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An Investigation of the Effects of Hysteresis on the Rotation Percept

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AN INVESTIGATION OF THE EFFECTS OF HYSTERSIS ON THE ROTATION PERCEPT

by
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A thesis submitted to the faculty of The University of Mississippi in partial fulfillment of the requirements of the Sally McDonnell Barksdale Honors College.

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ABSTRACT

MAXIMILIAN JAMES SHUMAKE: An Investigation of the Effects of Hysteresis on the Rotation Percept
(Under the direction of Nicolaas Prins)

Although much research has been done on the role of hysteresis in apparent motion displays, no research has investigated the effects of hysteresis for rotary motion. The present experiment sought to determine and quantify the effects of hysteresis on the rotation percept. Participants viewed two types of apparent motion stimuli, which consisted of tokens appearing to move in a clockwise, counterclockwise, or chaotic fashion. One of the displays slowly changed from favoring a percept of rotation to a percept of non-rotation and vice versa. We fit the data using a logistic function and compared the point at which the direction of motion appeared to switch between chaos and rotation. Our research suggests that hysteresis only had a significant effect on type of motion perceived when the stimulus was moving from "chaos" to rotation. Based on these findings, we conclude that our visual system does not contain low-level motion receptors coded for rotary motion and thus, the percept of rotation is not subject to hysteresis.

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1. Introduction

Though it seems like a simple task, motion perception is an extraordinary and complex process that is vital to our survival. As evidenced in the animal kingdom, an animal's ability to perceive motion is a fundamental tool required for detecting prey, predators, and possible mates. Many animals use the strategy of becoming completely still in the presence of a threat, as shown by the "deer in headlights" phenomenon. Similarly, predators also use this tactic when hunting their prey. Some lay still until the prey comes to them, while others move slowly, sometimes continually stopping, when stalking their prey. Animals that use camouflage as a means of protection are also strongly influenced by motion. The art of camouflage is to exploit Gestalt principles to erase borders, but when that animal moves the camouflage's effect is significantly reduced leaving itself exposed and vulnerable to predators (e.g., Wolfe, etc.). For example, a snake that blends in with the ground would be very difficult to spot by an aerial predator if stationary, but once the snake starts to move its camouflage effect is greatly diminished. The human's visual system for detecting motion has evolved into a combination of sophisticated mechanisms, which provide us with important information about our surrounding environment.

Motion is also a key component of depth perception as demonstrated by the motion parallax. This depth cue is created because objects at different distances will shift positions at different rates on the retina as one moves one's head (e.g., Wolfe, etc.). For example, when you close one eye your ability to perceive depth declines but is then regained when you move your head back and forth. This is why animals that have a small visual field of overlap between both eyes, such as the rabbit and the chicken, have a hard time perceiving depth and must constantly move their head to aid in depth perception (Hughes, 1977).

While it has been known that the human visual system is comprised of multiple motion detection processes, it was not until fairly recently that its functional architecture was more clearly understood. Braddick (1974, 1980) first proposed that our visual system is comprised of two different systems consisting of short-range and long-range processes. The short-range process occurs at an early stage of motion detection and is responsible for the perception of movements with a relatively short displacement. Short-range motion is carried out by neurons that are selectively coded for certain directions. The long-range system functions at a later stage in our visual system and is responsible for perceiving movements of a larger displacement. Long-range motion detection is more intelligent and allows for top-down interpretations of the scene. (Braddick, 1980)

Later research done by Lu and Sperling (1995) suggests that there are actually three motion detection systems that work independently from one and another. These three systems are responsible for detecting what they termed first-order, second-order, and third-order motion. First-order motion is motion characterized by changing patterns of luminance. Second-order motion refers to motion defined by moving patterns of contrast or texture. Both first-order and second-order motion systems are monocular, fast, and sensitive (Lu & Sperling, 1996). Monocular refers to the fact that motion can be perceived only if consecutive motion frames are presented to the same eye, which suggests that perception occurs very early in the visual system before information from both eyes converge. Third-order motion involves feature tracking and is relatively slow. Because third-order motion involves tracking features over time it is very versatile and is also affected by attention (Lu & Sperling, 1995). Third order motion is binocular, meaning motion is perceived regardless of whether the scene is presented to one or both eyes, suggesting that perception occurs later in the visual system.

Sensation and perception is driven by two theories, top-down and bottom up processing. Simply put, bottom-up processing occurs by first gathering low-level information and piecing it together to form a bigger picture or mental representation. Top-down processing states that higher order expectations from past experiences or concepts drive our perception and behavior. Lu and Sperling (1996) found that both "top-down" and "bottom-up" processes can influence motion perception.

Our visual system is also capable of perceiving motion when no actual motion occurs, a phenomenon called apparent motion. This illusion of motion is created when an object's location in one frame is different than its location in the next frame, and the frames are presented in the right spatiotemporal sequence. Even though the objects are independent of each other, the observer perceives motion of a single object (e.g., Wolfe, etc.). Many times our brain cannot differentiate true motion from apparent motion because motion-sensitive neurons respond to both identically (e.g., Wolfe, etc.). Apparent motion is everywhere around us including television, movies, and animations. Although apparent motion is a fundamental mechanism we use to perceive motion, certain situations can cause problems for the visual system as discussed below.

Arguably the biggest goal for our visual system is to try and perceive a three-dimensional world by interpreting information from a two-dimensional surface on the retina. Because of this incongruence, information received from the retinas cannot "preserve the full dimensionality of the physical world" (Dawson, 1991, p.569). This underdetermination can also be caused when the information we get from the retina is consistent with multiple possible interpretations from the physical world. An example of this underdetermination is the motion correspondence problem.

Braddick (1974, 1980) found that when objects are displaced a relatively large distance, our visual system uses the "long-range" system. Such is the case when we try and perceive apparent motion, but what happens when an object has two possible destinations from frame one to frame two? How do we assign correspondence? Although our visual system processes many variables when trying to assign correspondence, the overriding factor is displacement, also called the nearest neighbor principle (Ullman, 1979). Ullman (1979) found that the visual system favors assigning correspondence to objects that have the shortest displacement over larger displacement. Prins and Juola (2001) demonstrated that it is actually the displacement on the retinal image rather than actual 3-D displacement that has the larger effect when determining the correspondence.

Much research has also been done to see how other variables affect the correspondence problem in a bistable or ambiguous stimulus. In a bistable stimulus, an object has multiple possible destinations from frame to frame, yet all potential matches are equally possible. Using these types of stimuli has allowed researchers to explore how other variables affect the motion correspondence problem. Burt and Sperling (1981) discovered that when there are multiple possible interpretations for a scene, they compete with one another for precedence.

A common example of a bistable motion stimulus is a square with dots located in opposite corners in one frame and in the other corners in the next frame. When the frames are alternated the dots or “tokens” either appear to move vertically or horizontally because each is equally possible, as shown in Figure 1.

Bistable Motion Quartet

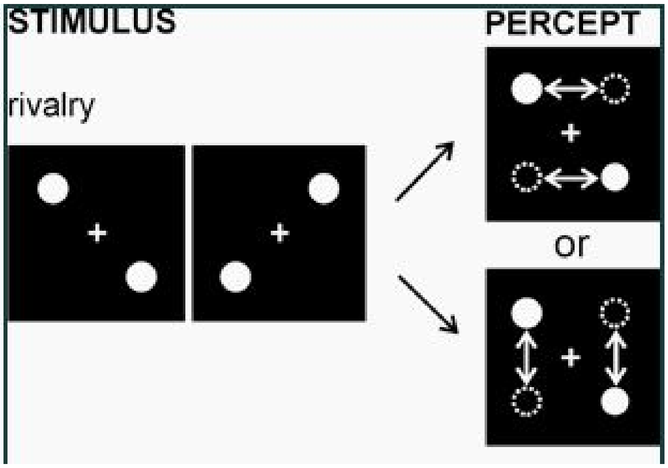

Figure 1. Bistable motion quartet. Adapted from “Watching the brain make up its mind about an ambiguous stimulus,” by D. Bownds, 2006.

Because each possible interpretation has the same displacement, the nearest-neighbor principle is no longer a factor, and other variables like color, depth, and spatial frequency have a more significant influence in determining the direction of motion that is likely to be perceived (Green & Odom, 1986; Caelli, Manning, & Finlay, 1993; Green, 1986).

Another interesting feature of this bistable motion quartet is that once a direction of motion is perceived, it is maintained and thus does not fluctuate rapidly between the other possible interpretations. For example, if vertical motion is perceived in the figure above, our visual system will hold on to his percept before switching to perceiving horizontal motion. This is believed to be due to a phenomenon called hysteresis, which is a form of memory that involves neural networks in the brain working cooperatively (Williams, Phillips, & Sekuler, 1986). Hysteresis can aid in motion perception because it allows our visual system to stabilize an ambiguous stimulus presentation. For example in Figure 1, hysteresis occurs when groups of motion detectors that are directionally selective for vertical motion facilitate other neurons selective for similar directions, while also suppressing motion detectors selective for competing directions (Hock, Kogan, & Espinoza, 1997; Chang & Julesz, 1983; Williams & Sekuler, 1984). This is why when presented with a bistable stimulus like the one shown in Figure 1, we perceive a single, stable direction of motion. This stabilization occurs because the neural networks coded for the more vertical orientation are excited, while also suppressing neurons responsible for perceiving more horizontally oriented motion.

This cooperative neural network also allows one to look at a scene containing a myriad of individual movements and perceive a mean direction vector, as shown in our ability to judge the direction the wind blows the leaves of trees "despite the random variation of the movement from one leaf to the next" (Williams, Phillips, & Sekuler, 1986, p.255). We suggest that hysteresis is most likely the reason that when presented with the bistable apparent motion stimulus, either vertical or horizontal motion is perceived but never rotary motion. Perceiving rotary motion would require successive switching between perceiving vertical and horizontal motion, which would go against the idea of hysteresis.

Our aim for this study is to investigate whether the percept of rotation is also subject to hysteresis. We will compare different types of apparent motion stimuli in order to determine and measure the effect of hysteresis. If there is evidence that hysteresis is experienced for the rotation percept, we can argue that our visual system contains low-level visual receptors that are capable of not only detecting simple motion, like vertical and horizontal directions, but also rotary motion, and it is not simply a combination of the two. If hysteresis is not experienced, we can argue that our visual system does not contain low-level rotation receptors. We hypothesize that hysteresis will have no effect because we believe the perception of rotation occurs at a later stage in the visual system where hysteresis has no effect.

2. Methods

Stimulus presentations consisted of two tokens positioned on an imaginary line, and between consecutive frames the imaginary line was rotated by some degree, as shown in Figure 2.

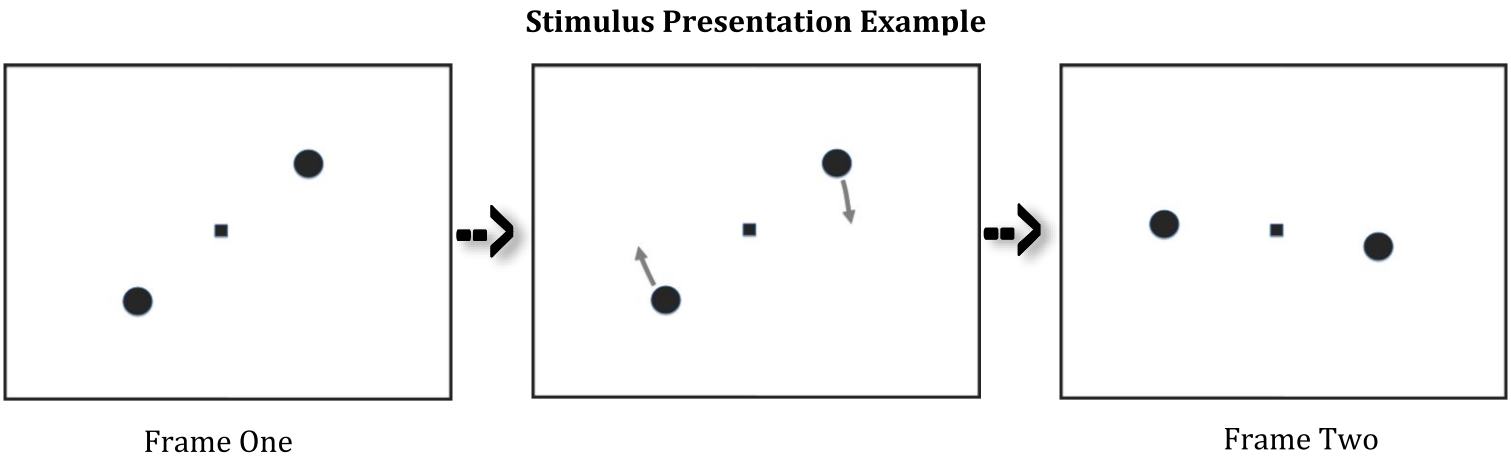

Figure 2. Stimulus Presentation Example

This would lead to the perception of one of three kinds of motion: clockwise, counterclockwise, or chaos (motion that is random, inconsistent, or lacking a uniform direction) depending primarily on the angle of the rotation. The task for these stimulus presentations was to report which type of motion was perceived.

We used two different types of stimuli in our experiment characterized as either dynamic or static, which refers to the token's angle of rotation from frame to frame. For the static stimuli, the token's angle of rotation remains constant, and for the dynamic trials, the token's angle of rotation increases incrementally each time between frames. An example of a static stimuli would be two token's that rotate by 18 degrees between each frame, and an example of a dynamic stimuli would be two tokens initially rotating by 18 degrees, then 20 degrees, then 24 degrees, then 30 degrees…etc. (if the angle of increase was 2 degrees).

For the static stimulus trials, the two tokens were rotated by a constant angle leading to the perception of either clockwise, counterclockwise, or chaotic motion. The task for the participants was to press a corresponding key depending upon the type of motion perceived. There were 25 possible angles of rotation spaced evenly between 18 and 162 degrees (inclusive). The presentations had a frame duration of either 167 ms or 250 ms. Thus, with 25 angles x 2 frame durations x 5 repetitions we had a total 250 trials, and the trials were randomly presented.

The dynamic stimuli consisted of tokens that had an initial rotation angle of 18 degrees and a final rotation angle of 162 degrees, and the angle of rotation increased in increments of either 2 or 6 degrees between frames. The initial angle of rotation remained at 18 degrees until the participant made a response indicating which type of motion they perceived. The first angle of rotation was either to the left or to the right (this was randomly assigned but not separately analyzed, since no effect was expected); thus, the tokens initially appear to move in a clockwise or counterclockwise direction. As the angle of rotation increases the tokens eventually appear to move chaotically, and then finally appear to move in the opposite direction of the initial clockwise or counterclockwise percept. The task for the participants was to press the corresponding “clockwise”, “counterclockwise”, or “chaotic” key once as soon as they perceived that type of motion.

The reason the tokens appear to “switch” direction as the angle of rotation increases is because one, when the angle of rotation reaches 90 degrees, the tokens appear to be on the corners of a square (of any orientation), and rotation by say 100 degrees clockwise, is identical to counterclockwise rotation by 80 (i.e., 180 – 100) degrees. Thus the reversal of apparent direction occurs at angles greater than 90. When neither direction of rotary motion is perceived, the token’s motion is like that explained in Figure 1, but it is perceived as chaotic because the square continuously changes its orientation.

We tested both types of stimuli with frame durations of either 167ms (1/6 s) or 250 ms (1/4 s). The dynamic stimuli had two different frame durations, two possible angles of increase, and 10 repetitions for each condition giving us a total of four experimental conditions and 40 trials.

We tested 7 participants who each completed 8 testing sessions, which consisted of 250 static stimuli presentations and 40 dynamic stimuli presentations. All stimuli were presented on a Mistubishi DiamondPro monitor driven by a VSG2/5 Cambridge Research Systems graphics card, and the refresh rate was 120 Hz. The participants sat 1 m away from the monitor. The radius of the imaginary circle on which the tokens were presented was 1.5 degrees of visual angle. The diameter of the tokens was .3 degrees visual angle.

3. Results

After all seven participants completed 8 testing sessions, a psychometric function was fit for each participant's static and dynamic data. However, SC's data was not included in the final analysis due to an apparent lack of testing understanding (further analysis found no change in pattern of results if included). Specifically, we fitted a logistic function using a maximum-likelihood criterion. This function fit a line for the summed data points for each condition (dynamic and static), while also determining the threshold and slope. Fits were performed using the Palamedes Toolbox (Prins & Kingdom, 2009).

Figure 3, which is solely used for explanation purposes because we eventually collapsed the data points, is an example of a static graph for participant AEM for the 250 ms frame duration condition. The thresholds, as shown by the dotted lines, represent the angle value where 50% of time the participant perceived a direction of motion (either clockwise or counterclockwise). The blue line represents the proportion of clockwise rotation perceived, and the red line represents the proportion of counterclockwise rotation perceived depending upon the token's angle of rotation. The black line represents the perception of chaotic motion and is greatest when the token's angle of rotation is about 90 degrees.

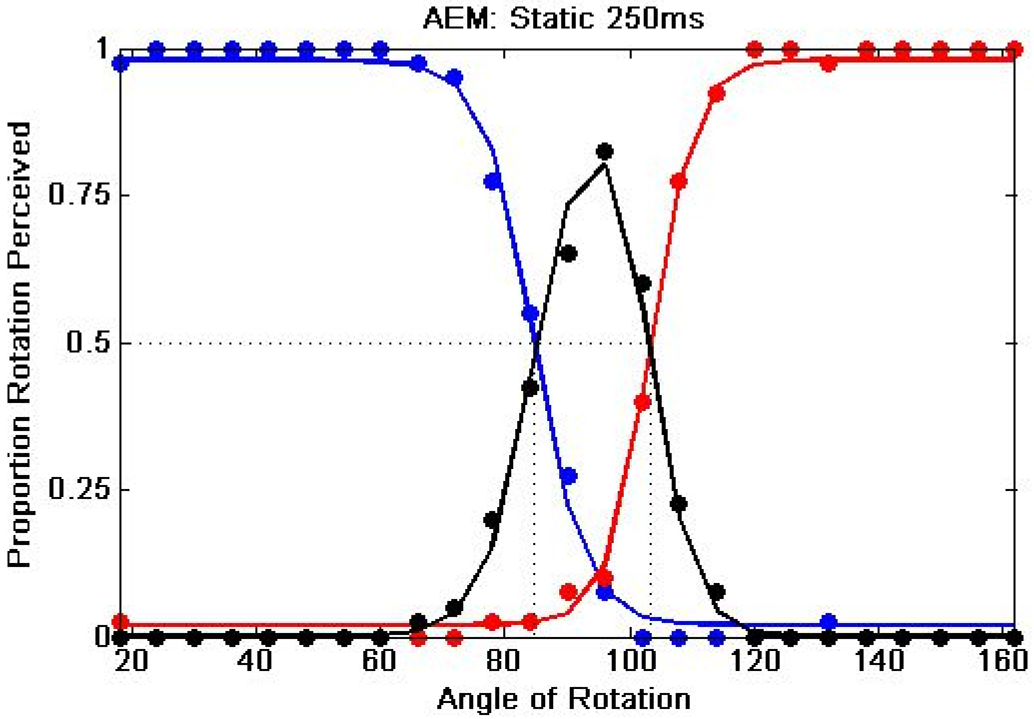

Figure 3. AEM Static Graph. Static graph for the 250 ms frame duration condition.

The purpose of the static stimulus was to set a baseline as to which angle of rotation produced which direction of perceived motion (clockwise, counterclockwise, or chaos) with no effect from hysteresis. In order to find a single numerical value to use as the baseline, we collapsed the static stimulus data before fitting the function. Since we are more interested in determining whether the participant perceived rotation versus chaos, the direction of rotation was not a significant factor for this analysis. This enabled us to combine the results for each angle of rotation that mirrored one another, like 18 and 162 degrees (180-18 = 162). For example, a participant will almost 100% of the time perceive clockwise motion at 18 degrees rotation the same way he or she will almost 100% of the time perceive counterclockwise motion at 162 degrees rotation. By collapsing the data we were able to extract one numerical value (the threshold) for each condition for each participant and use that as the baseline when comparing to the dynamic stimulus results. Table 1 displays the mean angle thresholds for both frame durations for the collapsed static data.

Collapsed Static Thresholds

	167ms	250ms
MJS	78.2582	75.342
AEM	79.197	80.6666
AMW	78.2765	77.4846
SC	82.5761	83.9187
EHF	76.7909	75.1975
NSJ	81.726	80.6266
BS	71.3444	72.8494

Table 1. Collapsed Static Thresholds. Data represents that mean thresholds of angle rotation for the collapsed static stimuli for both frame durations.

For the dynamic stimulus, the participants completed 40 trials with a total of eight different experimental conditions. Figure 4 displays a fit of AMW's dynamic data for the 2 degree angle of increase and 250 ms frame duration condition, which was fitted using the same psychometric function. The thresholds are represented by the dotted lines. These thresholds represent the angle of rotation where a switch from perceived rotation to chaos occurs, and vice versa.

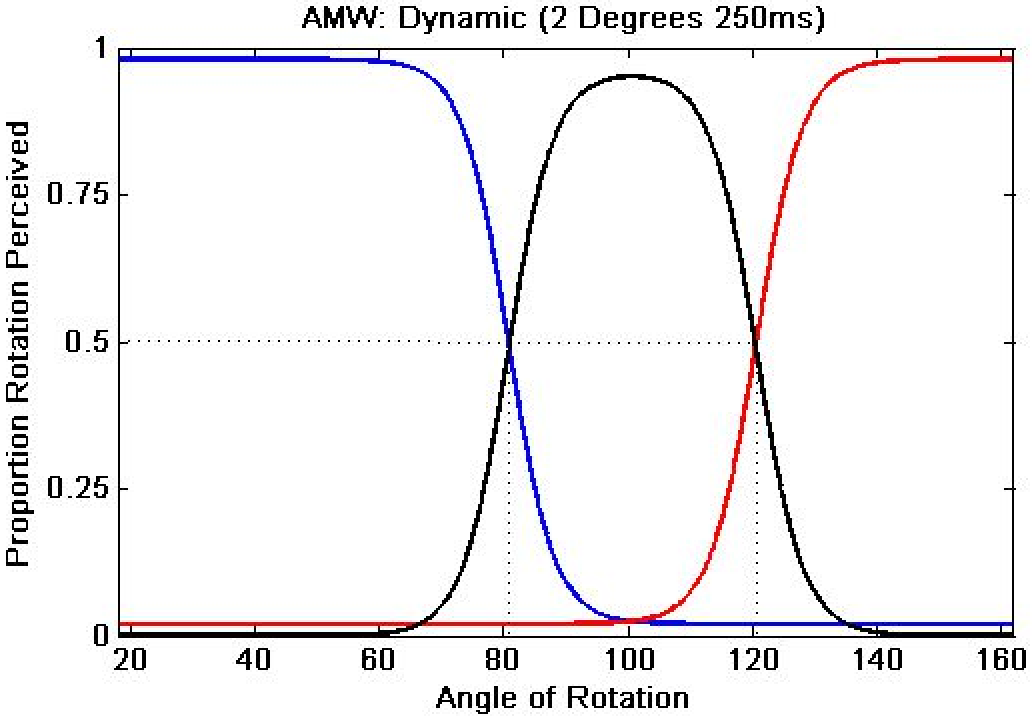

Figure 4. Dynamic graph for AMW. Graph for the 2 degrees angle of increase and 250 ms frame duration condition

Figure 5 plots three hypothetical functions that demonstrate how we quantified the effects of hysteresis on the type of motion perceived. The graph is limited to 90 degrees along the x-axis because all data points were collapsed, with each line in the graph representing a different function. The black line represents the static condition, and data values for this function display the proportion of trials on which the participant perceived clockwise rotation for one angle, or counterclockwise rotation for that angle's mirror image. For example, the black data point at 54 degrees represents the proportion of perceived clockwise rotation for 54 degrees or the proportion of perceived counterclockwise rotation at 126 degrees (180 – 54 = 126).

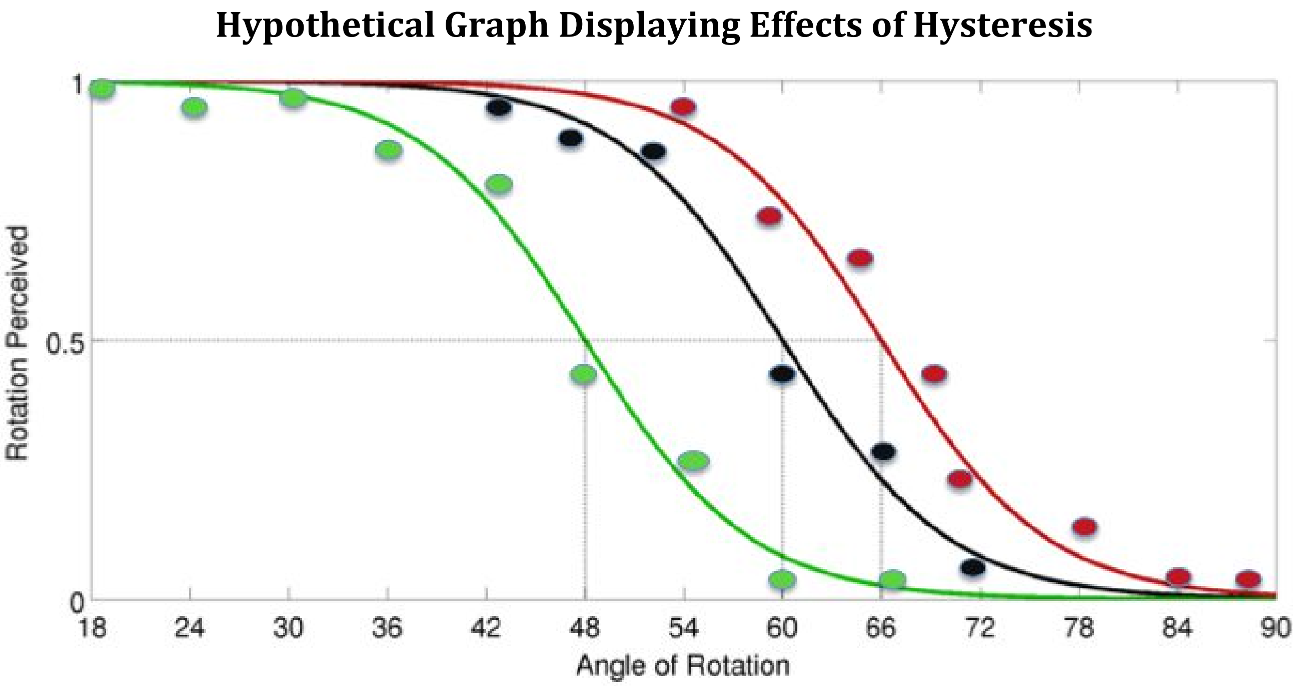

Figure 5. Hypothetical Graph Displaying the Effects of Hysteresis

The red curve represents the proportion of trials on which rotation was perceived in the dynamic condition when the angle of rotation was increasing (i.e., moving from left to right in the graph). The percept for this condition starts with rotation and moves to chaos. The green curve also represents the dynamic condition, but when the angle of rotation was decreasing (i.e., going from right to left in the graph), representing going from chaos to rotation.

In order to examine the effects of hysteresis, a single numerical value that represents the shift between the red curve and black curve is compared to the value representing the shift between the green curve and the black curve. An example of these numbers, in terms of the hypothetical graph in Figure 5, would be a “shift value” of 6 (66 – 60) for the red curve, and a “shift value” of 12 (60 – 48) for the green curve.

These “shift values” were found for each participant for each dynamic condition. Table 2 displays all the “shift values” for each direction of motion (RC = rotation to chaos and CR = chaos to rotation) for every dynamic condition.

Threshold Differences (“Shift Values”)

Condition	6° x 167ms x RC	6° x 167ms x CR	6° x 250ms x RC	6° x 250ms x CR
MJS	12.27	31.16	15.08	26.62
AEM	6.54	32.59	8.18	29.05
AMW	5.86	26.13	3.23	18.12
EHF	2.01	18.74	8.04	13.11
NSJ	17.84	32.02	16.94	24.13
BS	24.04	37.68	19.52	33.93
Condition	**2° x 167ms x RC**	**2° x 167ms x CR**	**2° x 250ms x RC**	**2° x 250ms x CR**
MJS	-5.18	11.54	-0.57	7.14
AEM	-12.26	4.21	-10.83	0.35
AMW	-11.93	7.34	-12.81	-0.1
EHF	-13.18	6.25	-8.27	-1.77
NSJ	-5.28	14.1	-3.07	10.29
BS	2.42	11.13	-0.08	9.37

Table 2. Threshold differences (“Shift Values”). Data representing the “shift values” for each dynamic condition for both directions.

All mean "shift values” for each condition were averaged and plotted as shown in Figure 6.

The data from Table 2 was analyzed by running a 2x2x2 repeated measures ANOVA via the SSPS software with a significance level of $\alpha = 0.05$. The three factors of our ANOVA test were direction, frame duration, and angle of increase each of which had two levels.

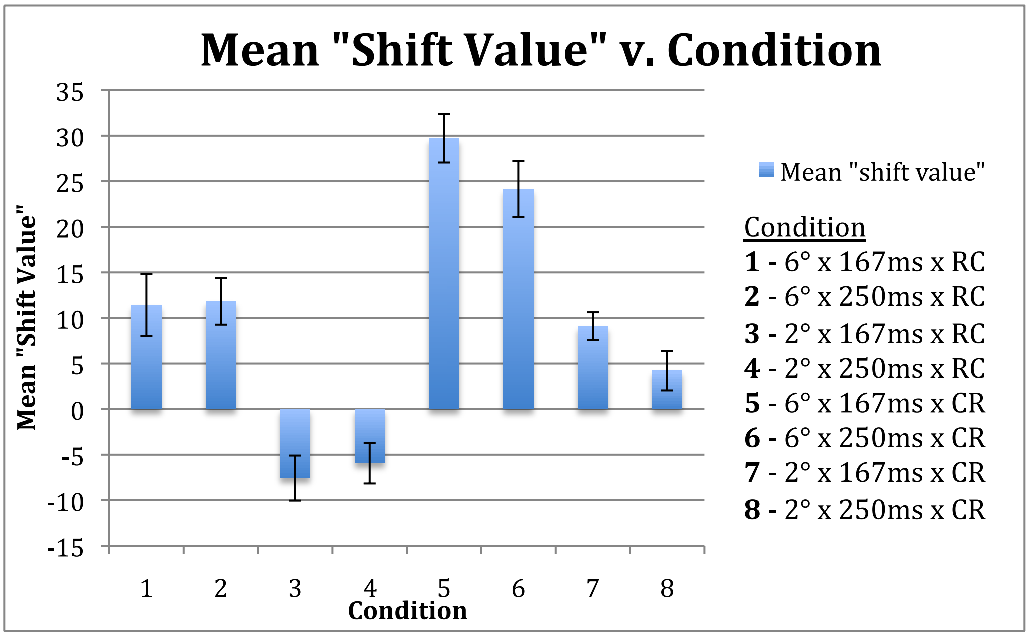

Figure 6. Mean "Shift Values" v. Condition. Mean shift values averaged for all 8 conditions.

The 2x2x2 ANOVA revealed that direction (either coming from chaos to rotation or vice versa) had a significant effect on the angle at which the switch of direction occurred. Comparing mean angles from the RC and CR directions (2.4 and 16.8 degrees respectively) yielded an F-ratio value of F(1, 5) = 158.153, $p \approx 0$. This significant effect is consistent with our hypothesis that hysteresis does not occur in the RC direction (rotation to chaos). The main effect of the mean angles for the 167ms and 250 ms frame durations (10.7 and 8.6 degrees respectively) were significant with F(1,5) =9.262, p = .029. This is likely because the duration of hysteresis is not only a function of angle, but also time. When the frame duration is short, a greater "shift value" is achieved in the same period of time compared to a longer frame duration, which is consistent with the idea that the mere passing of time would break hysteresis. The mean angles for the 2 degree and 6 degree angle of increase condition (-.05, and 19.3 degrees respectively) also had a significant effect with $F(1,5) = 189.1945$, $p \approx 0$. Similar to the effect of frame duration, this is likely because a shorter angle of increase yields a greater "shift value" for the same period of time compared to a larger angle of increase.

Figure 7 shows that frame duration and direction were the only variables that interacted with $F(1,5) = 12.902$ and $p = .016$. Mean "shift values" were plotted and analyzed in terms of angle; however, they could have also been plotted and analyzed in terms of time. If analyzed as a function of time, the "shift values" for the two frame durations are actually quite similar. For example, the mean shift value for direction CR and frame duration 167 ms is 20 degrees, and the angle of increase was 2 degrees (20/2), totaling 10 frames. Ten frames multiplied by a 167ms frame duration equals 1670 ms. The mean shift value for the 250 ms frame duration is about 14 degrees. This would correspond to 14 (degrees) divided by 2 (angle of increase) totaling 7 frames. Seven frames multiplied by 250 ms frame duration equals 1750 ms. Therefore if the mean "shift values" were plotted in terms of time, the points on the graph would coincide.

No significant effect was found for the interaction of direction and angle of increase with $F(1,5) < 1$, $p = .425$. The interaction between frame duration and angle of increase also did not produce a significant effect with $F(1,5) = 1.601$, $p = .262$. There was no significant effect for the three-way interaction of direction, frame duration, and angle of increase with $F(1,5) = 1.822$, $p = .235$.

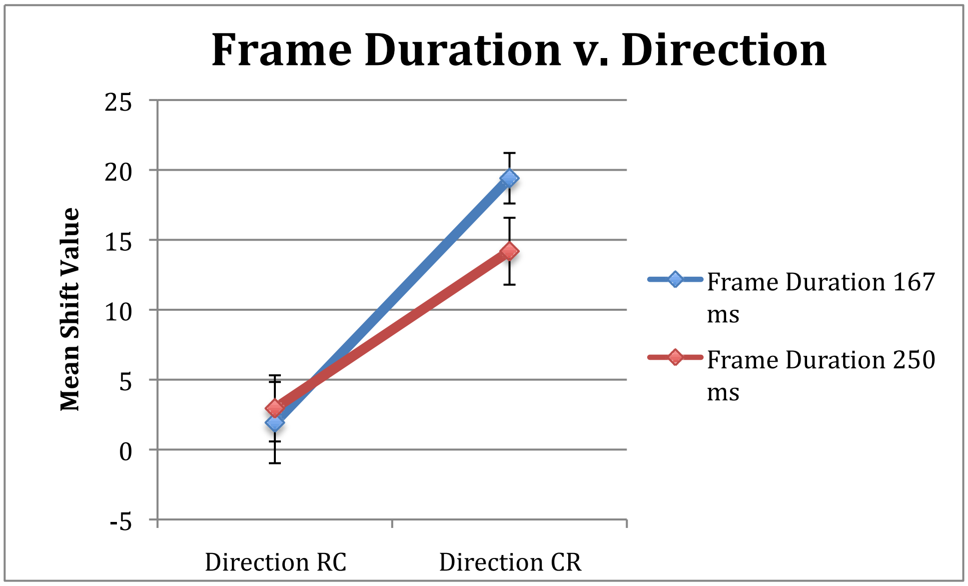

Figure 7. Frame duration and Direction. Graph displaying the interaction between frame duration and direction, F (1,5) = 12.902, p = .016

4. Discussion

The goal of this study was to determine whether the percept of rotation was subject to hysteresis. In order to determine the effect of hysteresis on the perception of rotary motion, participants viewed apparent motion stimuli, which consisted of tokens appearing to move in either a clockwise, counterclockwise, or chaotic direction. The stimuli either had a constant angle of rotation (static) or an increasing angle of rotation between frames (dynamic). The static stimuli established a baseline for which conditions induced which type of motion, and comparing that to the dynamic stimulus allowed us to investigate and quantify the effects of hysteresis on rotary motion.

We hypothesized that if our visual system does not have receptors coded for rotation early in the motion perception process, hysteresis will not have an effect on rotary motion perception. Since hysteresis occurs at a very early stage of motion detection, the only way it could have an effect is if we had low-level neurons specifically coded for rotation. To provide support for this hypothesis, in terms of this experiment, hysteresis would have to have an effect when perceiving the switch from rotary motion to chaos; however, our data does not support this claim. Our results suggest that hysteresis does not have an effect when going from rotation to chaos, but instead has an effect when perceiving the switch from chaos to rotary motion.

Our visual system is comprised of selective neurons that become excited by the perception of a range of similar directions. For example, a right-diagonal direction of motion would excite many neurons coded for similar directions, not just that specific orientation, while also suppressing neurons selectively coded for other directions. For example, neurons coded for movement by say 10 degrees would also respond well to motion by 20 or 0 degrees. When perceiving the chaotic condition these types of neurons are not aware of the overall percept of chaos, but rather are responding to the basic motion of the stimulus, which make them subject to hysteresis.

For example, in the condition where the angle of increase is 2 degrees and the tokens start with say an initial angle of 50 degrees, neurons coded for 50 degrees and 140 degrees (perpendicular to 50 degrees) will begin to compete for dominance. Both populations of neurons become excited, and the next frame displays a rotation of 52 and 142 degrees, which still falls well within the tuning range of those neurons. Because the difference between the angles is only 2 degrees and the range of excitement for directionally selective neurons is relatively large, there will be very little difference in the amount of neural excitation. This causes the neurons to respond similarly to how they would for the bistable square shown in Figure 1, where hysteresis is in full effect. For this reason, these neurons will respond very similar to the static and dynamic conditions. They function so early in the visual system that they cannot distinguish the difference between the two stimuli. The interpretation of the scene moving chaotically, or rotating occurs at a later stage in visual processing where hysteresis has no effect.

Our results support this hypothesis because the effects of hysteresis were only experienced moving from the chaotic direction to rotation. Hysteresis appears to occur only during this chaotic stage, which strongly suggests that we do not have early motion detectors coded for rotary motion, and thus confirming that a rotary percept is not subject to hysteresis.

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