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Abstract

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Humans, among other primates, rely heavily on vision for survival, navigation and social interactions. As social creatures, humans encounter many faces in our lifetime and can recognize them quickly and effortlessly. The efficiency at which this process is carried out belies the fact that face perception is a vital and complex procedure. Current findings in the field have supported holistic processing, over featural processing, as the main mechanism for upright face perception in adults human. However, unlike most mammals where newborn animals possess sufficient motor and sensory ability to navigate and explore its environment in matter of hours after birth, human babies need months to unlock those skills and years to perfectly master them, especially with visual system. This study aims to investigate the developmental trajectory of face perception in infants and see how the interactions between developmental and innate elements in early days dictate the use of holistic processing later in development. Using infant rhesus macaque, this study suggests an innate preference for holistic objects. However, early face perception is dominated by featural processing starting from around week four and five. This use of featural processing helps with orienting infants towards faces and lay out a foundation for holistic processing to develop later on.

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Chapter 1: Background

1. Face perception overview.

Humans, among other primates, rely heavily on vision for survival, navigation and social interactions. As social creatures, humans encounter many faces in our lifetime and can recognize them quickly and effortlessly. The efficiency at which this process is carried out belies the fact that face perception is a vital and complex procedure. Not only do faces tell us the gender (Burton, 1993), age (Rhodes, 2009), appearance of the individual we interact with, but also let us make predictions about their general emotions and affect (Ekman, 1969; Izard, 1971).

There have been many studies on face perception. Studies up until now have identified multiple pathways within the visual system; each plays a slightly different role in the face perception process (Tsao and Livingstone, 2008). For example, the identification pathway of a face is independent of the expression analysis pathway (Bruce & Young, 1986). These advances enable the development of models for face perception.

Face are processed in separated hierarchical parts/ code: Bruce and Young model (1986)

One of the more authoritative models on face processing is proposed by Bruce and Young in the 1980. Since its inception, it has influenced many face perception studies in the field. It makes two important points about face perception.

First of all, face processing involves a lot of different processes. Since face is a complex type of stimulus, careful data extraction can give information for different categories and purposes: emotional state, age, gender, and aid in speech comprehension. Bruce proposes that these cues are coded separately based on their specific use. *Pictorial codes* contain information about the details of the specific visual stimuli that is being inspected such as texture, color, brightness and so on. *Structural codes* are the information used to recognition and identification. *Structural codes* can contain *identity-specific semantic codes*- stored memory of familiar faces, *visually derived semantic codes*- information given by even unfamiliar faces, and *name codes*- information about how a person is called. In addition there is *expression codes*- information about the emotional state of the observed face, and *facial speech codes*- face expressions and arrangements that can help with the perception of vocal speech.

Second, face recognition occurs in a number of distinct, hierarchical stages. First the observed face is coded into the brain-processing pathway. The structural codes with the sub-codes: identity-specific semantic codes, and visually derived semantic codes, are at the base of this model; they contain all the description of the face stimuli. They activate possible connection to stored memories about that face. The structural codes then can be further interpreted for identification and recognition. On the other hand, the structural codes can be processed differently using the expression codes and facial speech codes. This way, information about the emotion of the face will be available for use and enhance communication. Theoretically, these two processes work in parallel and independent of each other. This dualism in face perception can give be connected to the dual-route hypothesis that will be discussed later.

The Bruce and Young's model is robust in terms of creating a framework for how facial information are logically assigned and processed. However, it fails to clarify how faces are encoded visually. Encoding is a complex procedure that involves different circuitries as well as the visual sensory system. As a result, to complete the gap in the hypothesis, it's useful to investigate how this process is actually carried out.

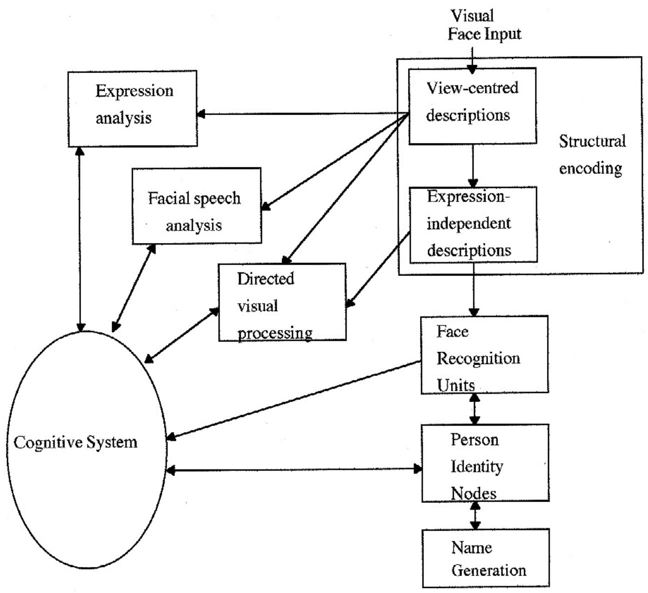


Figure 1: Bruce and Young's model for face processing includes multiple hierarchical codes distributed to two pathways, the expression-facial speech analysis and the face and identity recognition. (Bruce and Young, 1986)

2. Holistic face processing: hypothesis for structural encoding

The encoding process can be hypothetically broken down into smaller steps. The visual system has to first recognize that the stimulus is a face as opposed to the background and other objects. It's found that in adults, the main face perception occurs as information from the positioning and relationships between components, such as the eyes, nose and mouth, are integrated into a single structure (Farah et al 1998). This way of encoding is referred to as holistic processing.

In contrast, the process in which each of the features is analyzed separately is called featural processing. It's the proposed alternative to holistic processing. In this process, after each feature of an object is analyzed they are pieced together in a piecemeal manner. This is proposed to be the mechanism involved in processing non-holistic objects.

Behavioral and physiological studies of face perception have supported the idea that humans and primates use holistic processing to process faces.

a. Evidence of holistic processing in human and primates

Physiological findings

Fixation studies reveal that such holistic encoding for face identification and recognition may relate to fixations at the center of the face (Webster et al 2004), because primates tend to look at the center of the face (Tsao and Livingstone 2008). Some neural regions have also been identified as part of this pathway. Several clusters of cells in the upper and lower banks of the superior temporal sulcus are selectively active towards faces (Tsao, Freiwald et al. 2006). Fusiform face area (ffa), lateral to the fusiform gyrus on the cortex of the medial temporal lobe, is also found to react predominantly towards faces (Koutstaal et al 2001)

Photographic negation effect

Face recognition is largely disrupted in negative photos (Galper, 1970) and non-shaded paintings (Bruce, 1992). It's proposed that the disruption can be attributed to a lack of dimensional information given by the shapes and shades of the shadows casted by the brows, the nose, chin, ect. In normal lighting condition, the shading can act as a secondary source of information for estimation and visualization of faces in 3-D. This effect can also explain why bottom lit faces where the lighting and shadow are presented in an unfamiliar way (Bruce 1992).

Interestingly, as top lit faces are easier to recognize than bottom lit, bottom lit faces in negative photos are easier to be recognized than top lit (Hill & Bruce, 1996). This is because bottom lit negative photos will create dark shades in the same manner and location on the face that normal photos in top lit condition would. The result thus put an emphasis on the role of shading as an important feature for face recognition.

Overall, the findings provide evidence that our visual system is unlikely to employ of just simple analysis and measurements of facial features, since these are relatively the same in both negative and normal photos (Burton, 1999). As a result, recognition processing seems to involve a way to incorporate individual facial components in a template manner.

Figure 2: Negative effect makes it harder to determine the identity of belonging to. The photo belongs to British actor Rowan Atkinson, aka Mr. Bean. (Source gettyimages.com)

Face inversion effect

In a 1969 study Yin points out that faces are much harder to recognize upside down. As intuitive as it may sound, this revelation demonstrates that it is disproportionally harder for face recognition in inverted conditions. Further investigations of the inversion effect over the years have pointed out that while identification is disrupted, feature detection remains relatively intact (Barlett & Searcy, 1993; Friere, 2000, Leder & Bruce, 2000). Nonetheless, if the participant's attention is drawn to a specific feature of the face, the inversion effect there is totally eliminated (Barton et al, 2001).

Interestingly, the inversion effect is not an all-or-nothing effect. Rotational would be a better name for the process as the effects of inversion become gradually more prominent as the stimulus face is rotated towards 180 degree. The larger the angle displacement, the larger the deficit is (Valentine & Bruce, 1998). The rotational displacement also affects identity recognition much more than the featural recognition (Collishaw & Hole, 2002). On possible explanation for the findings is that perception for upright and inverted faces are different. Whereas inverted face are processed in piecemeal fashion where each components are processed individually starting from the eye region, upright faces seem to be process as a whole. The other reasonable explanation is that people are generally more exposed to upright faces in daily situation. Holistic processing are used to process upright, not inverted faces. As a result, it cannot help enhance featural processing, leading to the inverted face effects. The inverted face effect in this case boils down to a matter expertise rather than a switch in mechanism (Diamond & Carey, 1986).

Thatcher illusion

This illusion is first devised by Peter Thompson (Thompson, 1980). The illusion consists of two photos of the same face photo presented upside down. One face, however, has the eyes and mouths inverted with respect to the face. When the faces are upside-down it is difficult to discriminate between the photos. When the faces are upright, the differences are obvious. One face is normal and the other one is very disturbing because all its features are in the wrong direction.

The ability to pick out the differences seems to be hindered by the inversion (Barlett & Searcy, 1993; Boutsen & Humphrey, 2003; Lewis, 2001; Murray, 2000. Thompson, 1980). This finding implies that upright face perception normally relies more on the spatial interaction between the features rather than investigating each feature alone.

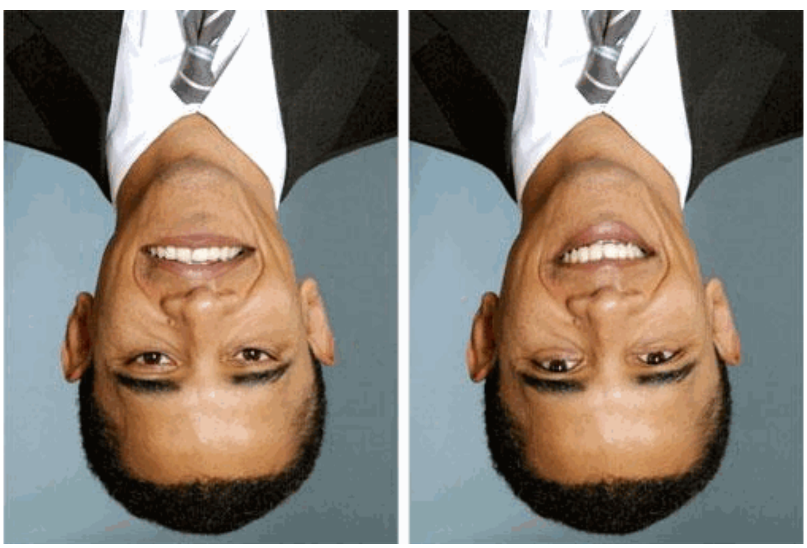


Figure 3: Thatcher effect- inversion makes it harder to realize one of the faces has all its features flipped upside down. (Source: gettyimages.com)

The inversion effect observed in the Thatcher Illusions is similar to the to that of the face inversion effect. It’s observed that the strength of the illusion is affected by rotation degree of the stimulus in comparison to the original photo- the closer to the 180 degree displacement, the stronger the effect (Edmond & Lewis, 2007). Then again, the effects can also be explained by the expertise hypothesis in similar fashion to the inversion effect above (Diamond & Carey in 1986).

In normal situation, by presenting the features in the context of a whole face, holistic processing enhances feature discrimination. When the face is upside-down, holistic processing is not engaged efficiently, and it's harder to tell that the features are flipped. Alternatively, holistic processing is engaged in both places, but because it's harder to process features when they are upside down, it's more difficult to tell the difference (Sekuler, 2004). The rotational effect implies that inversion simply makes face perception harder, but causes no differences in terms of mechanisms.

Composite face effect

The composite face effect is first investigated and demonstrated by Young in 1987. In the experiment, two faces are made up of the same top halves and different bottom halves. When presented upright, the two stimuli are perceived as two different faces. In addition, the combined parts of the faces seem to merge perfectly together. It's also found that people have an easier time noticing the top halves belong to the same face when the faces are inverted (Young, 1987). Because the first study stimuli are taken from celebrities, a follow up study where stimuli are made from random people was conducted (Hole, 1994). The findings mirror that of the Young's study. This gives further evidence that the ability to distinguish between halves of the faces is important for perception, but not necessarily memory.

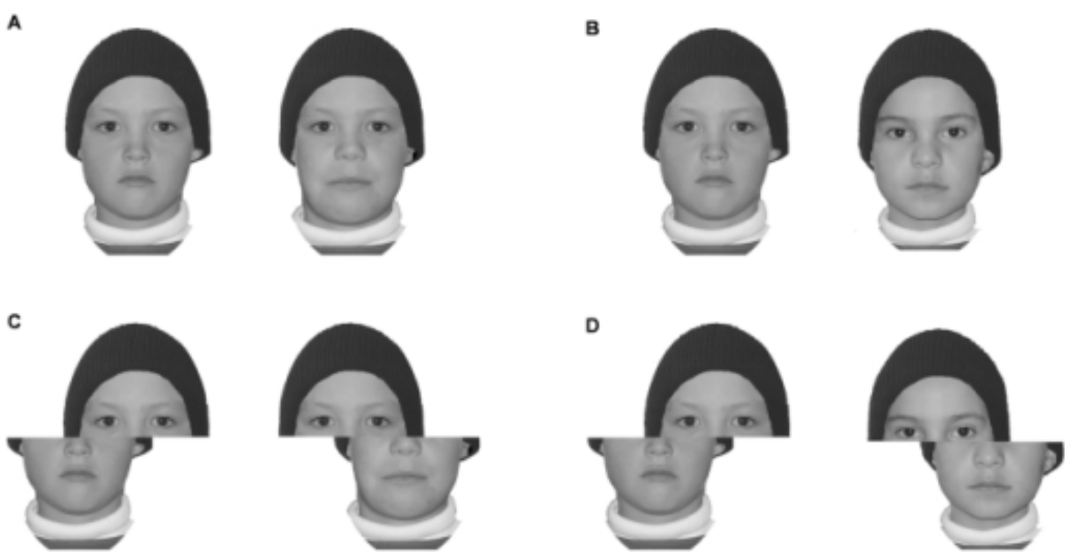


Figure 4: composite face effect: The faces share the same top half, different bottom halves. When shown upright, it is difficult to realize that they share the same top. Inversion makes it easier to distinguish. (Sulio et al, 2009)

The findings point out that when processing faces upright the visual system focuses more on the arrangement and combination of face features rather than on for the specific description of each feature (Steele & Hole, 2006). When processing inverted face, the holistic process does not come online and recognition has to rely on featural processes. This leads to a better change noticing the stimuli are in fact made up from parts of several faces. Alternatively, holistic processing is engaged in both places, but because it's harder to process arrangements in an unfamiliar orientation, face processing has to rely more on comparing parts by parts (Sekuler, 2004). The reliance on holistic processing that deals with familiar stimuli in this case is in essence a preference for efficiency in sacrifice of details. This also suggests that the differences in efficiency may just be cause by the differences in exposure to similar stimuli (Diamond & Carey, 1986).

Whole-over-part advantage

At the same time, it seems that facial features are best analyzed and recognized within a face context. In a study, participants are asked to memorize paring between certain face features and names. On testing, they are asked to assign the features to the correct name. A second condition is that the features are presented with a face as a background. The faces between the stimuli are the same; just the features in question are switched out. A third condition is similar to the second, but the faces are scrambles. The participants perform better in the second condition as opposed to the first and third condition. The results suggested that the features are encoded as part of a mesh that constructs information of a face, rather than a collection of separate features (Tanaka & Farah, 1993).

Further investigation of this paradigm reveals that while eyes are better recognized when they are presented within a face, the larger the distances between the eyes, the harder it is to recognize the eyes (Tanaka & Sengco, 1997). This can be seen as evidence for holistic processing since changes to the whole configuration of the face affects perception of the parts.

A study by Bruce, in 1991, also demonstrates similar results to those of Tanaka's. His participants are asked if they have seen a face before where one of the faces is slightly rearranged. It turns out people are very good at picking up patterns and can pinpoint exactly which face they have seen before.

Both studies show that inversion cancels out the part-whole effect and people recognize the face features equally well with or without being associated with at face (Tanaka & Sengco, 1997, Bruce, 1991). This is consistent with findings in other studies with inverted faces. It provides support that holistic processing is the primary process when it comes to perceiving upright faces. However, like previous effects, these study are unable to tell whether or not holistic is switched out by featural processing when dealing with inverted faces, or holistic became less efficient due to a lack of exposure (Sekuler, 2004; Diamond & Carey, 1986).

Glass pattern: Glass, 1969

There is a lot of evidence in the field supporting holistic processing face perception. However, faces are not the only type of stimuli that employs such processing pattern. Concentric Glass patterns, first introduced by Glass in 1969, are also processed holistically (Glass, 1969; Wilson, & Wilkinson, 1998).

Glass patterns comprise of two identical random dot patterns superimposed on each other. Concentric arrangement has each dot pattern rotated at a specific angle from one another, giving the perception of concentric circles. Translational arrangement has the dot patterns deviated at a specific distance either laterally, vertically or horizontally. It gives the perception of linear patterns.

Studies conducted by Wilson and Wilkinson showed that concentric and radial Glass pattern, and not translational become easier to identify and detect when the percentage of area containing the signal increases. This suggests the perception of radial and concentric are distinct from the translational and random patterns (1998). Further study by Aspell shows that when participants are asked to point out the global from two patterns, one Glass pattern, the other random, integration time for concentric forms decreased as the stimulus extent increased from 3 to 10.9 visual degrees. The opposite effect was found for translational forms. In similar fashion, Kobatake and Tanaka found that an important part of face processing circuitry is conducted within the same area of the concentric pattern detection circuitries (Kobatake, Tanaka, 1994).

With the initial findings of Glass in 1969 and subsequent studies, it's highly possible that concentric Glass patterns are processed holistically and in similar fashion to that of face perception (Wilson, & Wilkinson, 1998). In other words, concentric glass patterns are used to assess sensitivity to holistic forms, whereas translational Glass patterns are used to assess sensitivity to non-holistic forms (Glass 1969).

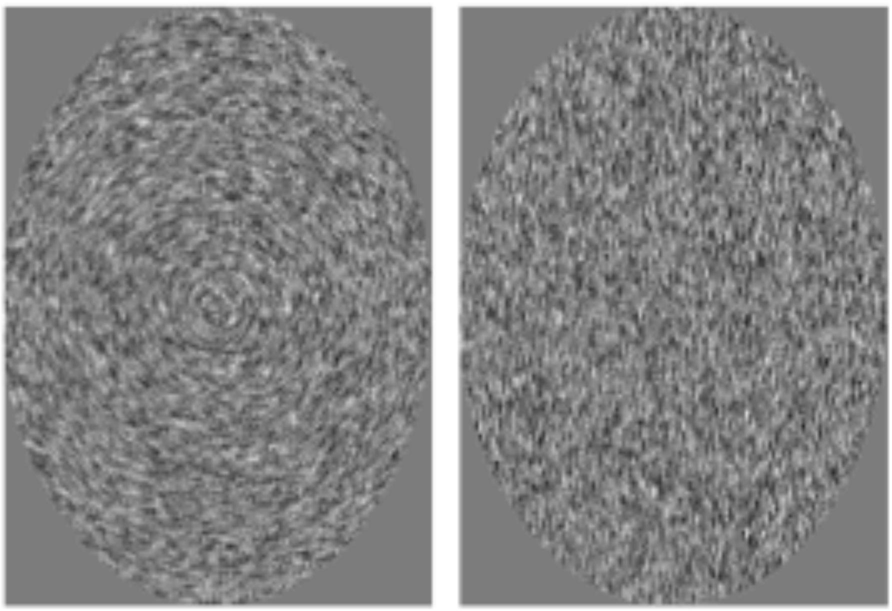


Figure 5: Glass pattern (Glass 1969). Glass pattern are made from superimposing random dot pattern on each other. Concentric arrangement has each dot pattern rotated at a specific angle from one another, giving the perception of concentric circles. Translational arrangement has the dot patterns deviated at a specific distance either laterally, vertically or horizontally. It gives the perception of linear patterns.

Quick Summary

In summary, a lot of evidence in the field point out that recognition of upright face stimuli typically relies on the assessment of interactions between the features. Photographic negative effects, inversion effects, Thatcher illusions, composite face effects, and the whole-over-part advantage share the same characteristics that upright face stimuli are processed holistically.

A lot of studies suggest that upright stimuli are process holistically while the inverted are processed featurally. Alternatively, it's also proposed that instead of a drastic switch, holistic processing is engaged in both places, but because it has less experience processing faces when they are upside down, it shows less of a role in inverted face perception.

b. Additional hypotheses involved in face perception

Holistic processing is flexible: the caricature effect

Interestingly, face perception can be even more adaptive and tolerant to distortions than just face scrambling and blurring. In examples like caricatures or cartoon faces, one can still recognize the person even if some features and arrangements are grossly exaggerated. People can still successfully identify the people in caricature even with 30% distortion (Kaufmann, 2008). As opposed to the normal holistic hypothesis, which relies on only interspatial arrangement between features, the caricature effect begs for a more flexible mechanism. This can probably be useful to think of a versatile alternative procedure where different mechanisms are employed based on the situation to best complete the task. This perhaps will allow better explanation how face recognition can still effectively perform in different lightings and perspective.

Dual-route hypothesis

The dual-route hypothesis can give a reasonable explanation for the versatile yet highly efficient performance of face perception. In this dual-route hypothesis, face recognition is described as a versatile procedure where it can switch between different mechanisms to best complete the task. Indeed it's suggested that featural and holistic processing cooperate and compliment each other (Barlett & Searcy, 1993; Cabeza & Kato, 2000; Collishaw & Hole, 2000; McKone, 2004; Moscovitch, 1997; Rhodes, 1993; Searcy & Barlett, 1996; Sergent, 1984).

In their 2000 study, Collishaw and Hole investigated the relationship between holistic and featural processing by applying various manipulations to faces. Their hypothesis is that if there is dual process, when either the holistic or featural is impeded, the intact one will kick in and allow recognition. To achieve this paradigm, the same face stimulus undergoes several transformations. Scrambling and inversion are made to impede holistic processing, while blurring is intended for featural. Interestingly, participats seem to be highly functional in all cases. This suggests that in face perception, there seems to be some interaction between the two processes at least at some basic level (Collishaw & Hole, 2000).

A neat study by Cabeza and Kato in 2000 with a different paradigm also shows this effect. They introduce participants to stimuli that either are averages of the donor faces or a constructed face by combining different features form multiple donor. Participants who are previously exposed briefly to the donors' face all claims that they have seen the average and construct faces before. The false positive in this case suggests that features do play an important role in face recognition.

One other possible advantage of such dual system apart from reserving a fail-safe is that it allows two separate streams of information to be processed simultaneously. This fits well with the Bruce and Young's model of parallel processing where expression codes are analyzed at the same time of the structural codes. In this scenario, interspatial relationship extracted from holistic processing can be used for identification and recognition while detail analysis of features such as the eyes or mouth provide body language and clues about the person's emotional status.

Expertise hypothesis

The dual-route hypothesis works really well with the expertise hypothesis. The expertise hypothesis explains that upright and inverted faces, and face-like actually use the same mechanisms (Diamond & Carey, 1986). However, since faces are usually seen upright, people naturally have more experiences viewing and processing upright faces. This higher exposure leads to a more efficient method by picking interspatial relations between the features instead of analyzing each feature one by one. As a result, by inverting the face, the expertise is canceled out, results in more primitive reliance on comparing features and slower and less accurate perception (McKone, Kanwisher, & Duchaine 2007). This hypothesis explains well all the effects attributed to holistic processing such as the negative face photo, the inversion, and Thatcher illusion effects.

It also implies how the dual-route hypothesis is set up. In dual-route hypothesis, the system has to constantly make a choice between relying more on holistic or featural processing. With the expertise hypothesis explanation, choices can be made based on the how much experience holistic processing has dealing with the visual stimuli. Since people generally have less experience with inverted face, holistic processing has less experience dealing with inverted stimuli. This leads to an increased reliance on featural processing.

3. Developmental component of face perception system

a. Early visual system in infants

Unlike most mammals where newborn animals possess sufficient motor and sensory ability to navigate and explore its environment in matter of hours after birth, human babies need months to unlock those skills and years to perfectly master them (Lebel, & Beaulieu, 2011). Accordingly, human visual system slowly develops throughout infancy and the visual system won't be completely matured until around puberty (Johnson, 1990). As a result, there is a huge discrepancy between infants' visual system and the adult's (Banks & Salapatek, 1981; Yuodelis & Hendrickson, 1986; Bartrip et al, 2001).

Babies lack many visual processes. At an early stage, there's a lack of full control of eye-movements due to undeveloped neural connection as well as muscle fine-tuning (Aslin, 1981; Bronson, 1990). Therefore fixation and smooth tracking pattern won't appear much later in development. On the neuron level, the cortex develops relatively slower than subcortical components. As a result, full control of visual such as eye movements will slowly shift to cortical areas (Johnson, 1990).

b. Infant's preference to attend to faces

Face perception may change over time. It has been suggested that children of different age are different in terms of the amount of face information they are capable of encoding (Pedelty, 1985). Ellis and Flin found the same trend in their 1990 study.

Based on the findings by Pedelty, Ellis and Flin above, infants may prefer to orient towards faces. In fact infants attention to faces are well observed in both laboratory and natural settings. A study by Goren, Sarty and Wu reported that infants as young as 9 minutes of age prefer looking at moving face schematics than scrambled face patterns containing the same elements but in jumble arrangements (Goren, Sarty, & Wu, 1975). The nine-minute-result has never been replicate. However, similar studies have report face preference starts as soon as the first hour after birth (Johnson et al 1991) and as late as between 12 hours and five days later.

Now if this implies holistic processing is an entirely different matter since no recognition test has been carried out this early. However, tests in later age show that holistic processing might need time to fully develop (Nelson, 2001; Kelly, 2005; Kelly, 2007). The final consensus is that infants are typically interested in holistic stimuli fairly early in their development. This can imply holistic processing, or a preference for holistic stimuli that allows infants to pay more attention faces so that they can learn to process faces better later on (Morton & Johnson, 1991)

Conspec-Conlearn model

Interestingly the preference for face seems to disappear after 4 weeks in most infants (Johnson, et al 1991). During this time, there is no specific preference for face or non-face stimuli. This lack of preference is then followed by an attention to all type of face stimuli regardless if it's static or dynamic at around the second or third month. (Morton & Johnson, 1991).

Morton & Johnson put forward a model in an attempt to explain this phenomenon. They suggest that there are two separate systems involved in this process. First, during subcortical control period, the visual system is directed to dynamic face stimuli. Later on, when visual control is transferred to cortical connections at around the beginning of the second month, a separate system kicks in and become the primary and permanent visual system. The first system is to drive the infants towards the caretaker whereas the second system allows the infant to actually learn faces. This system is dubbed conspec and conlearn, for the two-step process. This system explains the developmental process in terms of evolution and survival. The babies are first attracted to a certain type of visual stimuli- the face, and then by this exposure get more experience recognizing faces and thus develop the growing cortex that will undertake adult face recognition duties in the future (Morton & Johnson, 1991).

On the other hand, this arrangement can also fits neatly with the dual-process hypothesis. Conspec-conlearn model explains that there are two separate systems operating and mature independently in early development. These two systems can very well be the prerequisites for the development of featural and holistic processing later on.

Movement/ dynamic stimuli

There are different opinions on the role of movements in face recognition and identification. One theory suggests that it would add more contexts, such as body language, in which a face is related to and thus allow easier identification. In fact it has been shown that stereotypical movements of someone can help towards identification as well. Studies in extreme conditions such as negative images, pixelated images, and black and white thresholding images show that participant are more accurate in identifying the person in moving footages than still photos. Pike reported in his study that people can learn to recognize faces more accurately if they learn from rigid motion faces than static faces (Pike 1997). A later study by Thorton and Kourtzi also reports that moving faces act as better primes in a sequential face matching tasks than still face (Thorton & Kourtzi, 2002). With their involvements in priming and learning of new faces, movements are suggested to play a role in face recognition in early development.

c. Development of holistic processing

Infantile visual system is not fully developed by birth; it's logical that face perception will also need time to fully develop. Accordingly, there seems to be a great number of evidence showing that holistic processing is greatly influenced by infants' exposure to faces and environment (Nelson, 2001; Kelly, 2005; Kelly, 2007). In these studies infants initially possess a fairly un-differentiated processing system; with exposure and experiences, these systems are fine tuned and optimized to process a certain kind of faces that the infants are most familiarized with.

As infants get older, holistic processing seems to be used more efficiently. Carey and Diamond demonstrates that children between age six and seven have a harder time identifying the top halves of two different faces composite coming from the same donor when the halves are aligned than misaligned (Carey & Diamond, 1994). Tanaka and Pellicano separately point out that children up to age five can recognize facial features better when the features are presented within a face than presented alone (Tanaka, 1998; Pellicano, 2003). However, the use of holistic processing is still limited. In a 2003 study, Donnelly and Hadwin demonstrate that although children age nine can perceive the Thatcher illusion, how significant the perception is depends on how the children are familiarized with the stimuli and what the specific tasks of the study are (Donnelly & Hadwin, 2003). They also emphasize that although this process is observed in their study, children can best perform only in optimal conditions. Another evidence that holistic processing is still underdeveloped in children is paraphernalia. In this situation, addition of accessories like hats or scarves affect infants and children's ability to recognize faces. Children under age ten are seen to rely more on clothing and accessory rather than facial features to distinguish between faces (Carey, Diamond, 1997).

Overall, infants and children up to age nine, similar to their adult counterparts, may use holistic processing for faces to some extent. A specific time line is not well established but data suggest a developmental component to holistic processing. Some evidence suggests the development of holistic processing starts with a very early preference for faces and face-like configurals. This early preference, coupled with preference for moving objects, allows infants to focus more on faces. By doing so, they have more exposure to faces and are able to develop the holistic mechanism for faces perception.

4. Hypothesis and aim

a. Hypothesis

In summary a few major points have been made in face perception study thus far.

First of all, face perception is very complex and how it is processed is partially task driven. For recognition and identification, holistic processing is the primary mechanism when dealing with upright faces and face-like stimuli.

Second, holistic processing exists to some limited extent in infants and children, this suggests a developmental components to this processing mechanism. However, when this system is first activated and become the primary mechanism for upright stimuli is still largely unknown.

Third, there are observable changes in preference and looking patter during infantile development for face and face-like stimuli.

If all the above are true, we hypothesize that it is possible to link the changes in preference and looking pattern to the development of mechanisms like holistic processing through a longitudinal study. In addition, since holistic processing is being matured during this time, there will be an overall increase in preference for holistic objects as the infants grow.

b. Specific aim

Fixation study looking at different stimuli can be used to test this hypothesis, by monitoring the infant preferences and how these preferences between holistic and non-holistic objects change over time. By comparing the preferences between different types of stimuli repeatedly over a long period of time, it's possible to pick out a change or a trend that underlies significant development in holistic processing.

Aim 1: to test whether there is a change in preference for holistic stimuli over time.

Aim 2: to test whether there is a change in preference for non-holistic stimuli over time.

Aim 3: to test whether there is meaningful interaction between the preference for holistic and non-holistic stimuli over time.

Aim 1 looks at the changes in preference for holistic stimuli over time. By investigating aim one, we can verify the existence of a change in preference that may underlie a developmental stage for holistic processing. Similar, aim two focuses on the preference for non-holistic stimuli over time. This is significant since changes in non-holistic processing can be related to, or cause changes in holistic processing. Aim 3 is the most inclusive. By combining the findings of aim one and two, interactions between preferences for holistic and non-holistic stimuli can be monitored and interpreted. Consequently, this allows us to have a full picture of the developmental trajectory of face perception in infants.

Chapter 2: Procedure and method

1. Paradigm overview

To test out the hypotheses, changes in fixation duration were observed when test subjects were shown holistic and non-holistic stimuli side by sides. This paradigm had three advantages. Firstly, several reports show that infants are prewired to prefer looking at faces, or configurations that resemble faces (Goren, Sarty, & Wu, 1975). By showing holistic and non-holistic stimuli at the same time, we could test out if infants indeed prefer holistic or face-like objects to non-holistic stimuli. If they did, this would result in an overall greater amount of fixation in terms of duration and frequency at the holistic objects. Second, the longitudinal design could show the changes in duration of fixations at each object over time. This would allow inference of what processing methods are possibly being used and ultimately gives hint at how face perception developed.

2. Subjects

Infant macaque monkeys were the test subjects for this study. They were the ideal models because of three reasons.

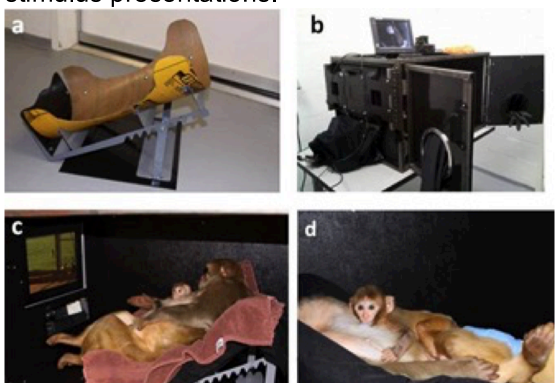
First, macaques have large and developed brains that are highly analogous to human brains in terms of anatomy and function, especially in the visual system (Tootell and Tsao, 2003). Second, like humans, macaques are also social animals, living in large groups with a structured hierarchy. They are capable of face recognition as well as modifying social interactions based on facial expressions and vocalizations (Ferrari et al, 2009). Third, macaques develop at a much faster rate than us human. It's reported to be four times as fast (Clancy, 2001). This allows us to study their developmental progress at a much faster rate. As a result, it will allow a much faster time scale to study with macaques and with human.

The study was conducted at Dr. Parr's lab at Yerkes National Primate Center. 11 infant macaques, residing at the Yerkes Primate Center field station (Lawrenceville, GA), participated in the study. These subjects came from five breeding compounds ranging in size between 50-130 individuals. The fixation pattern study was conducted with these infants from week 1 to 24. With the macaque's rapid development rate, the data collected were equivalent to those of a two-year study conducted with human infant.

3. Equipment

For this experiment, a customized testing booth was used (figure. 6a). The set up consisted of a built in screen at one end of the booth where the stimuli are displayed (figure. 6c); a built-in iSCAN infrared system (iSCAN, http://www.iscaninc.com/) was installed on that same side (figure. 6b). On the other end was the seating apparatus to seat the test subject (figure. 6a, 6d). The iSCAN system tracked the eye movements of the infants; by calibrating with 5 fixation points the exact location and duration of the eye movements on the testing screen could be calculated. With this apparatus, we could track the infants' fixation location and duration when they paid attention to the testing visual stimuli.

Figure 6. Novel eye-tracking behavioral testing set-up. Infant awake on anesthetized mom remains calm and engaged during stimulus presentations.



4. Procedure

An eye tracking session was conducted every week for the first five post-natal weeks, then once every two weeks through the first 24 weeks. Per session, the mother and its infant would be transported together to the testing facility from their housing compounds a few hundred meters away on the morning of the test. The mother would be sedated in a procedure room next to the testing room. During testing, the infant monkey would be introduced to the testing booth with the mother. The mother was secured in a seating apparatus inside of the testing booth. Once inside, the infant was shown the testing photos and videos via the built-in-screen. With this method, the infant would remain calm and focus more attentively to the testing screen.

A five point calibration was conducted at the beginning of the session and every time the infants moved out of the seating area. During this procedure, infants were shown five consecutive bright, rotating objects with interesting sound stimuli- four at each corner of the screen and the last one in the middle of the screen. The objective was to make the infants look at each of the object. The coordination of the objects were known, by comparing the eye movements of the infants during the test with the known location of the calibration test, accurate estimation of the location and duration of the infants' fixations were made.

During the main test session, stimuli were shown repeatedly in ten-second-video clips. This study had five stimuli; however, since the infants were also part of another fixation study, each sitting consisted of a total of about twenty-five videos. Due to the irregular nature of the infants' attention, the videos were shown multiple times during each thirty-minute-test session to extract as much valid information as possible. Only trials with fixations longer than 1 second were considered valid

A maximum of 4 infants were tested per day, and a maximum of 11 per week. After the test, the pair was transferred back to the procedure room for safety observation before being returned to the living compound.

5. Stimuli

Testing stimuli consisted of five different stimulus-pairs: upright and inverted face-like circle configural pattern, upright and inverted face-like square configural pattern, upright and inverted face photos, dynamic concentric and translational Glass patterns, and static concentric and translational Glass patterns. Each stimulus-pair was shown in the form of a 10-second video clip.

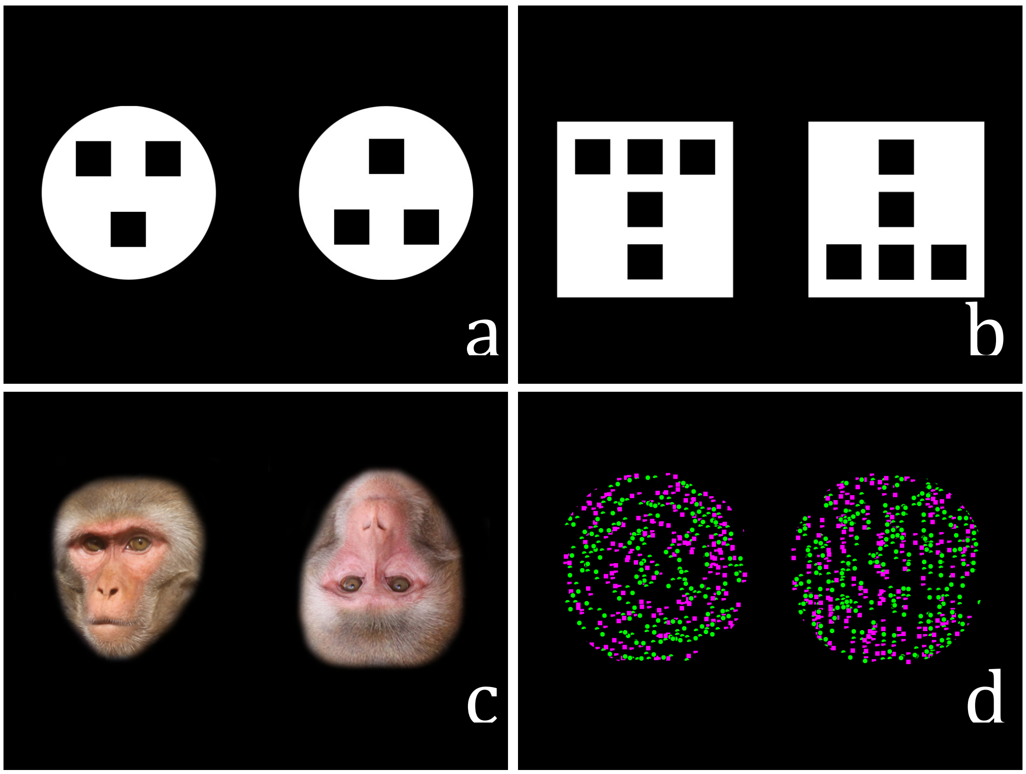


Figure 7: Actual stimuli used in our testing paradigm. Figure a and b are circle and square face-like configural. Figure c is upright and inverted face. Figure d represents both the still and dynamic Glass patter; both the dynamic and still stimuli are the same, the difference is that the dynamic emphasize on the movements that creates the patterns. The pattern on the left is concentric, which is processed holistically, while the one on the right is translational and processed non-holistically.

Face-like Configurals (Figure. 7a, b)

It's been previously reported that newborn babies move their eyes and heads in response differently based on the kind of stimulus (Johnson, 1991). Concurrently, they are reported to prefer looking at the face-like configuration than non-face-like configuration (Valenza, 1996). The findings suggest infants' interests in face-like configurals can underlie a prerequisite for learning holistic processing. At the same time, since infants don't general see a face configural in normal setting; so comparing the fixation preference between face configural and normal face may indicate a different expertise in dealing with such stimuli.

Based on these claims, face configural was used in the study. There were two types of face configural: the circle configuration and square configuration. These variants had similar spatial frequency, however, the circle type resembled a face more. Face-like configural were designed to resemble face stimuli. Upright face like configural would be processed holistically like upright faces, and similarly, inverted face-like configurals would be processed like inverted faces. However, since infants didn't usually see these stimuli in normal day settings, they could be considered novel or unfamiliar, in contrast to faces, which were familiar. With these different characteristics, comparing the preference in fixation pattern between these two groups allowed us to determine if there is any effect of familiarity is acting upon infants' early development.

Both types of configurals were presented separately each week. During each ten-second-video clip, an upright configural was shown side by side with its inverted version. The upright configural was switched back and forth from left to right to reduce familiarization in a longitudinal study like this. The overall fixations on each of the configural arrangement were measured. Each type of configural stimulus was divided into holistic and non-holistic stimuli. Face configural stimuli were shown up to week 7 of the testing. Later tests were canceled due to the lack of interests and cooperation from the subject.

Upright and Inverted Faces (Figure. 7c)

The effect of inverted faces is prominent and well studied in the field of face perception. Some suggest that upright faces are processed holistically in contrast to inverted faces, which are processed in a piecemeal manner (Yin, 1969, Barlett & Searcy, 1993; Friere, 2000, Leder & Bruce, 2000). At the same time, it can alternatively be just indications that human and monkeys are more efficient and familiarized with processing upright faces (Diamond & Carey, 1986).

This knowledge makes upright-inverted face paradigm the perfect match for this study. By comparing fixation pattern of upright faces on contrasts to inverted faces longitudinally, we can investigate and monitor the progression of holistic processing. At the same time, by comparing the fixation patterns between faces and unfamiliar face configurals, we can verify whether or not there is a preference for familiar stimuli.

The faces photos used in this study are headshots of monkeys taken at the Yerkes compounds (Lawrenceville, GA). During each ten-second-video clip, an upright head is shown side by side with its inverted version against a black background to control for distracting effects in the background. Each week, three sets of UPIN are shown. The left right orientation of the upright head is randomized to reduce familiarization. The overall fixations on each of the face are measured. The stimulus is divided into holistic for upright and non-holistic for inverted faces. This type of stimuli is shown for the whole 24 weeks of testing.

Glass pattern: Glass, 1969 (Figure. 7d)

There is a lot of evidence in the field supporting holistic processing face perception. However, faces are not the only type of stimuli that employs such processing pattern. Concentric Glass patterns first introduced by Glass in 1969, is one of the exceptions (Glass, 1969; Wilson, & Wilkinson, 1998). With the initial findings of Glass in 1969 and subsequent studies, it's highly possible that concentric Glass patterns are processed holistically and in similar fashion to that of face perception (Kobatake, Tanaka, 1994). In other words, concentric glass patterns are used to assess sensitivity to holistic forms, whereas translational Glass patterns are used to assess sensitivity to non-holistic forms (Glass 1969).

Similar to upright and inverted face paradigm, Glass patterns made excellent test stimuli. First, it showed the differences in fixation patterns between a holistic and non holistic stimuli. At the same time, it could be compared with face and face configural to see whether there was an effect for expertise influencing the fixation preferences. For this study two sets of Glass patterns were used: still and dynamic. The still variant consisted of a concentric pattern side by side with a translational pattern. The dynamic variant consisted of a moving concentric pattern side by side with a moving translational pattern. Similar to the previous types of stimuli measures were taken to reduce familizairation with the stimuli, the concentric Glass patterns were alternated between the left and right over the weeks. The overall fixations on each of the patter are measured. Each type of Glass pattern stimulus was divided into holistic and non-holistic. Glass patterns were shown for the whole 24 weeks of testing.

6. Data analysis

Raw data gathered from testing were transferred to the lab at Yerkes main station in Atlanta, GA. Here raw fixation data were ran through the Gaze Tracker program to create meaningful fixation data on computer. Gaze Tracker converted iSCAN coordinates for each testing session into specific data that corresponded to the exact locations on the shown stimuli video. "Lookzones"- the regions of interests- were manually added onto the stimulus videos on Gaz Tracker. In this case, they were the total aread that each of the stimuli occupy on the screen individually. Only fixations that fell into the "lookzones" on the videos were recorded. This allowed separation of the valid fixation into proper category, holistic vs. non-holistic and left vs. right.

Next, the data were transferred into Matlab (http://www.mathworks.com) by using in house codes written in the lab. In Matlab, fixation data were summarized for each subject per week. Then the data between eleven test subjects across all weeks were combined together in a single sheet. This step helped streamline the huge number of variables of the data into something much more easier to work with.

Using SPSS, the data were analyzed using ANOVA tests. We conducted ten ANOVA tests, two for each type of stimuli. In one of the set, the independent factor was the left-right distribution of the fixations, the random factor was the week, and the dependent variable was the total fixation in each category. In the other set, the independent factor was the holistic against the non-holistic distribution of the fixations, the random factor was the week, and the dependent variable was the total fixation in each category. These first set of tests examined the interactions between left and right to examine effects of bias, the other set examined differences between stimulus types. A significant interaction in ANOVA may signify two things, first was that there was a genuine interaction between the two types of categories where the rise and fall of one type drove the rise and fall of the other one. The other was that there might be a confounding factor that drove the changse in both categories. To rule this out, it was necessary to keep the results of both ANOVA test for each stimuli for consideration.

Using SPSS, we also conducted linear mixed model analysis (MMA), which was robust against sparse data points, which were likely in this study. With this model, we tested to see if fixation location and duration in lookzones of any of the stimuli would change by age. This test allowed us to track the change in fixation pattern and see what interactions best explained those observed changes. Also comparing fixation location and duration between composite face photos with face videos, upright and inverted face photos, upright and inverted face configural as well as concentric and translational Glass patterns allowed us to see whether there is any differences in holistic vs. non-holistic perception and between still vs. dynamic perception.

Chapter 3: Results

1. Results shows early preference for holistic stimuli in Glass pattern

The consistent factor mentioned before is found to be a rightward preference. The lack of no significance from the ANOVA test coupled with an over all higher rate of distribution seen in the graph indicates that there's a significant bias towards the stimuli on the right of the testing screen, regardless of whether it is concentric or translational

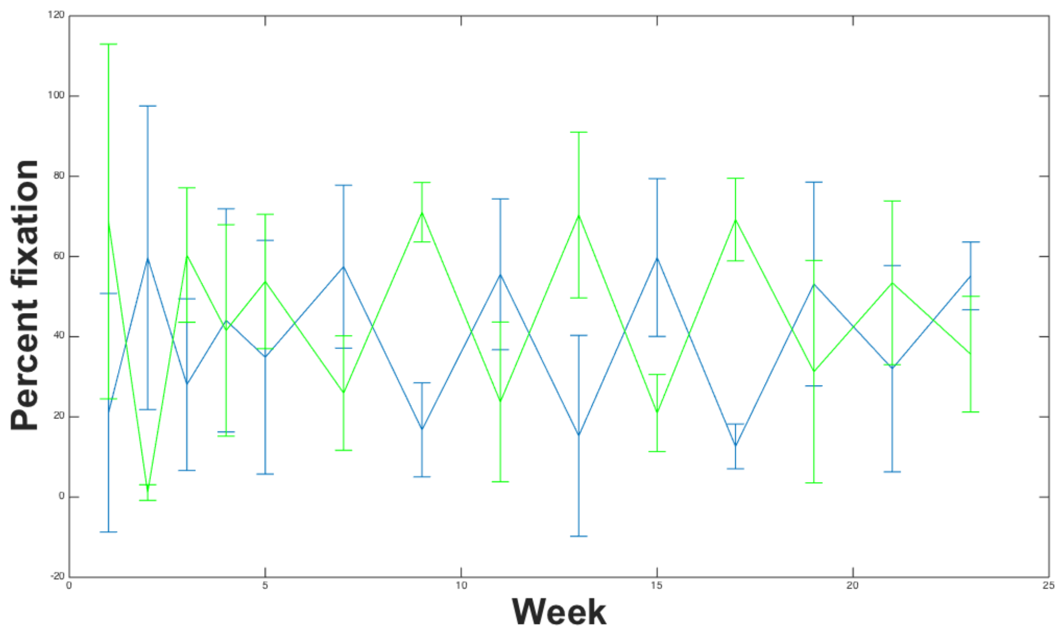


Figure 8: Distribution of fixation in percentage divided between the concentric and translational still Glass pattern by week. The blue line is for concentric-holistic stimuli, the green line is for translational, non-holistic stimuli.

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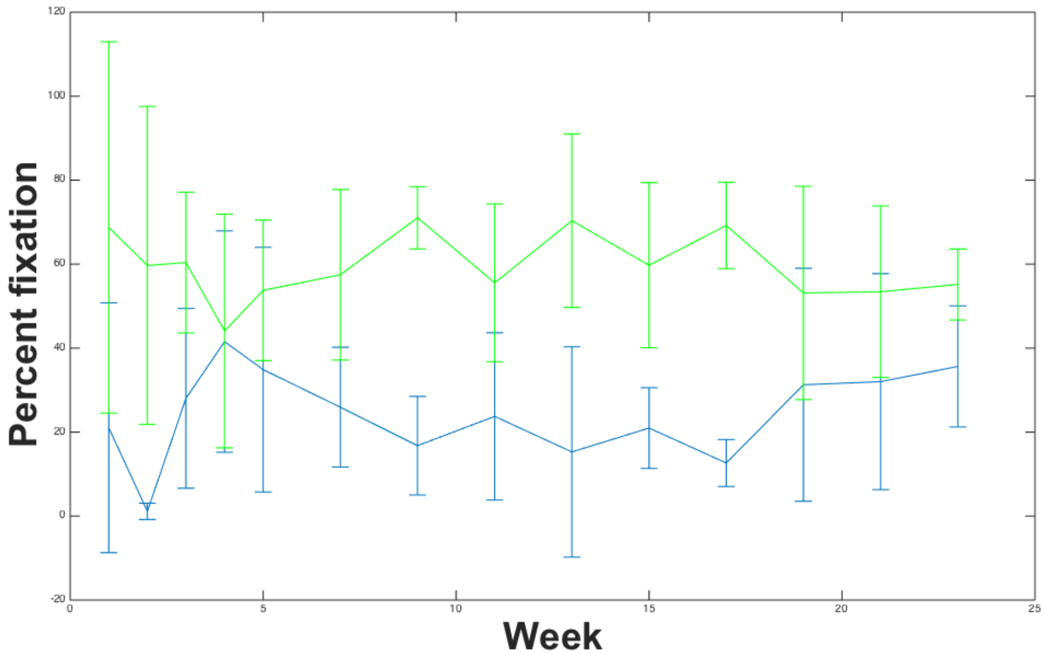

Figure 9: Distribution of fixation in percentage of still Glass pattern divided between the stimuli on the left and stimuli on the right by week. The blue line is for the left stimuli, the green line is for the right stimuli.

A similar rightward bias effect is found in the the dynamic Glass pattern. As seen from the graph there is an overall higher rate of fixation distributed to the stimuli on the right side of the screen. Interestingly, this dramatic distinction only happens from week 5 onwards. Within the first five weeks, the preference seems to be an oscillating between the left and right side. This indicates a possible interaction between the two categories. In fact, ANOVA tests reveals this interaction to be significant ($F(13, 170) = 2.40$, $p = 0.005$, $\eta_p^2 = 0.155$). Considering the stable rightward bias seen in all the trials for the still Glass pattern and about 80% of the trials for the dynamic Glass pattern (20 our of 25 weeks), the effect that drives the change in fixation distribution in the first five weeks of the dynamic Glass pattern must have been very robust.

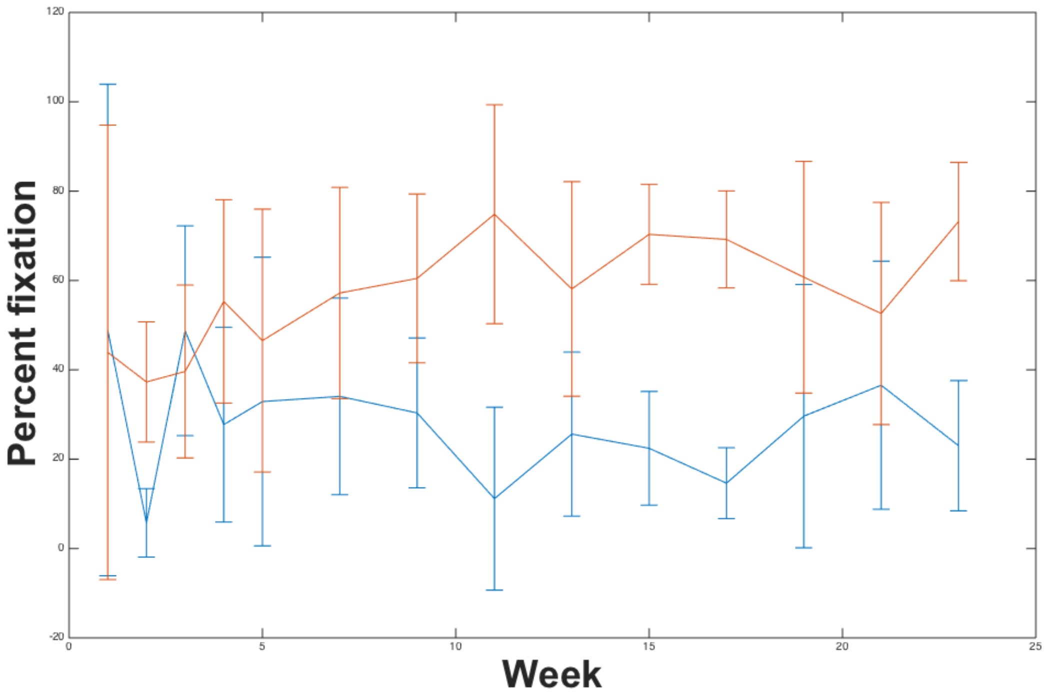

Figure 10: Distribution of fixation in percentage of dynamic Glass pattern divided between the stimuli on the left and stimuli on the right by week. The blue line is for the left stimuli, the green line is for the right stimuli.

Examination of the fixation distribution between the moving concentric and the moving translational Glass pattern reveal an early preference for the concentric form. However, the preference didn't last long and the signal went back to oscillation afterwards. The ANOVA tests pick up this alternating signal and indicate a significant interaction between the fixation of the holistic and non-holistic stimuli ($F\ (13,\ 170) = 6.76,\ p < 0.001,\ \eta_p^2 = 0.341$). Interestingly though, the duration and termination time of the preference for holistic stimuli and the oscillation pattern seen in left-right preference coincides perfectly.

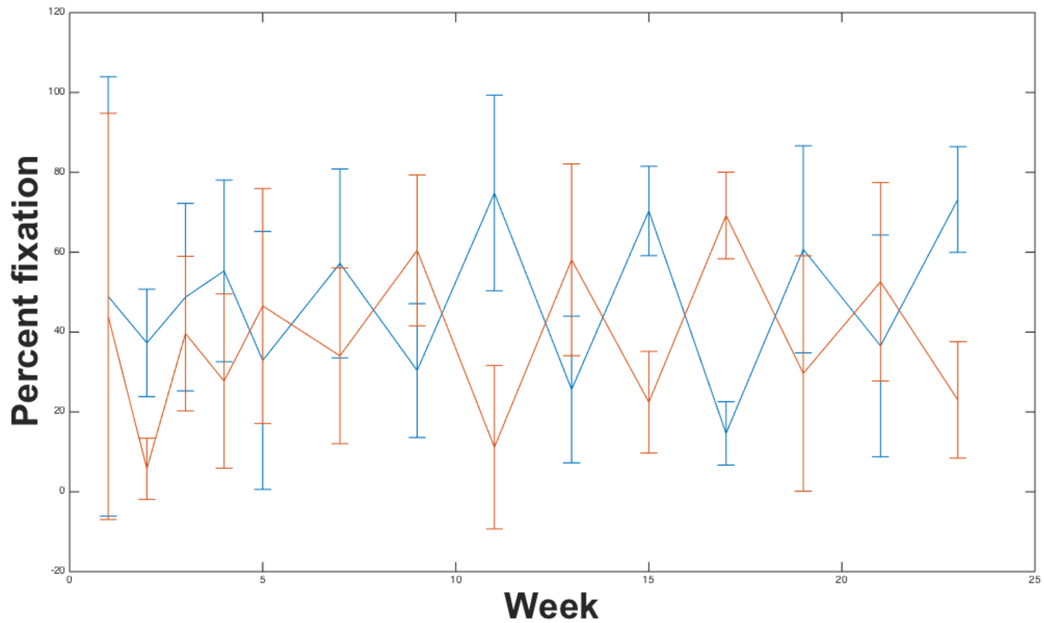

Figure 11: Distribution of fixation in percentage divided between the concentric and translational dynamic Glass pattern by week. The blue line is for concentric-holistic stimuli, the green line is for translational, non-holistic stimuli.

It has come to attention that there is an overall rightward bias seen in this testing paradigm. This indicates that there is a genuine preference for holistic objects and holistic very early on to the development. As the infants grow older, the effect disappears at around week 4. This suggests that there might be crucial a developmental change during this time period.

It is also interesting to note that the effect is only observed in the dynamic, not the still stimuli. One possible explanation for can be attributed to the fact that dynamic stimuli are more salient to visual systems. Infant might be able to pick out the Glass pattern from the background easier due to its movement agains the background. (Thorton & Kourtzi, 2002).

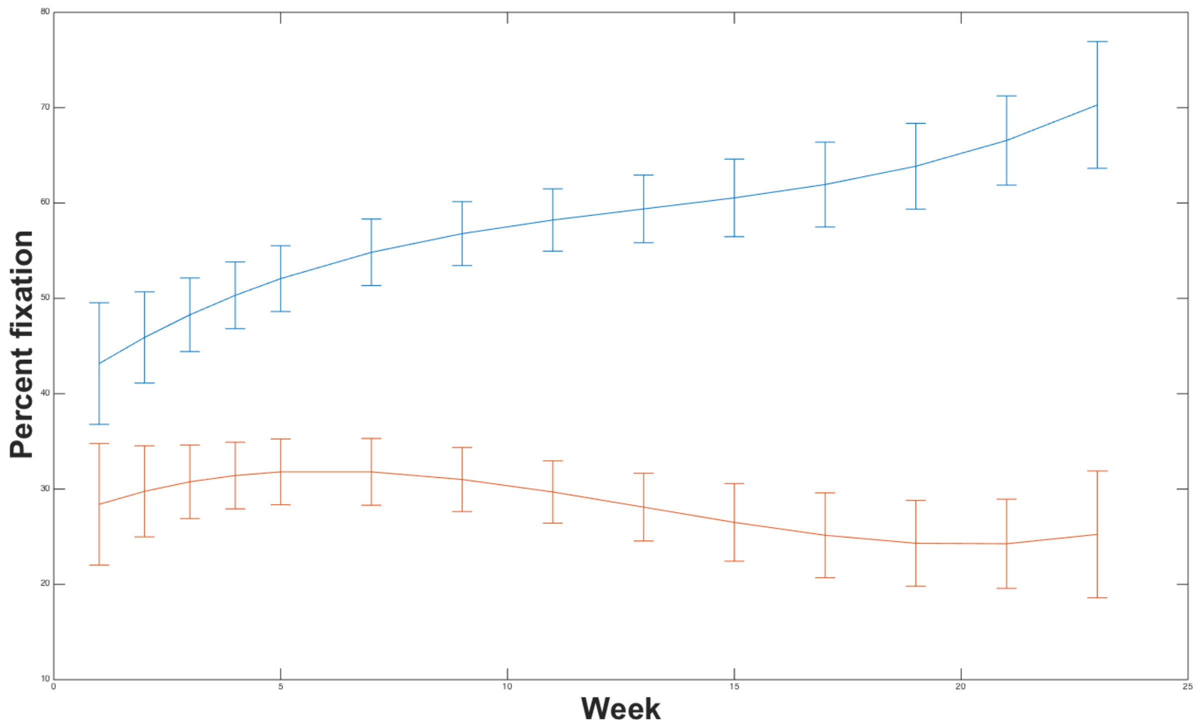

Figure: 12: Linear mix model predicting a right side preference in the dynamic Glass pattern trial over the twenty-four weeks. Blue line represents the fixation distribution on the right side of the screen, red line represents the fixation distribution on the left side of the screen.

Linear mix model analysis (MMA) reveals that a quadratic model most likely fit the fixation distribution in dynamic Glass pattern over time when comparing between the holistic and non-holistic stimuli (χ^2(A, N=198) = Δ AIC = 1841.97; $p < 0.001$). The model is shown in the graph below. Similar to the results of the ANOVA tests, there is a significant higher preference for rightward fixations. The MMA didn't find any model that could explain well the relationships between the fixation distributions over the week for the dynamic glass testing for holistic vs. non-holistic stimuli and all the still Glass pattern analyses.

2. Results show late preference for inverted face in upright-inverted face stimuli

In the analysis of the upright-inverted face stimuli, ANOVA tests show a significant interaction between the left and right distribution of the fixation (F (13, 240) = 4, 23, $p < 0.001$, $\eta_p^2 = 0.19$). This corresponded to the crisscrossing pattern observed in the figure below. In the Glass pattern case, the figure shows an oscillating effect where preferences are alternating between right and left preference, which is indicative of the rightward bias. Interestingly however, this bias is not the factor driving the effect this time. In fact, the rightward bias is being overshadowed here. Consequently, the oscillating pattern strongly predicts that there is a strong preference for either the upright or inverted stimuli.

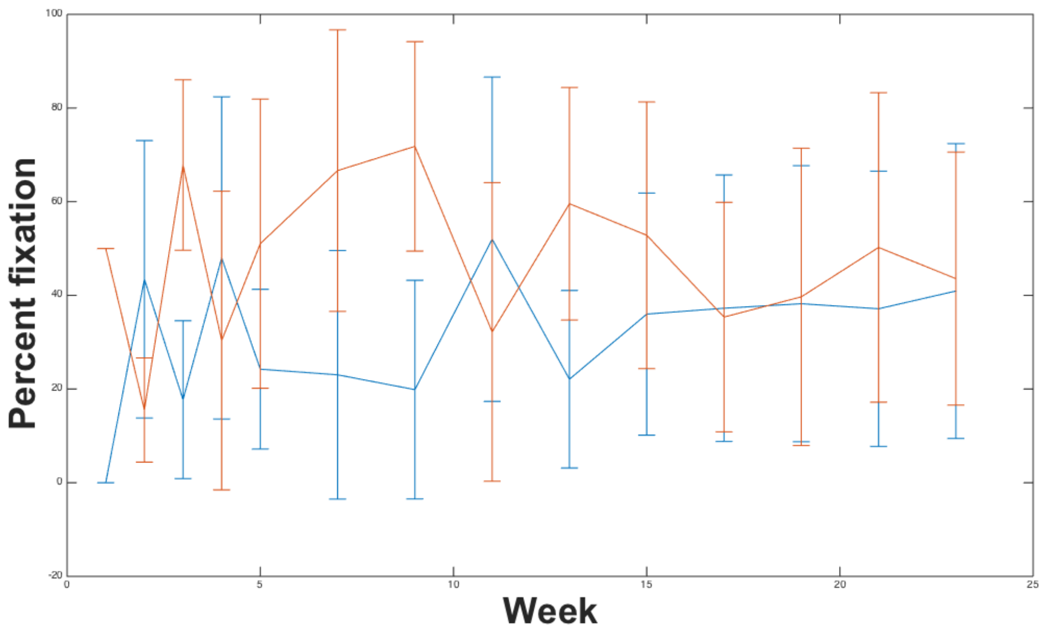

Figure 13: Distribution of fixation in percentage of upright- inverted face trial divided between the stimuli on the left and stimuli on the right by week. The blue line is for the left stimuli, the red line is for the right stimuli.

Indeed, the upright-inverted category graph confirms the prediction of a preference towards one type of stimuli. Interestingly, it's the inverted, not the upright faces that are favored. On the other hand, the ANOVA test shows a significant interaction between the two stimulus categories ($F(13, 240) = 2.86$, $p = 0.001$, $\eta_p^2 = 0.134$). This indicates that although there is a strong preference for inverted faces, this preference is not constant. In close scrutiny of the graphs, significant difference between preferences only occurs between around week five and fifteen. There is no significant difference before or after this period.

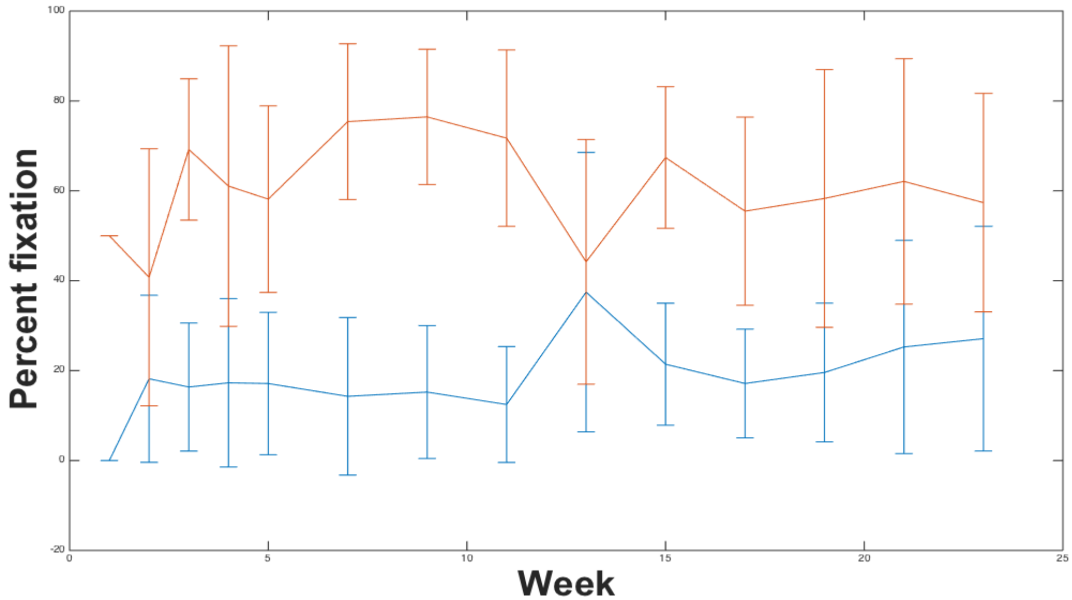

Figure 14: Distribution of fixation in percentage divided between the upright and inverted face trial by week. The blue line is for upright-holistic stimuli, the red line is for inverted stimuli.

This finding is very interesting for two reasons. The infants seem to prefer inverted face stimuli to upright face stimuli. In essence, the finding is contradictory to the popular finding of the field that infants prefer holistic to non-holistic stimuli. In addition, the preference is not constant. At first there is no clear favorite between the upright and inverted stimuli; however, during the fifth and eleventh week, the inverted preference become much more prominent. Then this effect slowly dissipates and by the sixteenth week significance in preference is no longer observed. This indicates a function of a change or a development in the system.

One possible interpretation of the data is that some mechanism that brings the infants attention towards inverted stimuli is turned on at the fifth week, and then turned off at around the fifteenth week. Alternatively it can also be possible that after the first mechanism comes online and drive attention towards inverted face, a second mechanism which favors holistic stimuli kicks in and overshadow the previous one. Regardless of the mechanism, the consensus is that there is a drastic developmental change at around week five that causes a significant change in fixation preference in the infants.

The MMA didn't find any model that could explain well the fixation distributions in both types of categories for the upright-inverted face trials. This could mean that the relationships couldot be distinguished from chance level and did not imply any consistent change over the weeks. Alternatively, it could also mean a linear model was not powerful enough to explain the relationships, in particular the oscillation, then increase and then decrease preference for right side stimuli. Since ANOVA tests, with more conservative predictions, indicated interactions in both categories, the latter reason explaining the MMA result seemed more likely.

3. Late preference for holistic subjects in configural stimuli

For the square configural upright-inverted stimuli, ANOVA tests reveal a significant interaction between upright and inverted stimuli categories and time (F (3, 16) = 3,74, p = 0.03). According to the data, there is an interaction between the two categories. The graph supports this by showing an overall increase in fixation in upright faces and a decrease in inverted stimuli. There seems to be signs of crisscrossing of preference at around week three and five (Figure.13). However, the data for these stimuli are scarce and thus may be underpowered to verify a significant effect.

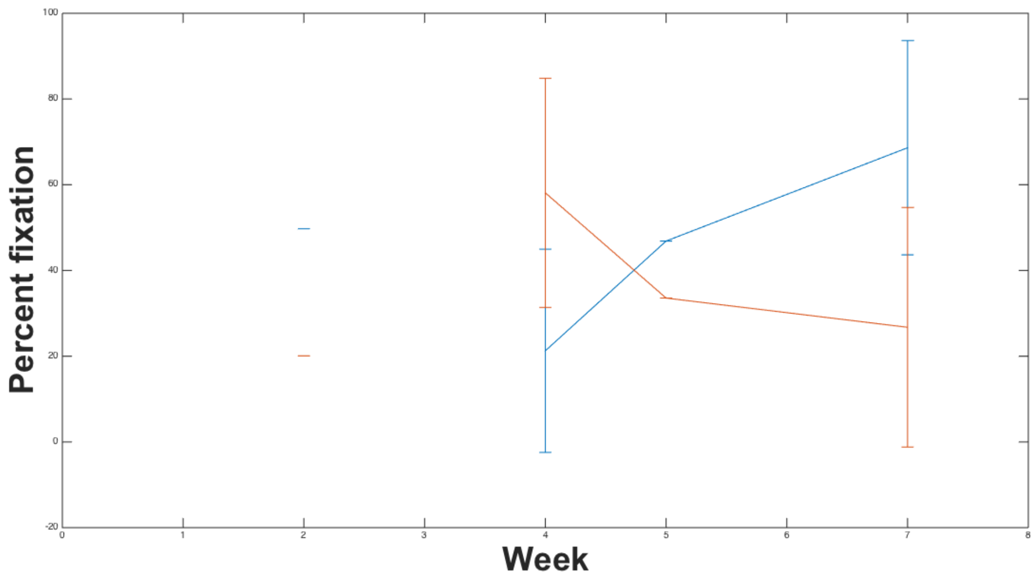

Figure 15: Distribution of fixation in percentage divided between the upright and inverted square face-like configural trials by week. The blue line is for upright-holistic stimuli, the red line is for inverted stimuli.

On the other hand, ANOVA tests show no significant interaction between the left and right categories for the fixation in this case. As shown by the graph, again there is an overall rightward bias similar to that observed in the Glass pattern trials.

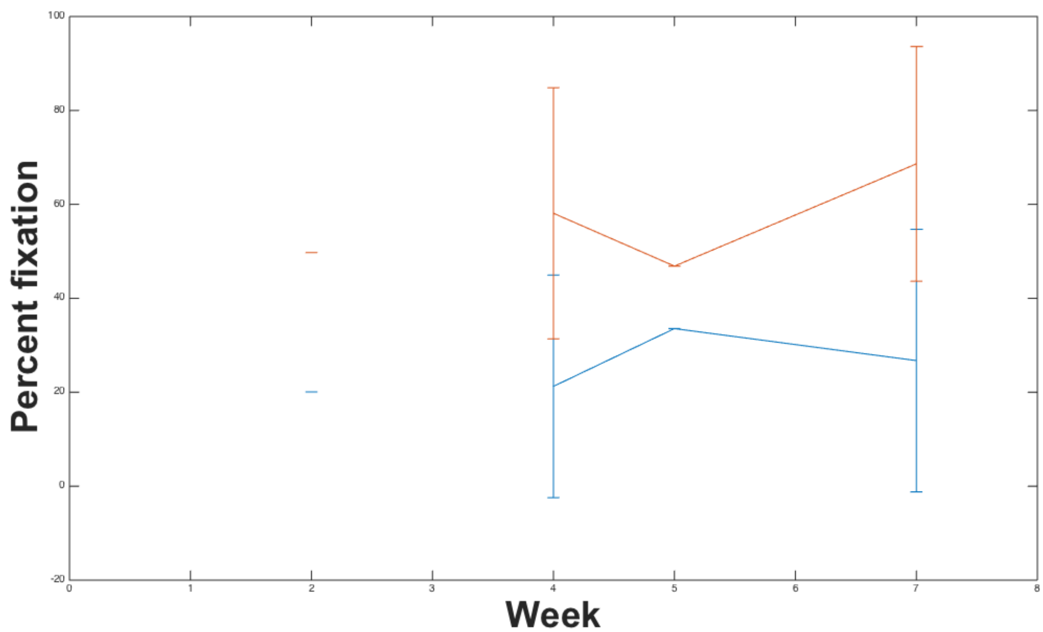

Figure 16: Distribution of fixation in percentage of upright- inverted square face-like configural trials divided between the stimuli on the left and stimuli on the right by week. The blue line is for the left stimuli, the red line is for the right stimuli.

In the circular face configural analysis, ANOVA tests show significant interaction between the upright- inverted categories ($F(5, 26) = 3.20$, $p = 0.022$) as well as the left-right orientation categories ($F(5, 26) = 11{,}13$, $p < 0.001$). The observed effect between the stimulus categories is particularly interesting and valuable to our experiment. Infants prefer looking at upright configural more as the weeks go on. At the same time, there is a drop in their attention towards non-holistic figures (Figure 14). This is consistent with the findings in the field.

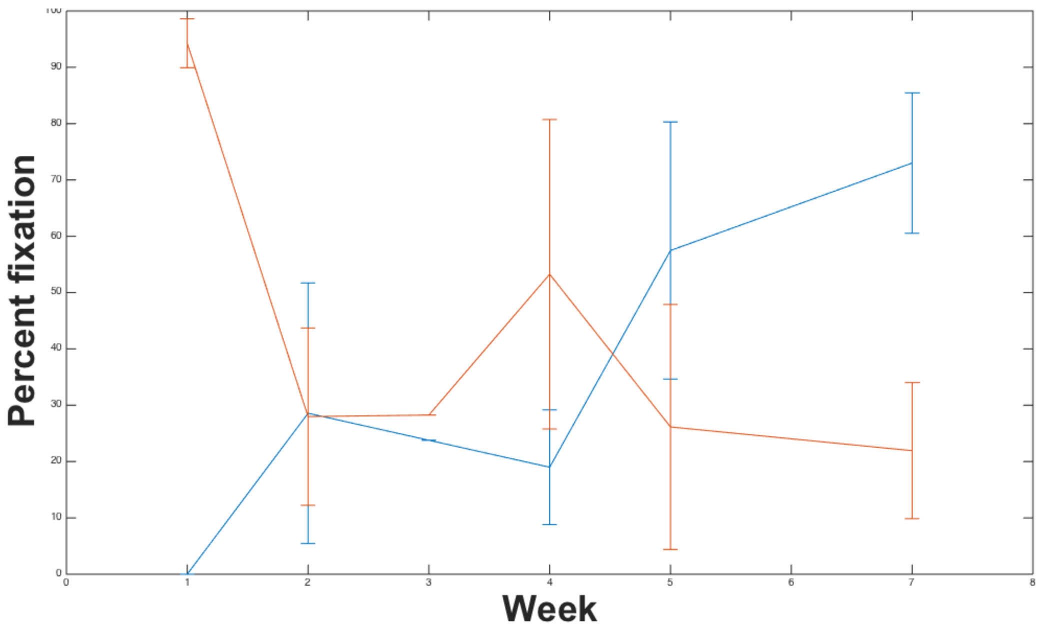

Figure 17: Distribution of fixation in percentage divided between the upright and inverted circular face-like configural trials by week. The blue line is for upright-holistic stimuli, the red line is for inverted stimuli.

In considering the left-right preference. As seen in figure. 16, the infant generally prefer looking at stimuli on the right side. However, during week two and three, the left and right preference aren't significantly different as they still closely follow each other. This indicates a gradual change more towards the right as the infants grow older.

Due to the design of the study, there is an uneven distribution of the stimuli in terms of left and right preference. During week two and three, five and seven, the holistic stimuli is on the right side of the screen, while during week one and four, the holistic stimuli is on the left. Tracing back to the distribution of fixations, there seems to be similarities between week two and three, and between week five and seven in both types of categories. More interestingly there is a huge discrepancy between the two groups. In terms of upright-inverted there is much higher fixation rate at week five and seven than at week two and three. This indicates a longitudinal increase of preference for upright stimuli.

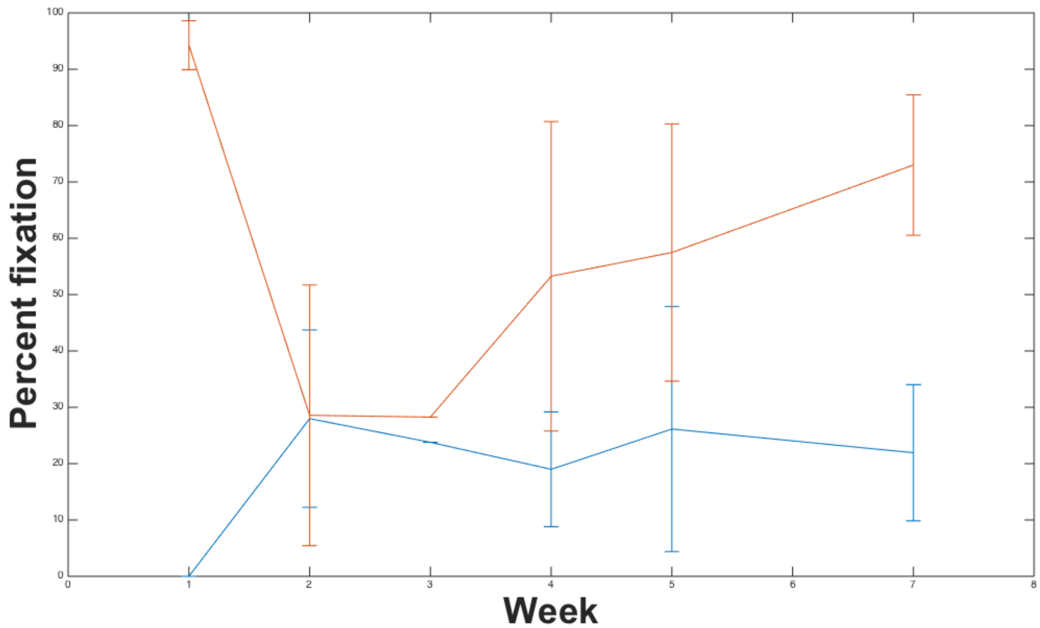

Figure 18: Distribution of fixation in percentage of upright- inverted square face-like configural trials divided between the stimuli on the left and stimuli on the right by week. The blue line is for the left stimuli, the red line is for the right stimuli.

One possible interpretation for the change is that at an early stage, the infants are equally interested in both stimuli on the screen. Later on, the infants slowly become more attentive towards the right side of the screen. This can be attributed to either in significant increase interests in the holistic stimuli or a significant increase in right side bias as seen other trials, or both.

Linear mix model analysis (MMA) reveals that a quadratic model most likely fit the fixation distribution in the circle face-like configural trial over time when comparing between the holistic and non-holistic stimuli (χ^2(A, N=38) = Δ AIC = 351.41; $p < 0.001$). The model is shown in the graph below. This model supports the ANOVA tests that there is an overall significant increase of preference for holistic stimuli and simultaneous decrease of preference for non-holistic stimuli.

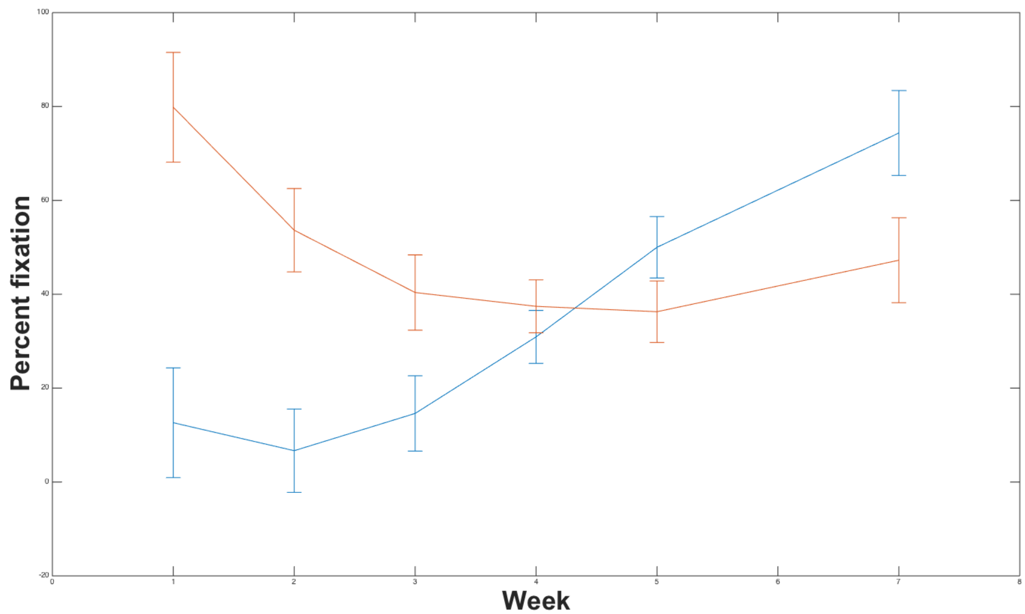

Figure. 19: Linear mix model predicting a increase of preference for upright-holistic stimuli and a decrease preference for inverted stimuli in the circular face-like configural trial over the twenty-four weeks. Blue line represents the distribution of upright stimuli, red line represents the distribution of the inverted stimuli.

Overall, the data collected form the face configural stimuli shows a general increase of holistic processing as the infants grow older. In comparison to the effect observed in the Glass pattern, the effect in the configural seems to have a bit later onset. In particular, based on the figures presented above, the usage of holistic processing for both square and circular configuration start almost simultaneously at around early week three, late weak four.

Chapter 4: Discussion

1. Result shows changes in fixation preference within the first 10 weeks.

Overall the consensus gathered from the study is that preferences for upright faces, face-like configurals, and concentric Glass patterns change over the first ten weeks of life.

In the Glass pattern paradigm, infants prefer holistic objects in the first four weeks of life. This effect seems to go away past the four-week-mark, suggesting that holistic processing of Glass patterns may be present from birth or from very early in the maturation process. At the same time, data from the face configuration stimuli show a constant increase in preference for the upright configurals, which may be processed holistically, as the weeks go on. In comparison to the Glass patterns, preference for upright configurals seems to occur later in life. In particular, the preference for the upright square and circular face-like configuration starts almost simultaneously at around early week four, late weak five. These two results suggest that holistic processing is present from birth and there seems to have a change starting at around week four and five.

However, the data from the upright inverted face stimuli appears to contradict the established notion of holistic face processing. In contrast to the findings from both the Glass pattern and face-like configural studies, infants generally prefer looking at inverted faces in upright-inverted trials. Moreover, there also seems to be a solid increase of attention to inverted stimuli between week five and eleven. If we believe that inverted faces are to be processed in piece meal manners, this finding would suggest that the infants in this study prefer stimuli using featural processing to stimuli using holistic processing, as they grow older. Because this explanation contradicts the explanation from the configurals and Glass patterns, this begs for another explanation that can possibly incorporate all three seemingly conflicting findings.

The effect of holistic perception may be masked by habituation to the stimuli.

One possible explanation can be attributed to the habituation of the testing stimuli. Since we cannot verbally communicate with the infant monkeys, an infant's ability to recognize an object or the extent of preference for holistic processing are inferred from the amount of time the infant spends looking at each visual stimuli. However, it has been well known and used as a testing paradigm that animal and infant humans alike tend to spend less time with the objects/animals they are familiar with, and spend more time on the novel objects (Humphreys, 1973).

In our study, the infants may spend less time with the upright faces and more with the inverted because they are simply more familiar with the upright face. This suggests to a certain degree the involvement of an expertise effect proposed by Diamond and Carey (1986). Since baby monkeys are raised in a normal condition in colonies of about a hundred individuals, they are constantly exposed to upright faces. It is found that the ability to recognize face is influence by the amount of early exposure to faces in the environment (Nelson, 2001; Kelly, 2005; Kelly 2007, Sugita, 2008). Therefore, when presented with the upright and inverted face, a monkey may quickly recognize the normal upright face. At the same time they perceive the inverted face to be unusual and as a result, spend a longer time investigating the inverted face.

In the upright-inverted face trials, there are no significant differences in preference for face orientation in the first four weeks. Starting from week five to fifteen there is a split in the distribution and infant become significantly more interested in inverted faces. Because inverted faces may be unusual, sudden increased preference for inverted faces may suggest a change in upright face perception. This could be a sign of a new recognition system being kicked into operation. Perhaps at this point, holistic processing starts developing towards that of the adult version and allows more rapid, and accurate face perception.

One could question why this effect of habituation is only present in upright and inverted face trials. This may very well be attributed to differences in the amount of experience with the test stimuli. Monkeys raised in large compounds see faces of other monkeys all the time. On the other hand, face-like configurals (both circular and square) and Glass patterns are not something they would normally see. As a result, even if they process the concentric Glass pattern and upright configural faces more efficient than their counterparts, they might still consider these to be novel.

This is a promising explanation. However, it fails to explain why infants do not show any habituation to either the Glass pattern or the face-like configurals even when the testing goes on for a rather long time. In addition, the preference for inverted faces diminishes as the infant reach around week ten. If we assume that the split in preference is caused by unlocking holistic processing, then what may cause this change of preference?

Are inverted stimuli and translational Glass pattern really the same?

As explained above, the interpretations regarding the timecourse of holistic processing development assumes that perception for holistic face-like configurals, Glass patterns, and faces are relatively the same, and that their counterparts are also the same. However, this may not be true. Infants might react differently to distinct test stimuli even if they are design to be analogous in terms of holistic versus non-holistic paradigm. It is possible the three stimulus pairs used in this study might be very different with regards to each other.

As pointed out by numerous studies, translational Glass patterns are considered non-holistic due to the way they are encoded (Glass, 1969; Smith, 2000; Wilson, & Wilkinson, 1998). Due to their particular arrangement, translational Glass pattern will never be processed holistically no matter how much it is rotated. On the other hand, inverted faces will be holistically processed when rotated upright. This is consistent with the fact that the inversion effect is not all-or-nothing. It is a gradual change and becomes more prominent as the stimulus face is rotated more towards 180 degree (Valentine & Bruce, 1998). The same phenomenon is observed in Thatcher illusions (Edmond & Lewis, 2007). This suggests that switching between holistic and featural processing does not occur in an abrupt fashion.

In other words, holistic processing and featural processing may be working simultaneously and in complimentary of each other in accordance with the dual-route hypothesis (Barlett & Searcy, 1993; Cabeza & Kato, 2000; Collishaw & Hole, 2000; McKone, 2004; Moscovitch, 1997; Rhodes, 1993; Searcy & Barlett, 1996; Sergent, 1984). In addition, with the expertise hypothesis, the inability to perceive inverted face holistically comes as a function of exposure (McKone, Kanwisher, & Duchaine 2007). In articularly, the higher exposure leads to the development of a more efficient method by picking interspatial relations between the features instead of analyzing each feature one by one. As a result, the expertise is canceled out in dealing with unfamiliar stimuli like inverted faces. Here face perception has to rely more on primitive comparison between features, leading to slower and less accurate perception (McKone, Kanwisher, & Duchaine 2007).

2. Revisit the upright-inverted results: Dual-route hypothesis

Based on this logic, the testing stimuli can be divided into two groups holistic vs non-holistic and holistic vs inverted holistic. Within the holistic vs. inverted holistic, it's subdivided into familiar, for faces, and unfamiliar, for face-like configurals. So in total we have three different groups of stimuli with overlapping characteristics. Returning to the strange findings of the upright and inverted trial, the results might point out to a different scenario if we consider it in light of the new categorization of the test stimuli.

In this case, during the first four weeks, there is no significant preference for inverted or upright faces, but heavy preference for concentric Glass pattern over the translational pattern. Since Glass pattern trials show holistic and non-holistic, while upright inverted trials show holistic and inverted holistic, infants are showing a holistic preference early in development. Infants showed no preference between the upright and inverted faces because they are practically both holistic stimuli. This suggests that during these four weeks, the infants consider the upright and inverted face as similar. In other words, there are no differences in holistic and inverted-holistic processing. This is in accordance with findings in the field where children and infants are less affected by inversion effects and Thatcher illusions (Rose, 2008; Turati, 2004; Donnelly & Hadwin, 2003; Mondloch, Le Grand, & Maurer, 2002).

Similarly the disappearance of this preference after week four for the Glass patterns and the start of preference for inverted faces around week five again seem suggest that there may be a preference of featural over holistic processing emerging after the first month of life. It is appropriate at this age that featural processing is more prominent due to the underdeveloped anatomy of the sensory and cerebral systems (Nelson, 2001; Kelly, 2005; Kelly, 2007). However, the evidence for an overall preference for holistic stimuli in the first four weeks can suggest that featural processing is not fully in operation at that time. As a result, featural processing emerges from week five onwards, and infants will pay more attention to features and details of faces and objects. This explains why preference for concentric Glass pattern diminishes; infants are paying attention to the individual features independent of the arrangement. Habituation can also help to explain the drive for inverted face preference around this time. Since infants are familiarized with upright faces and upright features, inverted features can be considered more novel and they will naturally pay more attention to these details.

As the maturation marches on, infants slowly learn to combine holistic and featural processing. This is inline with the CONSPEC CONLEARN hypothesis. The introduction of featural processing allows infant to focus more at faces, and thus allow them to learn how to recognize faces efficiently. At the same time, neural circuitries are being optimized in the brain. This whole process leads to a more streamline way of face processing and allow holistic and featural processing to operate in parallel as a dual-route for face perception.

Although the face-like configural trials only lasts up to seven weeks, they also so help support this hypothesis. In the first weeks, there has always been an interest in holistic arrangements. When featural processing starts kicking in, there is a minor surge in preference for inverted-holistic stimuli. However, as the testing continues, this surge disappears, replaced by an over all preference for holistic stimuli, because the infants have the same experience with both inverted and upright configurals. This preference later on can be attribute to the activation of holistic processing, perhaps because the face-like configural has a similar arrangement as a face.

This explains why later on, the preference for inverted face stops at around week fifteen. This is may be, in some part due to the emergence of the dual-route. The emergence of this new pathway forms the basis for adult-like face perception later on in life. Through development, the holistic and featural processing pathways work in tandem, complimenting and supporting each other. There is evidence that if the holistic process is impeded, featural will take over and help with the face perception process (Collishaw & Hole, 2000).

Overall, the development process of infant macaque can be modeled as follows. There is an innate or very early preference for holistic stimuli; this preference is preexistent before the first week of trial. However, during this time, the infants' sensory and neural systems are still incapable of processing these stimuli systematically. At around week four, the infants are able to access featural processing. This featural processing allows further attention to face features and the development of an overall holistic processing mechanism for face. Slowly during this time, holistic process for faces is being refined and becomes fully online at around week fifteen.

This model neatly explains the differences between the three main results. The three results stem from three different stimulus pairs that capture different aspects of holistic and featural processing and the effect expertise may have on these processes. It also helps tie up the disagreements in the field regarding the encoding switch hypothesis that describes a sharp transition between featural and holistic processing in early development (Carrey & Diamond, 1977). While there are a lot of evidence supporting this hypothesis (Ellis & Flin, 1990; Carrey & Diamond, 1997; Carey, 1981), there are also a lot of evidence that oppose to it (Flin, 1985, Baenninger, 1994; Freire & Lee, 2001), but only if one considers the two processes to be mutually exclusive. If the two processes work in tandem, where the primary roles can switch back and forth based on the development of the sensory and cerebral system of the infant these studies are consistent with one another.

3. Short comings of the study

Similar to other studies, this study does have several shortcomings that could be potential confounding factor.

First of all, this whole study bases on the idea that infants pay attention and interests to whatever visual stimuli they engage at. However, human infants as young as six month old are capable to conduct covert attention (Richards, 2000). In macaque terms, it would be at around week six. This creates the possibility that the inferences based on fixation are not completely correct in terms of what specific details the test subject are looking at. This is a common risk factor for all gaze tracking study. However, it's fortunate that the further away from the visual fixation point, the less likely and less accurate the covert attention is. For this study, the infant is in close proximity to the screen and thus even if there is covert attention, it won't be too much of a difference in terms of preferences.

Second, infant macaques are not always the best participants in the study. They tend to loose interest in the testing screen after a while. They also fall asleep easily in the testing booth due which is rather dark and cozy. In addition, the some times also move away from their seating locations. This might result in an accurate tracking of the fixation on the screen. However, due to the close proximity to the screen, again, this won't be too much of an inaccurate estimation of the fixation coordination.

Third, the testing booth might prove to have a flaw. As observed during experiment and analysis, there seems to be a rightward bias overall in every testing trial. This may be because the door to the testing booth is on the left side. This might create some distraction that prevents the infants from fully paying attention to the stimuli shown on the screen.

Forth, some of the holistic stimuli might be biased towards one side of the test. Since holistic and non-holistic stimuli are presented side by side, to prevent familiarization with the presentation of the test, the two types of stimuli are switched back and forth between weeks. In review of the stimuli, it's found that holistic stimuli are placed more on the left side for upright inverted trials and more on the right side for configural trials. This combined with the over all right bias as discussed above might create a confounding effect that drives results into certain presentation.

Lastly, human error although is always a considerable factor regardless of how much care and attention to detail are paid to the process.

4. Future direction

This study proposes a new hypothesis that can potentially bridge the gap in the current knowledge in the field regarding the development of holistic and non-holistic processes. However, as discussed above, some of the shortcomings might be influencing the results of the study. Consequently the next important step is to conduct another study with revised procedure to eliminate the said factors. This will help verify the findings of this study and provides background for further development.

If these findings hold true in the follow up study, it would mean that there is a developmental progress that involves the interaction between holistic and featural processing. It would be nice then to have a way to link that to the physical development of the nervous connection in the brain during that critical time. fMRI studies coupled with known knowledge about the anatomy of the visual system can be conducted to localize the areas that may be responsible for this development. In addition, transcranial magnetic stimulation (TMS) can also help test the specific role of certain cortical areas that are involved in this process.

On the totally different end of the spectrum, the findings of how biological visual system develop to process faces can be used to develop interface for face recognition that are currently being tried at in the field of artificial intelligence and computational sciences. This will have huge implications in civilian infrastructure, security, transportation, and technology.

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