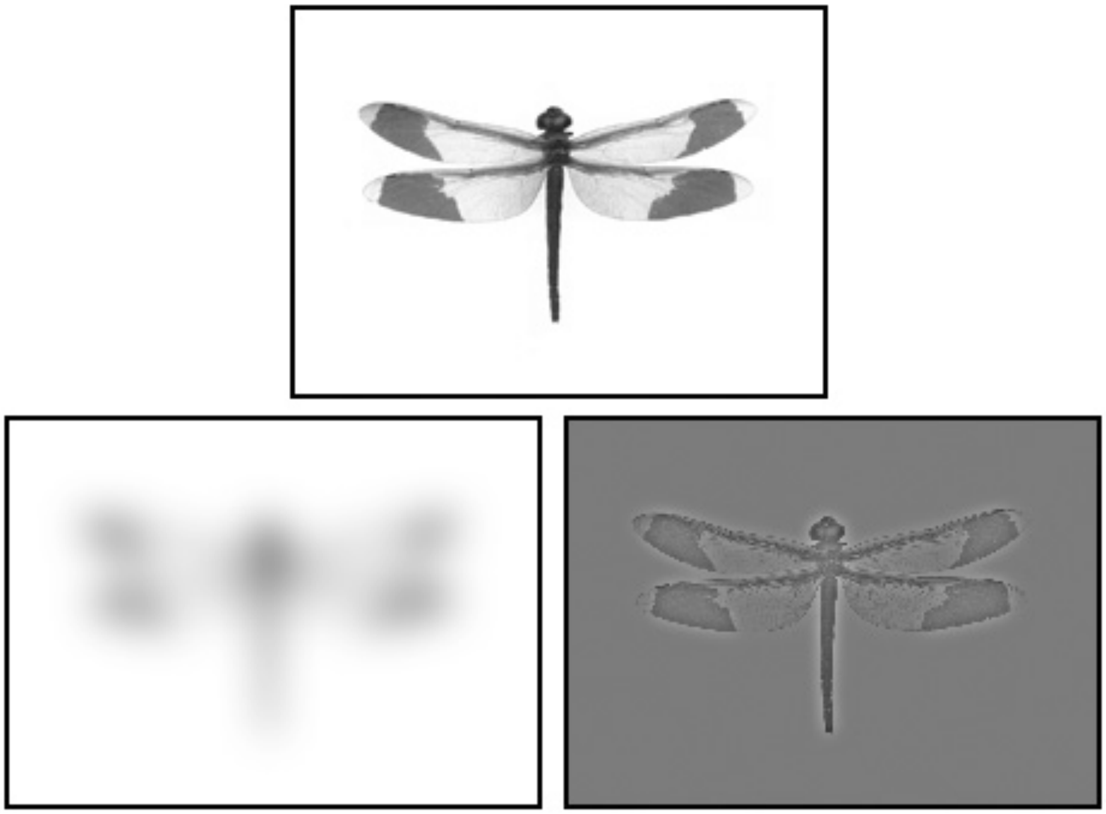

Figure A2. Dragonfly in broadband, low spatial frequency and high spatial frequency.

Figure A3

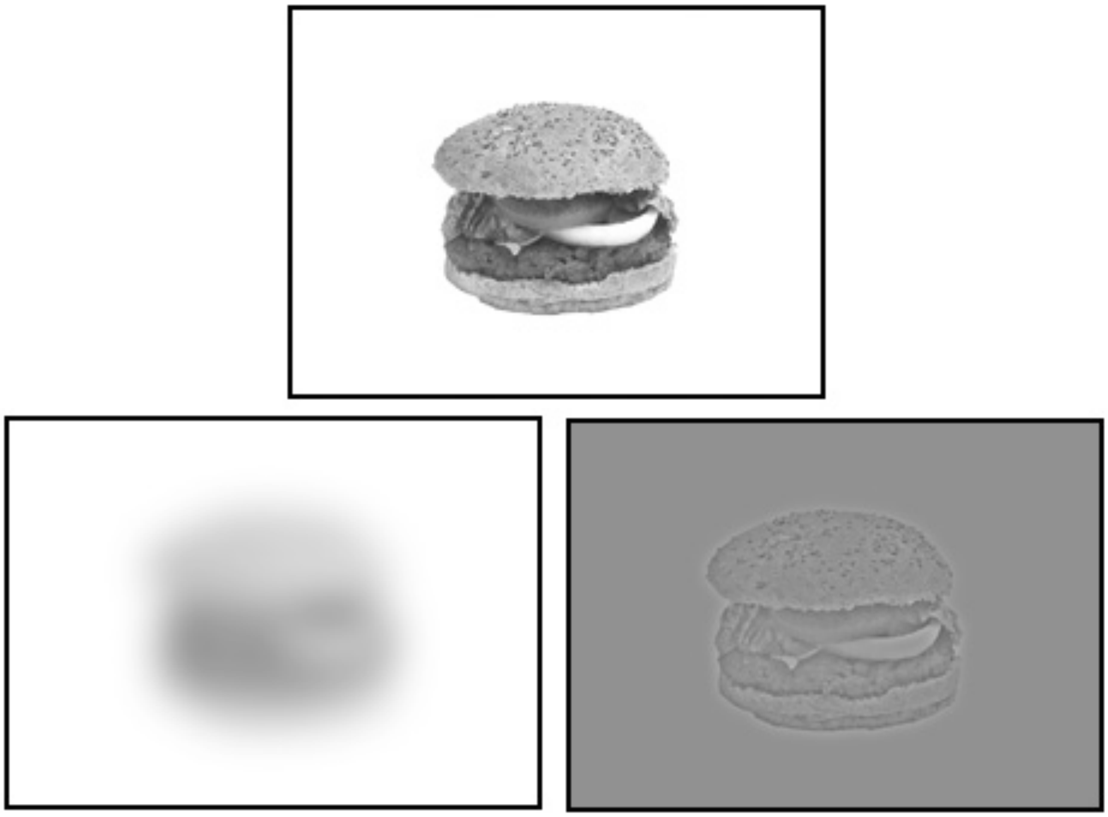

Figure A3. Hamburger in broadband, low spatial frequency and high spatial frequency.

Figure A4

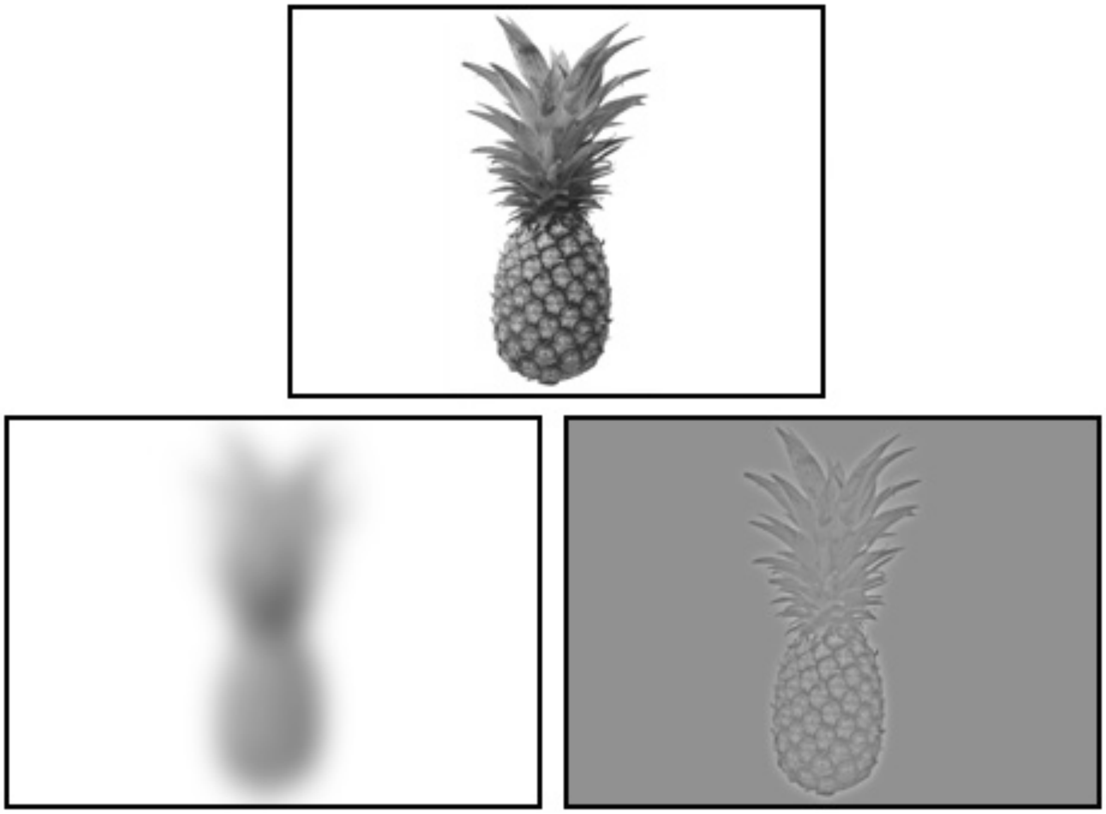

Figure A4. Pineapple in broadband, low spatial frequency and high spatial frequency.

Footnote

1. “Object” refers to the item contained within a two dimensional image.

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