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HOW COLOR SEGREGATION ENHANCES GLOBAL MOTION DETECTION
IN CHILDREN AND ADULTS

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I am submitting herewith a thesis written by Susan Danielle Minniehan entitled "How Color Segregation Enhances Global Motion Detection in Children and Adults." I have examined the final copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Arts, with a major in Psychological Science.



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How Color Segregation Enhances Global Motion Detection in

Children and Adults

A Thesis

Presented for the

Master of Arts

Degree

Austin Peay State University

Susan Danielle Minniehan

August 2000

DEDICATION

This thesis is dedicated to my parents
Joseph and Gayle Minniehan
for their love and support
throughout my educational endeavors

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ABSTRACT

One of the many features of our visual world is that we can perceive objects as moving. Motion perception has been studied in both children and adults using specialized stimuli known as random dot cinematograms, which are presented on a computer. This stimulus is a series of dots that are consecutively presented on a computer screen and create a motion stimulus. Previous research has shown that when color is present in the stimulus, adults can more easily detect global motion. However, little focus has been given to how color affects a child's ability to detect global motion. The present study examined the effect of color on a global motion task in children and adults. The results indicated that when the stimulus was segregated by color both adults and children performed significantly better on the global motion task than when color was not present. Adults performed significantly better than children across both the no-color conditions and color conditions. These findings suggest that color enhances performance on a global motion task for children and adults, but children do not exhibit adult level performance at 8 or 9 years of age.

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CHAPTER I

INTRODUCTION

One of the many features of our visual world is that we can perceive objects as moving. The visual system is sensitive to this motion and processes it in such a manner that we can interpret what the object is, which direction it is moving, and how fast. This is thought to be one of the most important tasks the visual system performs (Goldstein, 1999). It is also thought to be a difficult perceptual problem, for several reasons. The stimuli for motion perception are the retinal image motions produced by object movements in the world. However, an object can be moving while the observer is not, or vice versa. Both situations may produce identical retinal image motions, but only in one case is the object actually moving. Also, nearby objects may be moving or the eye itself may be moving. These factors work independently or combined to alter the stimulus that falls on the eye, but the brain still accurately determines the motion of objects in our world.

Motion perception abilities have been studied extensively. Research in this area has focused on the visual anatomy and physiology responsible for processing motion (Newsome, Britten, & Movshon, 1989), as well as animal and human motion perception (Celebrini & Newsome, 1994; Hiris & Blake, 1995). The following sections include a brief discussion of how motion perception is studied with specialized stimuli, physiological studies using both human and

animals as participants, and the different stimulus features that enhance motion perception.

Our Current Understanding of the Neural Processing of Motion Information

The brain processes motion information in a highly organized way. Motion detection begins in the retina. Two types of bipolar and ganglion cells exist in the retina (Shapley, 1990). Midget bipolar cells project to midget ganglion cells while diffuse bipolar cells send information to parasol ganglion cells. The axons of these cells project from the retina of the eye and are responsible for initiating two distinct visual pathways called the parvocellular pathway (P pathway) and the magnocellular pathway (M pathway). It is the latter, the magnocellular pathway, which is responsible for relaying information about motion.

These pathways are named for the layers of the lateral geniculate nucleus (LGN) of the thalamus where these axons synapse. These pathways continue to area V1 of the visual cortex (Shapley, 1990). After area V1, the M pathway projects to the medial temporal (MT) area of the visual cortex and the P pathway projects to area V4 (Merigan & Maunsell, 1993). Area MT is said to be a “module” for motion processing and MT neurons are known to be direction selective (Merigan & Maunsell, 1993; Movshon & Newsome, 1996). For example, some neurons are sensitive to one direction of motion and are not sensitive at all to the opposite direction of motion.

Motion Perception is studied With Specialized Stimuli

In order to gain a better understanding of motion perception, researchers have developed specialized stimuli that allow them to study only motion and control for other visual cues such as brightness, color, or form (Williams & Sekular, 1984). One type of stimulus used to study motion is called a random dot cinematogram (RDC); (See Figure 1). Similar to a movie, individual frames of an RDC are presented rapidly giving the viewer an illusion of motion. In an RDC small dots appear to move across a computer screen. Under computer control, some of the dots can be instructed to move in the same direction and some may move randomly. The dots moving in the same direction are referred to as "signal" dots, while those moving randomly are referred to as "noise" dots. A common psychophysical task is to have human or animal subjects try to detect a motion signal in noise (Williams & Sekular, 1984).

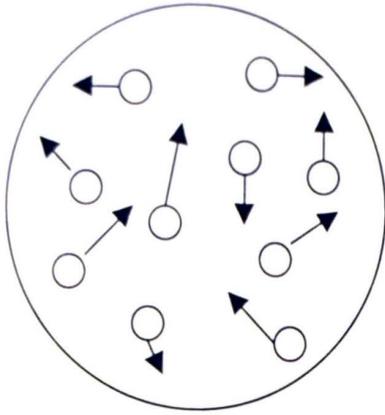
The RDC has become a prominent tool for studying motion detection. One aspect of motion perception that has been studied closely is "global" motion perception. Global motion is described as the ability to see the overall motion of something even if its individual parts move in different directions (Movshon & Newsome, 1992). This perception, one of motion coherence, is identified as "cooperation" or "common fate", as described by Gestaltists. A good, real-world example of global coherent motion is our perception of a large group of birds flying overhead. While each individual bird makes small fluctuations in the direction it is flying, as a group they are perceived as flying in a single direction.

The group shows global or coherent motion.

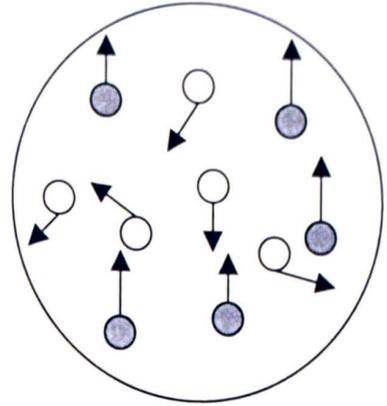
By studying motion perception using these specialized stimuli, researchers have been able to examine the nature of human motion perception and the stimulus characteristics that affect it. This is possible because these artificial dot stimuli can be manipulated in correlation, step-size, dot density, duration, bandwidth, and speed, as described below.

Correlation is defined as the percentage of dots moving in the same direction (Newsome & Pare, 1988); (See Figure 1). For example when all of the dots on the screen move in the same direction they are said to have 100% correlation. However, if none of the dots move in the same direction there is 0% correlation. If correlation is manipulated in an experiment then a correlation threshold can be measured. This threshold is considered to be the smallest amount of correlation needed to detect motion in a given direction (Newsome & Pare, 1988). Research has indicated that humans are quite good at detecting global motion. (Movshon & Newsome, 1992). According to these authors the correlation of the dots in an RDC with optimal values need only to be about 3% to 5% for both humans or monkeys to detect a coherent flow of motion.

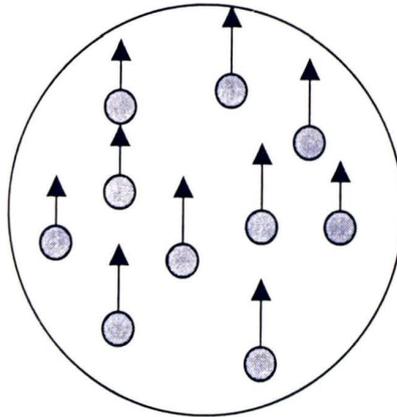
The step-size, density, and duration of the stimulus dots have also been studied (Williams & Sekular, 1984). The step-size of each dot is described as the distance each dot travels between frames of the RDC (measured in degree of visual angle). Dot density is the number of dots in the display. Stimulus duration



RDC= 0% Correlation



RDC= 50% Correlation



RDC= 100% Correlation

Arrows= direction of moving dots

● = signal dot

○ = noise dot

Figure 1. Examples of the global motion stimuli (RDC) at 0%, 50%, and 100% correlation

is defined as the number of frames seen by a participant during the experiment (Williams & Sekular, 1984).

Motion Perception: Behavioral Studies Using Animals

These specialized stimuli have been used in studies of animal and human motion processing. A study by Newsome, Britten, and Movshon (1989) examined the sensitivity of neurons in monkey area MT using RDC's. The researchers determined that not all of the direction selective neurons in area MT were needed to perceive motion; rather a small number of these available neurons can do the job. The study developed by Newsome, et al. (1989) is important because the researchers tested both individual neurons of monkeys and the behavioral ability of the monkey to perceive motion, simultaneously. The findings suggested that a small set of neurons were equal to or did better than the whole monkey when detecting motion and supports the idea that there are select neurons in this area of the visual cortex which respond vigorously to motion (Newsome, Britten, & Movshon, 1989).

Another study of the motion sensitive neurons in MT was performed by Movshon and Newsome (1992). The authors predicted that when lesions (using an injection of ibotenic acid) were made in MT they would have a profound impact on the motion perception abilities of the monkeys. Using the RDC, the authors found that the monkeys' ability to detect motion decreased substantially when lesions were present in area MT. The experiment supports the findings presented by Newsome, Britten, and Movshon (1989), which concluded that only

a small number of neurons were actually needed to make perceptual decisions of motion detection.

Instead of using lesions to assess the MT area, scientists have also used electrical stimulation (Movshon & Newsome, 1992; Salzman, Britten, & Newsome, 1990). In the study by Movshon and Newsome, groups of neurons in area MT were stimulated by the researchers and found to be directionally selective. Then, remarkably, these researchers presented motion stimuli and electrically enhanced the cells' response. For example, if the monkey could see global motion at 50% correlation without stimulation of the neurons, then the researchers set the correlation at 25% instead of 50% and stimulated particular neurons to emit action potentials equal to 50% correlation. The monkeys were able to see movement equal to 50% correlation, even though the actual correlation was only 25%. By stimulating the neurons the monkeys were able to detect global motion at lower correlations. This is a stunning method for further demonstrating that it is the activity in these neurons that is responsible for the monkey's motion perceptions.

Motion Perception: Behavioral Studies Using Humans

The previously stated research has provided a better understanding of the physiological underpinnings necessary for motion detection, particularly global motion detection. This research has also provided an understanding of motion perception in animals as identified by the underlying anatomy and physiology. However, it is also important to understand how humans perceive motion.

Researchers have investigated human motion detection using the same RDC stimuli that have been used in animal studies.

As stated earlier humans are quite good at detecting global motion and need only a minimal amount of correlation (3%-5%, under optimal conditions) to do so (Movshon & Newsome, 1992). However, another important and converging line of research has focused on individuals with impaired motion perception abilities. Some of the most interesting studies investigating impaired motion perception have been directed at children and adults with dyslexia.

Dyslexia is a type of reading disorder and is characterized by several features, which may include confusing different letters or sounds (while speaking or reading) and having difficulty with organizational skills. Researchers have gained a better understanding of some of its underlying causes by studying the visual system of these individuals. A review by Stein and Walsh (1997) proposes that the M pathway is vital to visual tasks, specifically motion. The authors note that impairments in this area may result in the complications exhibited by those with dyslexia such as blurred letters or transposing letters while reading.

One study investigated male subjects with dyslexia and found that they performed poorly on a motion sensitivity task using a random-dot display (Eden, et al., 1996). The authors concurrently measured activity in the M pathway (area V5/MT) by using magnetic resonance imaging (MRI). Males with dyslexia showed less activity in this area of the M pathway. Therefore, they suggest that

these deficits in motion perception are small in individuals with dyslexia.

In another study Cornelissen, Richardson, Mason, Fowler, and Stein (1995) report that children with dyslexia have higher motion correlation thresholds on a coherent motion task using RDC than children without dyslexia. In another study, Cornelissen, Hansen, Hutton, Evangelinou, and Stein (1998) studied a group of children using a coherent motion task and a reading task to determine if a relationship existed between the two. The authors hypothesized that the M pathway might be impaired, which would lead to the incorrect encoding of letters when reading. These researchers found higher motion correlation thresholds in children with dyslexia. This supports their theory that a relationship exists between a coherent motion task and a reading task and the magnocellular pathway is important in visual processing and motion detection in humans.

The previously discussed experiments support the animal work which has found that motion perception is dependent upon the M pathway and the neurons sensitive to this motion perception are located in area MT. Studying both normal participants and those with sensory deficits or reading disorders has prompted further studies of motion perception, particularly how this ability develops.

Human Motion Perception Develops Early

The way in which motion perception abilities change over time as a result of normal development has also been studied. The current literature reveals that infants as young as six weeks old can detect motion (Wattam-Bell, 1996a).

Wattam-Bell (1996a, 1996b), in two separate experiments, investigated the ability of one month olds to detect global motion using two dependent measures, habituation and preferential looking. In the author's first experiment infants younger than six weeks old were tested on their ability to discriminate motion direction and their ability to detect coherent motion using an RDC. For example, the researchers had a task where the infants had to detect only the direction of movement of the stimulus and a task where the infants had to detect if coherent motion was exhibited. The results indicated that under six weeks of age children cannot identify motion direction, but can identify that the motion stimulus exhibits coherency (Wattam-Bell, 1996b).

Banton and Bertenthal (1996) also studied the ability of six-week olds to detect motion. In this study the ability to detect motion was also tested using an RDC and was found to be evident in six-week olds. However, the ability is still immature because it did not reach adult levels of performance. However, these results provide good evidence that motion perception begins developing very early in life.

This ability is still not mature at three months of age (Wattam-Bell, 1994). The author used RDC to determine the threshold of the infants on the global motion task. Infants reached correlations of 50%, while adults performed better reaching correlation levels of only 5%-7%.

While it is necessary to understand how motion detection matures in infants it is also important to understand how it continues to develop and at what

age children can perform similarly to adults on a motion detection task. Children have been studied with respect to global motion using different methods and it is still unclear when this ability to detect global motion first develops.

According to Hollants-Gilhuijs, Ruijter, and Spekreijse (1998b) children between the ages of 6 and 16 have higher thresholds than adults on a motion task in which they identify the location of the gap in a Landolt ring. This ring is a 360 degree ring with a gap located at the top or bottom of it. However a study by Schrauf, Wist, and Ehrenstein (1999) indicated that children around the age of 15 performed similarly to adults (higher number of correct responses) when presented with a random dot stimuli, in which they also identified the gap in a Landolt ring. The authors tested 400 participants and found that for this specific task older children exhibited improved performance.

However, a study by Raymond and Sorensen (1998) finds that children around the ages of nine or ten perform similarly to adults on a global motion task. These children were tested using a RDC. They were compared to adults and found to perform nearly as well. This led the authors to conclude that global motion perception is just as mature in 9 and 10-year olds as it is in adults.

These three studies, while different in methodology, indicate the need for further investigation into the age at which a child's ability to detect global motion is similar to an adult's. These differences have laid the foundation for the present study.

Physical Stimulus Features Enhance Figure/Ground Segmentation in Global Motion Perception

Research has found that thresholds are quite low for both humans and animals when detecting motion coherence (Movshon & Newsome, 1992). What would occur, however, if the noise dots or the signal dots were further segregated by an additional stimulus feature?

One stimulus feature that has been used to segregate signal and noise dots is color. According to a review by Dobkins and Albright (1993) the role of color in motion processing has been investigated to test the theories concerning the functions of the M and P pathways. As stated earlier in this paper the parvocellular pathway is known to aid in color detection, while the magnocellular pathway involves motion detection. According to the authors monkeys were tested using a colored (red and green) moving grating stimulus. MT neurons were stimulated and exhibited improved performance with respect to direction discrimination, which indicated that color could aid the detection of motion.

Croner and Albright (1997) tested human participants using an RDC with different hues and luminances. Their findings indicated an improvement (an average of 6-fold) in global motion detection when the signal and noise dots were different colors (e.g. signal dots were red and noise dots were green or vice versa).

However, according to Edwards and Badcock (1996) color may not have such a large effect. In their study thresholds where two different colors were

used were similar to thresholds where only one color was used. They report that these findings may indicate that the participants' performance on the global motion task was not enhanced when the dots were segregated by different colors. The authors state that the differences between their study and the study by Croner and Albright may be the result of different methodology. In the study by Edwards and Badcock (1996) the signal dots and noise dots were not completely separated by different colors, while Croner and Albright (1994) did separate the noise from the signal dots with two different colors.

If the P and M pathways are parallel, how could color influence motion perception? Dobkins and Albright (1993) suggest that these two paths may indeed share some information as they make their way through the visual cortex. Because different areas of the visual cortex develop at different rates and different behavioral tasks develop at different ages, an interesting question becomes, is the effect of color segregation on global motion similar for children and adults?

Hollants-Gilhuijs, Ruijter, and Spekreijse (1998a) have shown that children between the ages of 6 and 16 do not perform as well as adults (higher correlation thresholds) when detecting the gap in a motion-defined Landolt ring. In this study the minimum color differences between the Landolt ring and the background were measured for three different colors (blue, red, and green). The authors note that this ability to detect small color differences did increase with age.

The Present Study

The previously stated research has provided a better understanding of motion perception, how it develops, the stimuli used to study it, and the factors that influence it (e.g. color, coherence, etc.). As mentioned above Raymond and Sorensen (1998) reported that the development of global motion perception is mature around the age of nine or ten. This study investigated how color affected global motion perception and whether the enhancement seen in adults was also present in children and if so, to what magnitude.

There are four hypothetical outcomes presented in Figure 2. The first hypothetical outcome shown in Panel A is that performance would improve similarly for children and adults when color was present, with adults performing slightly better across both conditions. The second is that adults would perform better than children in the no-color condition and that color would enhance adult performance, but not the children's. The third hypothesis was that in the no color condition children and adults would perform almost equally, but in the color condition adults would exhibit an improvement in performance while the children would not. The fourth was that performance would improve at the same rate for both children and adults in both the no color and color conditions, with both groups performing at near equal levels.

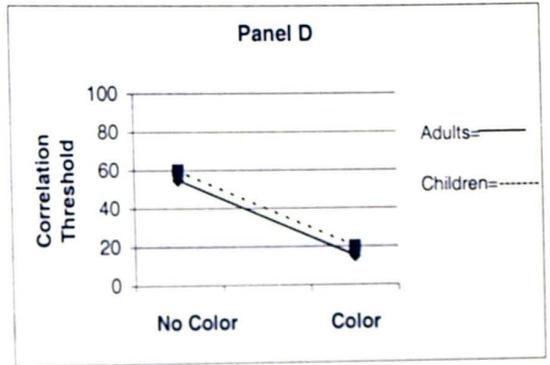
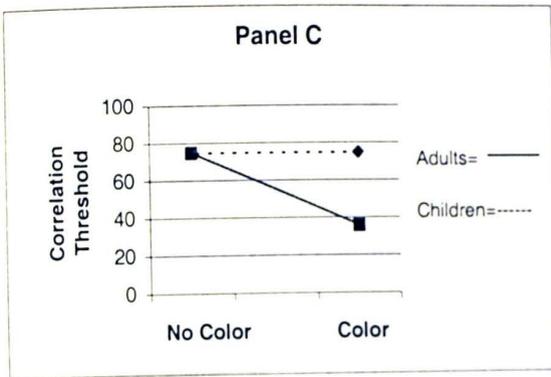
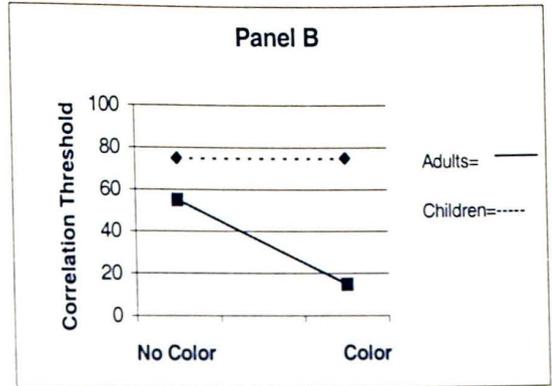
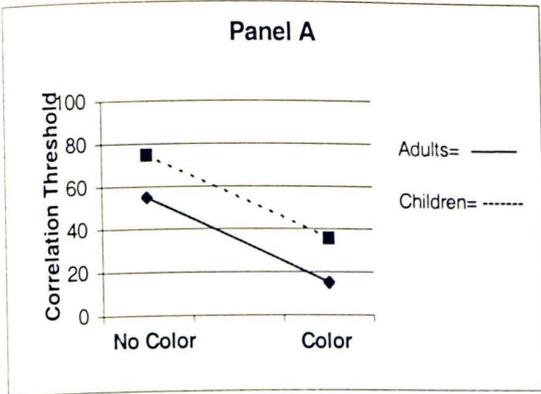


Figure 2. Representation of Hypotheses 1 (Panel A), 2 (Panel B), 3 (Panel C), and 4 (Panel D).

CHAPTER II

METHOD

Participants

Twenty-three adults and 20 children participated in this study. The adult participants were undergraduate students from Austin Peay State University. Eleven children between the ages of 8 and 9 (3rd graders) were recruited from the Clarksville Academy in Clarksville, Tennessee and 9 were the children of undergraduate students at Austin Peay State University.

Apparatus & Stimuli

A Macintosh computer (iMAC) was used to present the stimuli to the participants and record the data. The stimuli consisted of two RDC's, presented simultaneously. One stimulus was on the left side of the screen and one was presented on the right side of the screen. Of these two stimuli, one contained only noise (randomly moving) dots, and the other contained noise and signal dots at a correlation determined by the psychophysical method discussed below.

For one part of the experiment the noise and signal dots were white on a black background and only stimulus correlation could be used to differentiate the two RDC's. In the other part of the experiment the noise dots were red and the signal dots were white and both color and correlation could be used to differentiate between the two RDC's. In this part of the experiment each RDC contained the same proportion of red and white dots.

Psychophysical Method

Each participant was asked to determine which of two stimuli (left or right) contained coherent motion using a two-alternative, forced-choice method of discrimination. Each participant viewed two motion stimuli and selected the one stimulus that exhibited coherent motion. Thresholds for each participant were determined using a 2-down, 1-up staircase procedure where the stimulus presented on a given trial was dependent on the participant's response on the previous trial. In the 2-down 1-up staircase when a participant responded correctly twice in a row the correlation decreased and the task got harder. However, if the participant gave an incorrect response the correlation increased and the task got easier. The procedure ended when the participant made twelve reversals (e.g., decrease to increase). The mean of the last eight reversals was averaged together to determine a participant's threshold. Each participant completed two staircases for each experimental task (color and no-color).

Procedure

This study was a mixed 2X2 experimental design with both between and within group comparisons. There were two participant groups that included the undergraduates and the 3rd grade children. There were also two motion stimuli that included one with color and one without.

Each participant was asked to read and sign an informed consent (undergraduates and parents) or assent (child). After receiving directions from the researcher each participant sat in front of the computer monitor at a distance

of one meter. The participant was then presented with the global motion stimuli and asked to determine which of the two stimuli shown exhibited global motion, either the left or the right. The researcher recorded the participant's responses on the computer. For the purposes of this study the conditions (no color vs. color) were counterbalanced. A participant completed either two staircases of the stimulus without color first, then two staircases of the color stimulus or vice versa. Each participant completed four staircases. For each participant the total length of testing was approximately 30 minutes.

CHAPTER III

RESULTS

Two staircases were collected on each participant for each condition. The individual staircases for each group and condition are included in the Appendix in Figures 4-7. The two staircases for each participant were averaged together. The standard deviation and standard error were also calculated for each condition and for each group and these data are shown in Figure 3.

An analysis of variance (ANOVA) was computed to determine the existence of an interaction between the groups and conditions. For example, did the effect of color on the participants' thresholds differ for children and adults? The results indicated that no interaction was present, $F(1,41) = .111, p = .740$.

The two conditions (no color vs. color) were also compared and were found to differ significantly. The results indicated that when color was present both children and adults performed significantly better (lower thresholds) on the global motion task, $F(1,41) = 16.239, p = .005$.

To determine if statistically significant differences existed between each group (i.e., adults and children) and across conditions (i.e., no color vs. color) an ANOVA was again computed. Adults performed significantly better (lower thresholds) than children at detecting global motion, $F(1,41) = 5.30, p = .027$.

Color Segregation and Global Motion

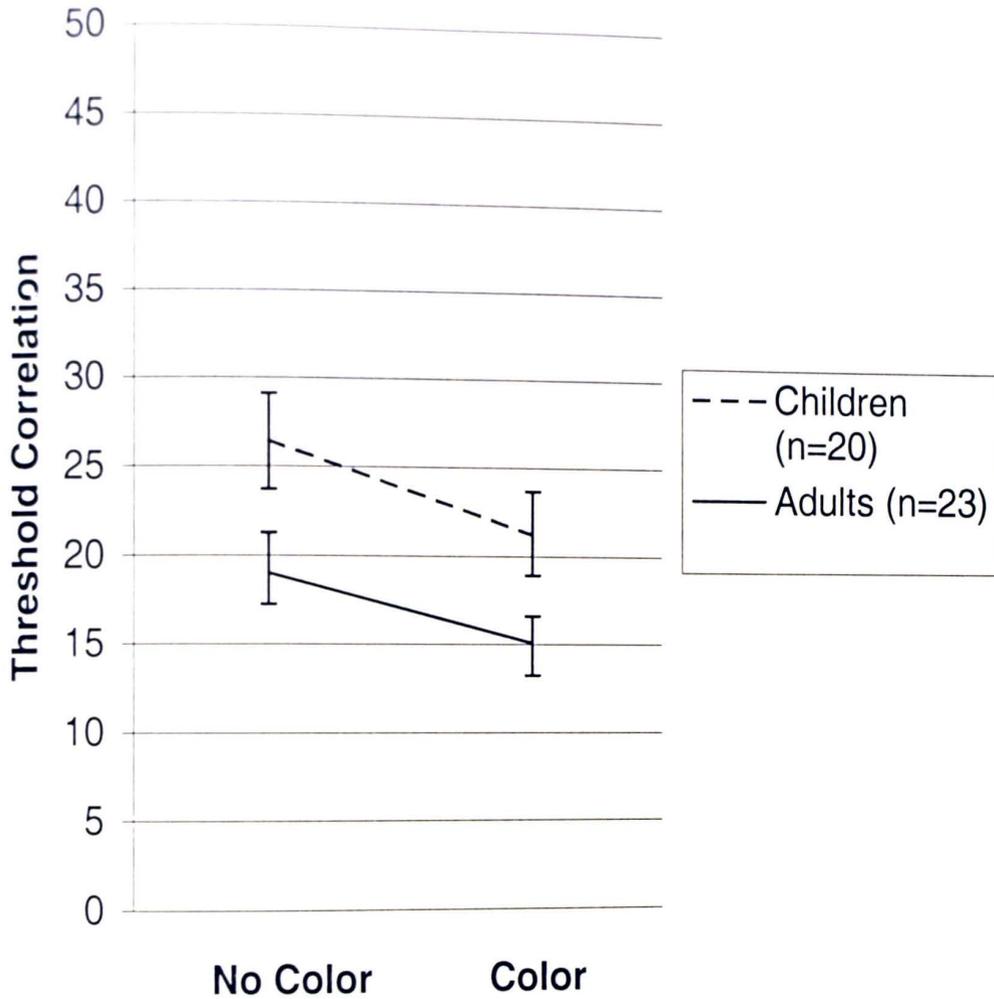


Figure 3. The thresholds for both children and adults across both conditions. Performance was better (lower thresholds) in the color condition for both groups. The results indicate that the adults had lower thresholds (performed better) than the children for both conditions.

Chapter IV

Discussion

The present study investigated the differences in global motion perception between adults and children and the effects of color segregation on a global motion stimulus. The results indicated that performance was significantly better in the color (versus the no-color) condition for both groups and the children did not perform as well as adults over all. These findings support the hypothesis that stated that performance would improve similarly for children and adults when color was present, with adults performing significantly better across both conditions. This was the hypothetical outcome presented in Figure 2, Panel A.

This enhanced performance is consistent with the findings of Croner and Albright (1997) that color can aid in motion detection, but not to the degree (6-fold) that the authors reported. The results are also consistent with the findings of Dobkins and Albright (1993). These two authors tested area MT of monkeys and found that color could aid in motion detection. While the present study focused on humans the findings indicate that color can also aid in human motion detection, as well.

Raymond and Sorenson (1998) found that children around 9 or 10 years of age did perform similarly to adults on a global motion task. The present study found that children did not perform as well as adults on the global motion task. The differences between the study by Raymond and Sorenson and the present

study may involve differences in methodology. For example, the participants in the study by Raymond and Sorenson were presented a global motion stimulus that moved left or right not up as in the present study. Also, participants were seated closer to the stimulus (50cm vs. 100cm for the present study) in the Raymond and Sorenson study. It is unclear, however, if these differences in methodology do have a substantial impact on the outcomes of the two studies

However, the threshold correlations for the adults in both conditions were higher for the present study and for Raymond and Sorenson than for Croner and Albright (1997). These threshold differences may be due to practice. The participants in the study by Croner and Albright were able to practice for two weeks before the start of the experiment, while the participants in the present study and those in Raymond and Sorenson's were not given practice.

This experiment focused on two important factors. One was to determine the effects of color on a global motion task. The second was to determine if children at age 8 or 9 performed at similar levels when compared to adults while completing a global motion task (including both color and no color). For example, have children developed this skill for detecting global motion with both color and no color?

The present study indicated that children indeed possess the skills to detect global motion and exhibit improved performance when color is present. In fact, the amount of improvement is similar to that seen in adults. However, the results indicated that perhaps this motion perception skill may not be fully

developed at the age of 8 or 9. It is with this information in mind that further research may be necessary to determine at what age this is fully developed and gain a more thorough understanding of global motion perception in both children and adults.

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APPENDIX

Staircases for Adults (n=23) No Color

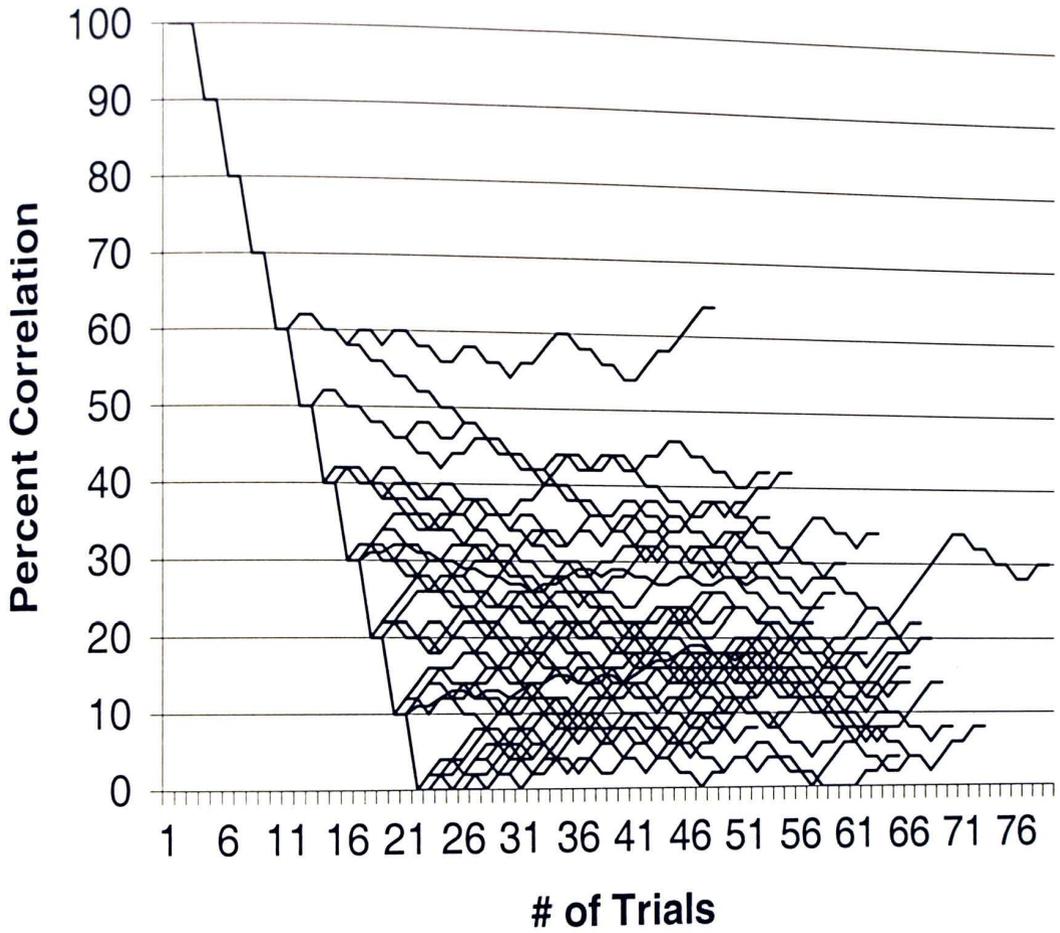


Figure 4. The individual staircases for adults (n=23) in the global motion task with no color. Thresholds are represented by the percent correlation.

Staircases for Adults (n=23) Color

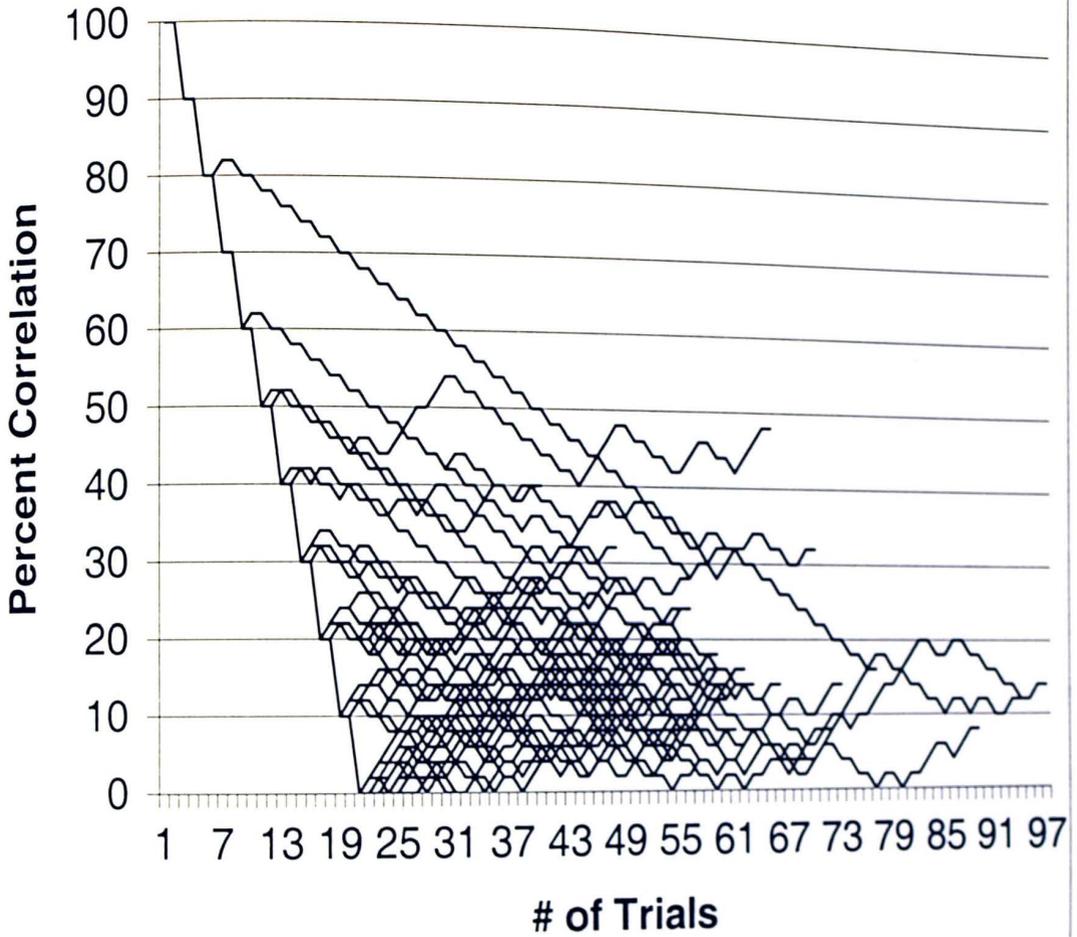


Figure 5. The individual staircases for adults (n=23) in the global motion task with color. Thresholds are represented by the percent correlation.

Staircases for Children (n=20) No Color

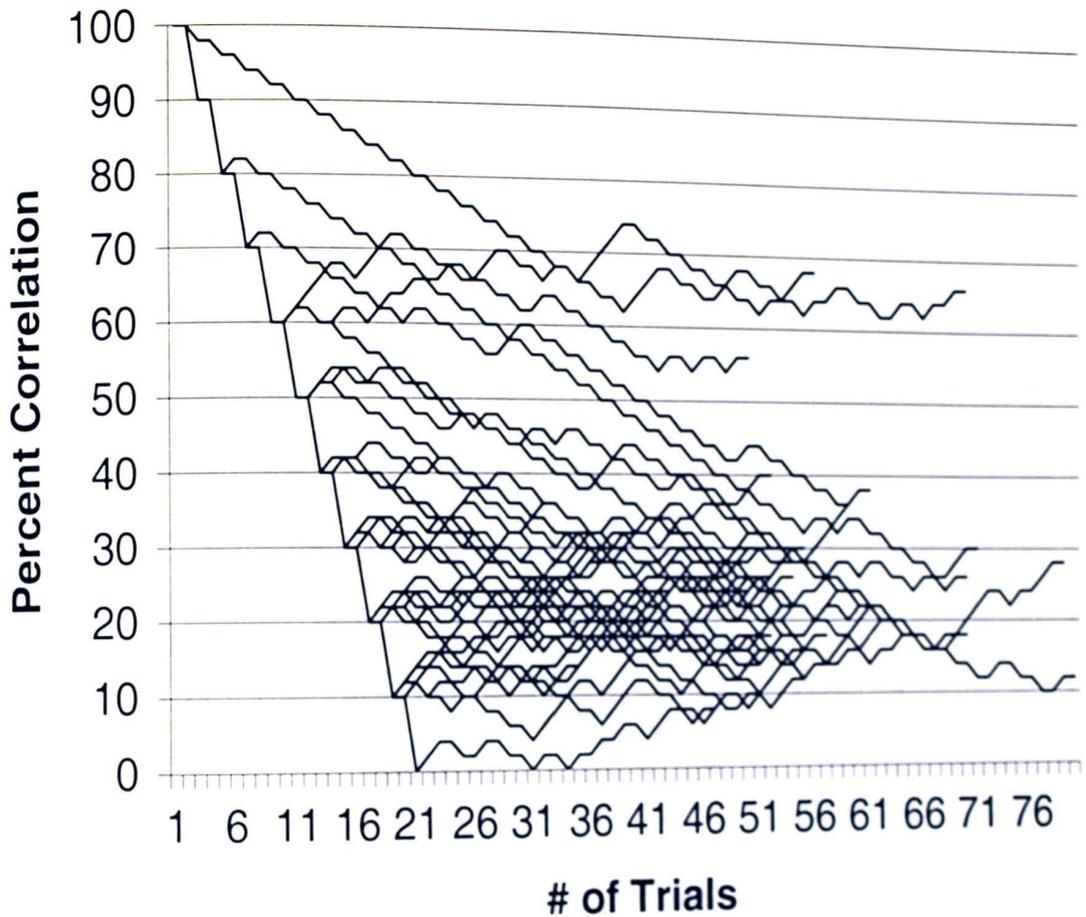


Figure 6. The individual staircases for children (n=20) in the global motion task with no color. Thresholds are represented by the percent correlation.

Staircases for Children (n=20) Color

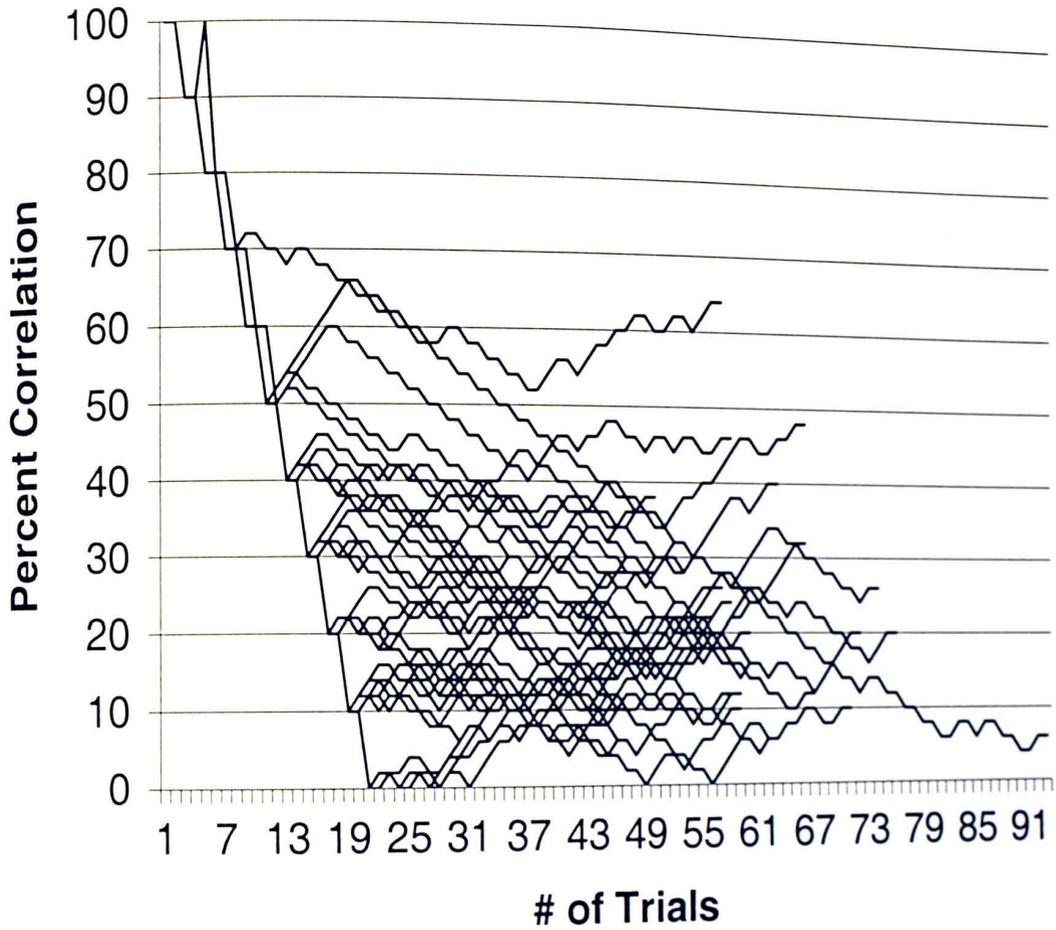


Figure 7. The individual staircases for children (n=20) in the global motion task with color. Thresholds are represented by the percent correlation.

VITA

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