THE DOUBLE-DRIFT ILLUSION AFFECTS BOTH THE PERCEPTION OF WHERE THE TARGET *IS* AND THE MEMORY OF WHERE IT *WAS*

by

SYDNEY GILBERT

A THESIS

Presented to the Department of Psychology
and the Robert D. Clark Honors College
in partial fulfillment of the requirements for the degree of
Bachelor of Arts

March, 2017

An Abstract of the Thesis of

Sydney Gilbert for the degree of Bachelor of Arts
in the Department of Psychology to be taken March, 2017.

Title: The Double-Drift Illusion Affects Both the Perception of Where the Target *Is* and the Memory of Where It *Was*

Approved: ____

Dr. Paul Dassonville

To successfully hit a curveball, how does your conscious perception of the curving ball effect where your bat actually swings? From evading car accidents to using basic hand-eye coordination, we often rely on our perceptions of the world to help guide our actions. Successfully perceiving and interacting with a moving object requires the brain to encode how the object's edges (global motion) and the object's internal texture (local motion) are moving through space. In order to quickly process moving objects, the brain typically assumes that these motions are in agreement. However, this assumption is a simple shortcut that does not always reflect the true physical world, often leading to a visual illusion. Previous research has shown that the perceived trajectory of an object with contrasting global and local motion is a combination of the two motion directions.

The purpose of this thesis was therefore to investigate the relative influence of the local and global motions over time and how the memory of the stimulus' previous locations are affected by the perceived trajectory. We assessed the change in the observer’s memory of the trajectory’s starting location by asking the observer to compare the onset location with a probe that could be presented before or after motion onset (-250, 0, 250, 500 or 1000ms). Participants maintained fixation in the center of the screen while an object containing leftward, rightward, or no internal motion traveled upward for 500ms in the periphery. The global motion of the stimulus was adjusted for each observer so that the perceived double-drift trajectory appeared purely vertical. For probes presented 250ms before motion onset, the local motion induced a small but significant distortion of the perceived starting location. This bias grew significantly with later probe presentations, reaching a plateau for delays of 250ms or longer. Given that a delay period enhances the effect of the illusion, these results suggest that at least a portion of the distortion in the perceived trajectory of a double-drift stimulus is caused by a bias in the memory of its earlier locations, which are pushed in a direction opposite the local motion.

Acknowledgements

I. First, I would like to express my sincerest gratitude for the support and knowledge bestowed upon me by Dr. Paul Dassonville and the Perception & Action lab.

Dr. Paul Dassonville – Without your time, patience, and insight, none of this thesis would have been possible. Thank you for guiding me to this thesis topic, after jumping around between several other potential thesis topics. Thank you for taking time out of your busy schedule to program the experiment and meet with me over the past two years. Thank you for editing my prospectus and thesis, as well as attending my prospectus and now thesis presentations. Most of all, thank you for believing in me and welcoming me into the lab after I wandered into your office as a lost and confused RA hoping to study optical illusions. I truly cannot thank you enough for the experience I have gained by working in this lab and running an experiment by myself.

Daryn Blanc-Goldhammer – Ever since I joined the lab, you've always being so kind and willing to help me out or let me pick your brain. Thank you for helping teach me about the Infinite Regress and Fröhlich illusions, thank you for editing my thesis, and especially thank you for your mentorship and being such a strong role model.

Jeffrey Peterson – Even though we've never worked on the same illusion, you have also been so supportive and helpful since I joined the lab. Thank you for taking on the daunting task of teaching me how to work (and troubleshoot) the eye tracker.

II. Next, I would like to thank the other outstanding members of my committee.

Dr. Margaret Sereno – Your knowledge of visual illusions and research experience is a definite asset to have on my defense panel. Thank you for joining my committee and taking the time to review my thesis and attend the defense. I am very excited to volunteer as an RA in your lab following the completion of this thesis and look forward to other future opportunities to learn from you!

Dr. Kelly Sutherland – I greatly appreciate your willingness to serve as my honors college representative even though I have never taken a class from you. Thank you for taking the time to listen and help me out with the honors college requirements, and for providing advice during the writing process as well. Thank you for taking time to attend my thesis defense and keeping in touch with me throughout the term.

III. Finally, I would like to thank my parents.

Dad, thank you for always telling me to work hard to pursue my dreams.

Mom, thank you for always reassuring me that I work too hard and need to relax.

You've both always believed in me and I wouldn't have had the courage to challenge myself and write a thesis without knowing that you'll always be there loving and supporting me. I love you both so much and this thesis wouldn't have been possible without your unconditional encouragement. I could write another 40 pages about how much I appreciate everything you've done for me, but instead I hope you're just proud knowing you made the person that made this thesis.

Table of Contents

List of Figures

Introduction

To perceive an object in motion, the brain processes the motion of the object's edges and the motion of its internal texture to determine the overall trajectory. These motion signals are typically in agreement, which can lead the brain to create assumptions about objects in motion in order to quickly process what we see. While usually beneficial, these assumptions are often simple shortcuts that do not always reflect the true physical world. Under certain circumstances, these shortcuts are an inaccurate representation, which leads to a visual illusion. Researchers recreate visual illusions in lab settings in attempts to understand the assumptions the brain makes when processing an incoming visual image.

Double-Drift Illusion

A series of recent studies have explored how the perceived motion of an object is impacted by both its trajectory within the visual field (external, or global, motion) and the motion of the texture elements on the object's surface (internal, or local, motion). In the double-drift illusion, a target in the visual periphery moves globally in one direction, but contains perpendicular internal motion, resulting in a perceived trajectory that is a combination of the two directions of movement (Figure 1). Global motion is defined as the overall path that the stimulus takes when moving across the screen, while local motion is movement within the stimulus. Local, or internal, motion in a Gabor patch is created using a translating luminance grating (Figure 2).

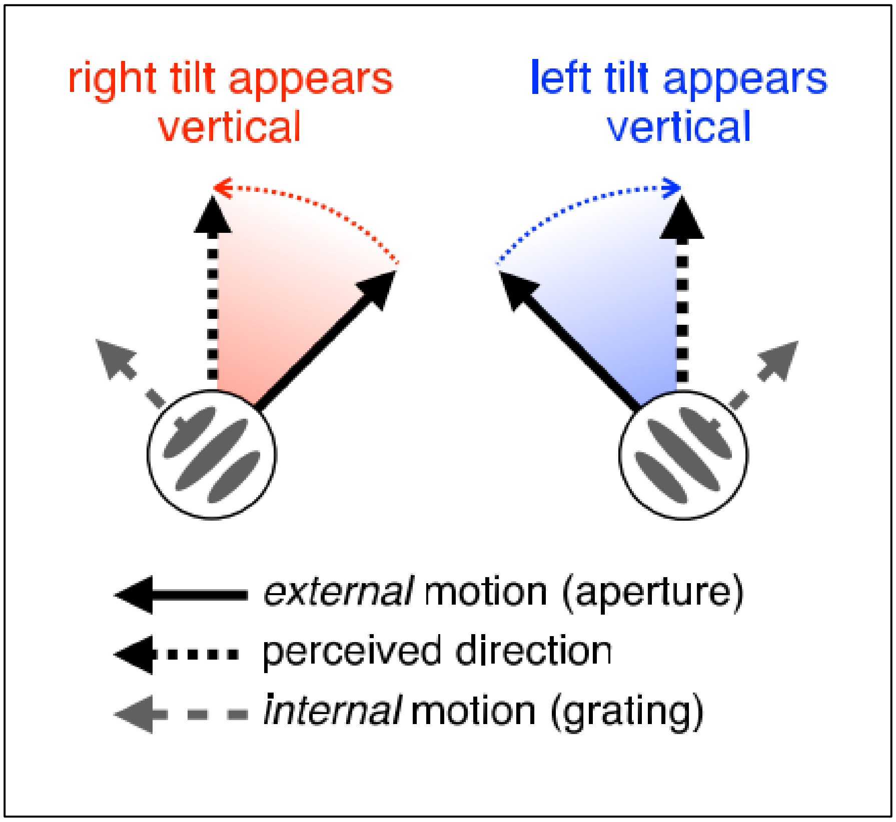

Figure 1: Breakdown of Motion Components in the Double-drift illusion

The left figure illustrates a Gabor with leftward local motion (internal motion) moving along a rightward global trajectory (external motion). The red shaded region represents the offset in the perceived global trajectory. The right figure illustrates a Gabor with rightward internal motion moving along a leftward global trajectory. The blue shaded region represents the offset in the perceived global trajectory. Both targets would appear to be travelling vertically, despite moving along opposite vectors. This figure was published by Lisi and Cavanagh (2015).

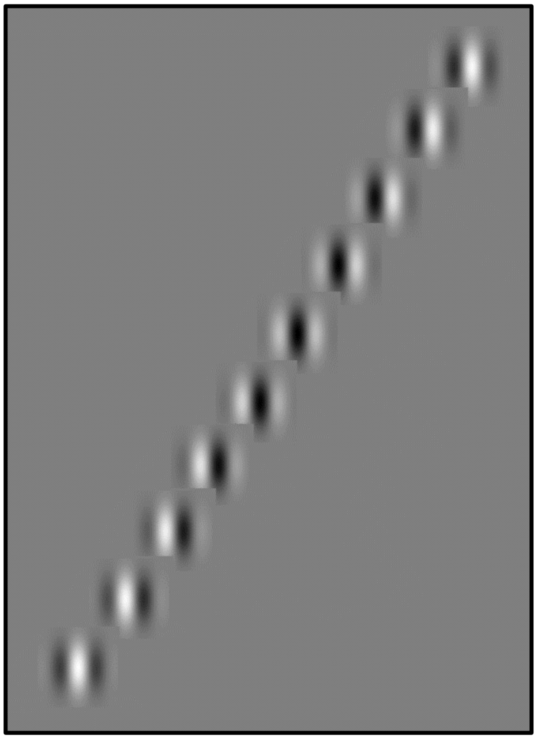

Figure 2: Schematic of Rotating Luminance Grating Broken Down Frame-by-Frame

A series of snapshots depicting the double-drift stimulus as it travels across the screen. Note the location of the sinusoidal luminance gradient in successive images; when shown as an animation, the texture of the image appears to rotate horizontally.

Despite the visual effect caused by a double-drift illusion, findings by Lisi and Cavanagh (2015) suggest that reflexive actions, specifically eye movements (or saccades) directed at a target, are not fooled by this illusion. Their first experiment consisted of two tasks - one to measure perception and one for action. The perceptual task displayed a double-drift illusion repeatedly travelling between the bottom and top of the screen. The participants then indicated whether the trajectory was tilted clockwise or counterclockwise with respect to vertical. Their results show that the local motion of the stimulus caused an illusory tilt of the trajectory of ± 50° (depending on the direction of the local motion).

In the action task, participants were shown oscillating double-drift Gabor stimuli in their periphery while maintaining fixation in the center of the screen. The fixation point and Gabor target disappeared after 1-3 oscillations, and participants performed a saccade (the action) to wherever they perceived the target to be when it disappeared. The researchers were testing whether the saccades would land along the veridical physical path (Figure 3.1), or if the saccades would correspond with the visual effect, targeting the perceived path (Figure 3.2).

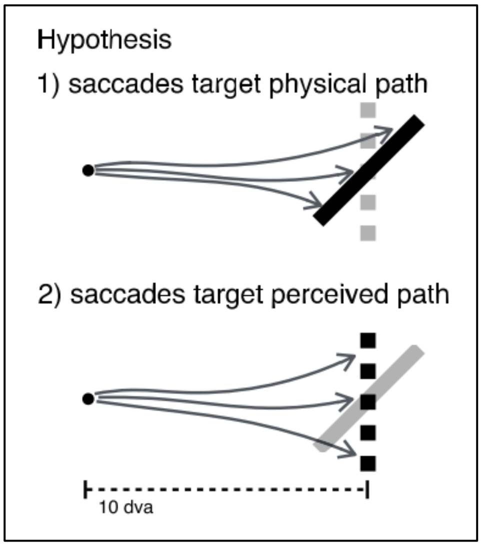

Figure 3: Hypothesized Saccadic Landing Points in relation to Double-Drift Stimulus

The arrows represent the saccades, with the arrowheads depicting the saccadic landing points. In Figure 3.1, the saccades are shown landing along the veridical global trajectory of the stimulus. In Figure 3.2, the saccades are shown landing along the perceived vertical trajectory. This figure was published by Lisi and Cavanagh (2015).

In contrast to the perceptual task, the endpoints of the saccades did not significantly differ from the actual physical path of the trajectory (Figure 4, right side). This result indicated that the saccade system tracks the actual global motion of the Gabor effectively.

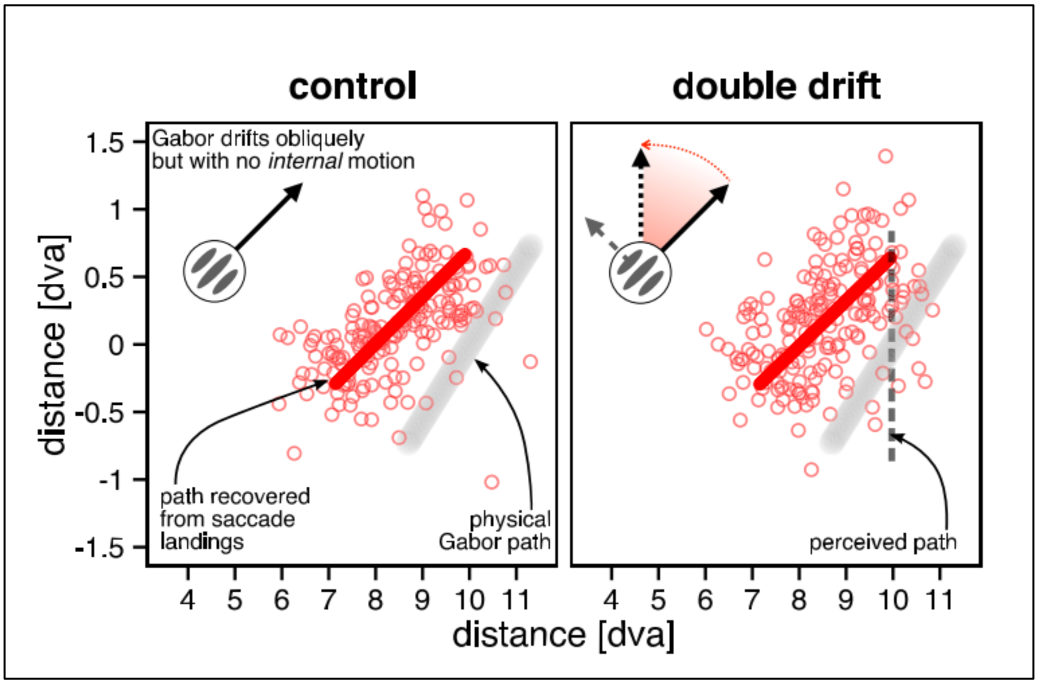

Figure 4: Results from Lisi and Cavanagh (2015)

The graph on the left depicts the saccadic landing points in relation to a moving target with no internal motion. As to be expected, saccades reflect the actual trajectory (the saccade endpoints do not perfectly match the physical Gabor path due to the typical undershoot of saccades directed to brief targets). The graph on the right depicts the saccadic landing points in relation to a moving target with internal motion (a double-drift stimulus). The saccades to the double-drift target closely resemble the saccades to the control target, indicating that the saccadic system fails to process the local motion that leads to the perceptual illusion. This figure was published by Lisi and Cavanagh (2015).

A recent study by Massendari, Lisi, Collins, and Cavanagh (2016), further explored the accuracy of saccades to double-drift stimuli, examining the effects of a delay between stimulus presentation and saccade onset. Participants maintained fixation on a center point while a double-drift stimulus oscillated in their right periphery. The stimulus could disappear in one of four possible locations along its trajectory, and the disappearance of the fixation point signaled the participants to make a saccade to the location of the target’s disappearance. Unlike the previous study by Lisi and Cavanagh (2015), variable delay (0-1000ms) was included between the disappearance of the target and the fixation point. Without a delay, participants could perform reactive saccades that accurately landed on the target’s true location (Figure 5, left). However, with delays as brief as 250ms, the saccades became memory-guided and reflected the target’s illusory location instead (Figure 5, right). Their results suggest that the longer the delay, the more likely it was that the saccades would reflect the perceived location instead of the physical one.

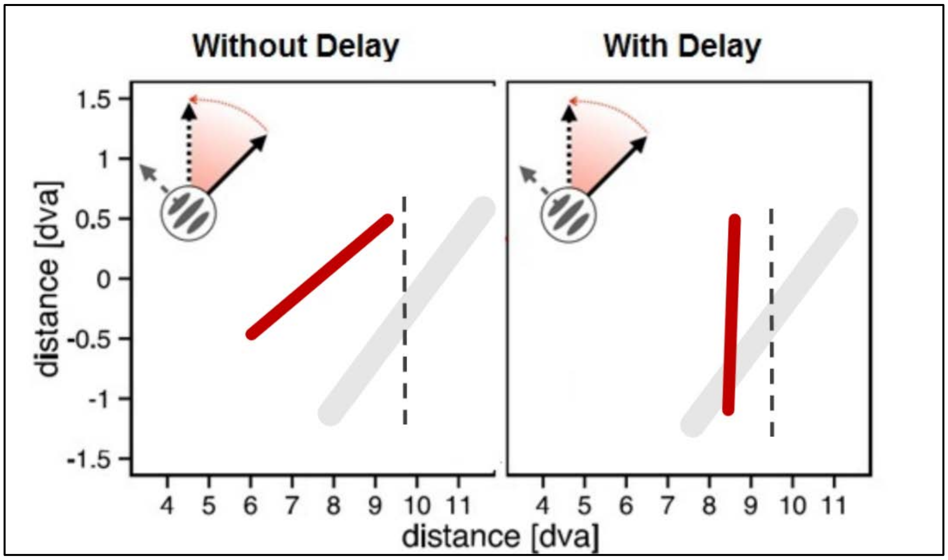

Figure 5: Interpreted Schematic of Results from Massendari et al. (2016)

The graph on the left depicts (in schematic form) the cloud of saccadic landing points (red line) when there was no delay, which closely matches the angle of the actual global trajectory (gray line), albeit with a typical saccadic undershoot, replicating the findings of Lisi and Cavanagh (2015). The graph on the right depicts saccadic landing points when there was a delay, which instead closely match the perceived trajectory (dashed line). These findings from Massendari et al. (2016) are presently unpublished, but were presented at VSS 2016. Ergo this schematic was not produced by them, but is merely acting as an interpretation of their findings for this thesis.

The vertical dashed lines in Figures 3 and 4 represent the authors inference of the perceived vertical path of the double-drift stimulus.[1] Notably, this line has been drawn in the middle of the path taken by the double-drift stimulus, bisecting its trajectory. Though results of the perceptual tasks indicate that the perceived double-drift trajectory is vertical, there is no evidence to suggest that it intersects at the midpoint of the global trajectory. The perceived trajectory could be translated to the left or the right,

---

[1] This line is also featured in Figure 5; however, Figure 5 is a homemade interpretation of Massendari et al. (2016)'s findings. The vertical line in Figure 5 is included to reflect the presence of the vertical line in Figure 4.

depending on the interaction between the memory of the target's beginning location and its perceived ending location (Figure 6).

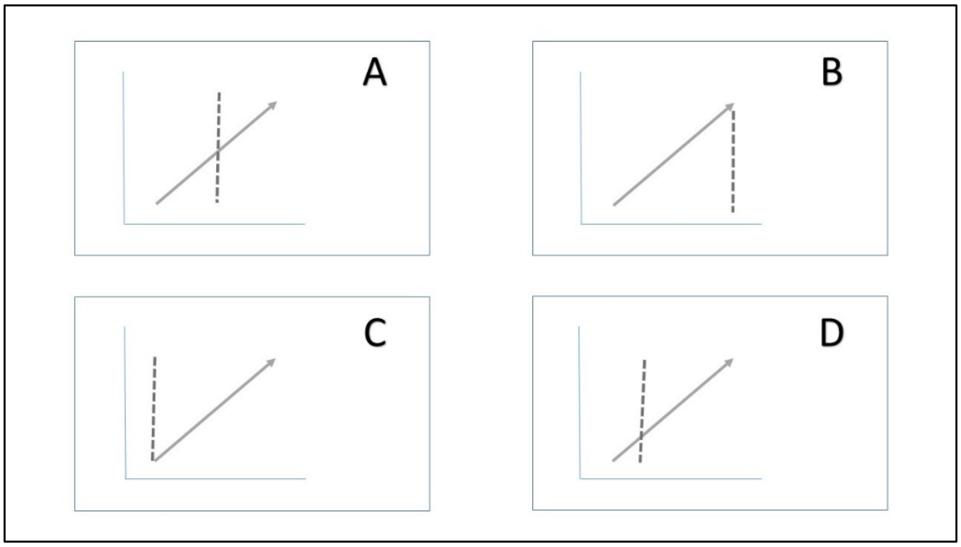

Figure 6: Potential Perceived Vertical Trajectories in relation to Actual Global Trajectory

The solid gray arrow in all subplots represents a double-drift stimulus with rightward global motion and leftward internal motion. The dashed line represents a possible location of the perceived vertical trajectory with respect to the double-drift stimulus. A) As assumed by Lisi and Cavanagh (2015) and Massendari et al. (2016) the perceived vertical trajectory could fall in the middle of the double-drift trajectory, with both the start and end of the trajectory inaccurately perceived (A). Alternatively, it could be that the endpoint of the trajectory is correctly perceived, but the remembered starting location gets pushed in a direction opposite the local motion (B). Or it may be that the starting point of the trajectory is remembered correctly, but the perception of subsequent positions of the target become biased in the direction of the local motion (C). The results of Blanc-Goldhammer et al. (2016) suggest that although there is a small bias in the perceived location of the starting position, there is a much larger mislocalization of the perceived endpoint of the trajectory (D).

Blanc-Goldhammer, Araujo Sanchez, and Dassonville (2016) investigated the accuracy of the perception of the start and end of the trajectory of a double-drift stimulus. Participants compared the beginning (or ending) location of a double-drift trajectory to a probe presented 250ms before (or after) a single sweep of the stimulus. Their results indicate that the illusion caused a small distortion of the perceived starting location, which was biased in a direction opposite the local motion. Additionally, there was a larger distortion of the perceived ending location (about 3x larger), biased in the same direction as the local motion. Blanc-Goldhammer et al.’s (2016) findings demonstrate that the perception of both the beginning and ending points of a double-drift trajectory are influenced by the illusion. However, they are affected to different extents, resulting in a vertical line slightly translated to the left (Figure 6D). The leftward translation suggests that the remembered location of the starting point determines the alignment of perceived vertical more so than the endpoint, resulting in a greater disparity between the real and perceived trajectory endpoint locations. This discrepancy could be because participants were allowed to respond as soon as they had seen both the flashed probe and target trajectory extremity.

Given Blanc-Goldhammer et al.’s findings, we can infer that the perception of both the beginning and ending points of the trajectory are influenced by the double-drift illusion (Figure 6D). In their experiment, the perceived vertical trajectory was computed by comparing the target’s immediate perceived beginning location to the perceived endpoint, but they did not test how the remembered beginning location changed or influenced the trajectory over time. The memory of the target onset location could influence where the target is perceived to be as it travels along the rest of its trajectory (Figure 6). The purpose of this thesis experiment is therefore to monitor the impact of memory on the double-drift illusion by having the participants recall the beginning location after various delay intervals.

Methods

Participants

All participants were undergraduate students from the University of Oregon Human Subjects Pool. There were 31 participants (ages 18-46; 21 females; all with normal or corrected-to-normal vision). Four participants did not finish the entire task so their data were not included. Participants were awarded class credit in exchange for their participation in the study and signed a consent form approved by the University of Oregon Institutional Review Board. The study lasted approximately two hours and all participants were debriefed afterwards.

Procedure

Participants sat at a desk facing a screen (135.9cm tall x 101.6cm wide with a screen resolution of 1920 pixels x 1440 pixels) on which all visual stimuli were back-projected (Marquee 8500 projector, Electrohome, 60 Hz refresh rate). Lights in the room were extinguished, to eliminate extraneous cues that may aid in determining the locations of the visual stimuli. The participant’s eye position was 86.3cm away from the presentation screen and monitored with an eye tracker (Eyelink 1000, S-R Research), which was calibrated at the beginning of the experiment with the tracker’s built-in calibration procedure. All stimuli were red on a black background (stimuli were colored red to take advantage of the red cathode ray tube’s faster decay rate, compared to the blue and green, to minimize ghosting). Throughout both tasks in this experiment, participants maintained their gaze on a fixation point positioned in the center of the screen, using their peripheral vision to observe the stimulus. If a participant looked away from the fixation point for longer than 200ms, the trial was aborted and participants had to start that trial over. Participants pushed a button on a gamepad to start each trial, triggering a target (a Gabor patch) to appear on the right side of the screen.

The Gabor patch (Figure 2) comprised a sinusoidal grating (2.35 cycles/degree) situated inside a Gaussian envelope with a standard deviation of 0.94 degrees of visual angle. For some stimuli, a rightward or leftward local motion was created through an animation that caused the grating to rotate at a frequency of 3.0 cycles/second. For other stimuli, the Gabor had no local motion.

The goal of this experiment was to quantify any distortion in the perception of the starting location of a double-drift illusion, so it was necessary to ensure that the participants' responses were not contaminated by the Fröhlich illusion (Fröhlich, 1923). To achieve this, the trajectory of the global motion of the stimulus was adjusted so that the horizontal local motion of the stimulus offset the horizontal component of the global trajectory, so that each stimulus would be perceived as moving vertically (i.e., with no horizontal motion). With this arrangement, the Fröhlich effect would cause an illusory vertical displacement of the trajectory's starting location but its horizontal location would remain unaffected. For each participant, an initial task (Task 1) was used to quantify the magnitude of the horizontal component of the global trajectory necessary to offset the effect of the local motion. Then, in a second experiment (Task 2), these parameters were used to ensure that the perceived trajectory of the double-drift illusion was vertical. We predicted that, within-subjects, the magnitude of the offset in Task 1 would correlate with the effect of the illusion across conditions in Task 2.

Task 1

The first task was implemented to measure the angle of the global trajectory that, when combined with local motion, caused the participant to perceive the trajectory as vertical. For example, to perceive a trajectory containing leftward internal motion as vertical, the global trajectory would need to be tilted to the right. In this task, participants were instructed to rotate the trajectory of the moving target, using the method of adjustment, so that it appeared vertical (a button under the left index finger was used to rotate the trajectory counterclockwise, or under right index finger to rotate it clockwise). Rotation of the trajectory pivoted around the lowermost point on the trajectory for all stimuli, so that this point was consistent for all three local motion conditions (left, static, and right).[2] Each single pass of the trajectory took 500ms, and repeated until the participant submitted their response. The angles of the global motion resulting in apparent vertical trajectories were recorded and used as parameters of Task 2 to modify the illusion to the sensitivity of the individual participant in efforts to prevent errors due to the Fröhlich effect. To measure the strength of the illusion, we calculated the difference between the necessary global motion angles for each participant to view the trajectories containing internal motion as vertical. A one sample

---

[2] The first task came from another experiment and originally contained additional trials that were anchored at the top and went to three different locations on the bottom. We were not using these measurements, so we removed them to cut down the length of the experiment. The revised experiment only had the trajectory starting at a single location on the bottom, traveling to three different locations on top. The first seven participants did the longer task, while the rest of the participants did the revised task.

t-test was used to test whether the effect of the illusion was significantly different from zero.

Task 2

In the second task, participants were instructed to judge whether a probe, flashed for 30ms, was located to the left or the right of where the double-drift target appeared on the screen when beginning its trajectory (Figure 7). The participants used a gamepad to submit their response, and could respond as soon as they had seen both the probe and the onset location of the trajectory. As in the previous task, the trajectory always started in one location on the bottom of screen and moved to one of three locations on the top. In this task, the target only did a single global pass before disappearing at the top of the trajectory. The angles of the trajectories for the three different local motion conditions (leftward motion, static, and rightward potion) were specified for each individual participant based on the data collected in the first task, aligning the trajectory so that each condition would appear vertical for each participant. There were five probe delay conditions (-250, 0, 250, 500, and 1000ms, with a negative delay indicating that the probe was presented before the start of the target trajectory), for a combined total of 15 trial types. The flashed probe duration was 30ms and it always appeared just below the starting point of the target’s trajectory, while its horizontal location was adjusted in a staircase fashion (see appendix) to determine the location in which the probe was judged to lie with equal probability to the left and right of the starting location of the double-drift illusion (the point of subjective equality, or PSE).

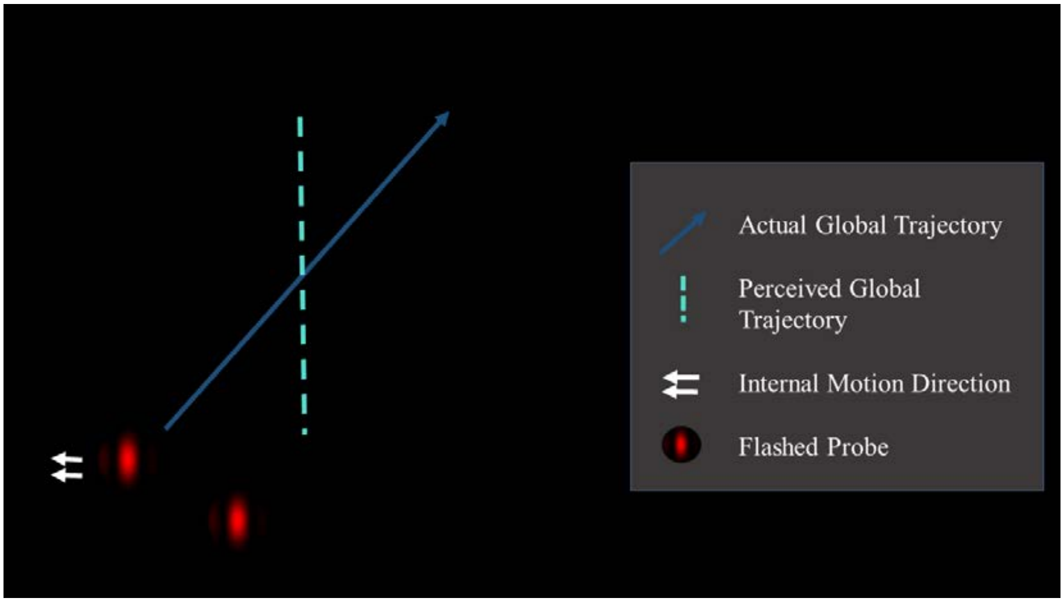

Figure 7: Illusion Visual with Flash Example

If the trajectory is viewed without an illusory effect, participants should correctly respond that the flashed probe was to the right of the target's starting point. Where the perceived vertical aligns determines when the participant falsely judges the location of the flash. For example, if the participant views the vertical trajectory as bisecting the veridical trajectory, they would respond here that the flash is to the left of the target's starting point.

To measure the effect of the illusion, we calculated the location in each condition where the flash appeared to be aligned with the beginning of the trajectory. We used an adaptive staircase procedure to narrow in on the flash location that had a 50% chance of being viewed on either side of the trajectory for each condition (see appendix). A univariate ANOVA with repeated contrast was used to test for differences in effect sizes between the different delays.

Results

Task 1

We measured the extent of the illusion in the first task by calculating the difference between the necessary endpoint coordinates for trajectories with leftward and rightward internal motion to be perceived as vertical. The effect of the illusion, as indicated by the difference values, was found to be significantly different from zero (one sample t-test, *p*<0.01, Figure 8).

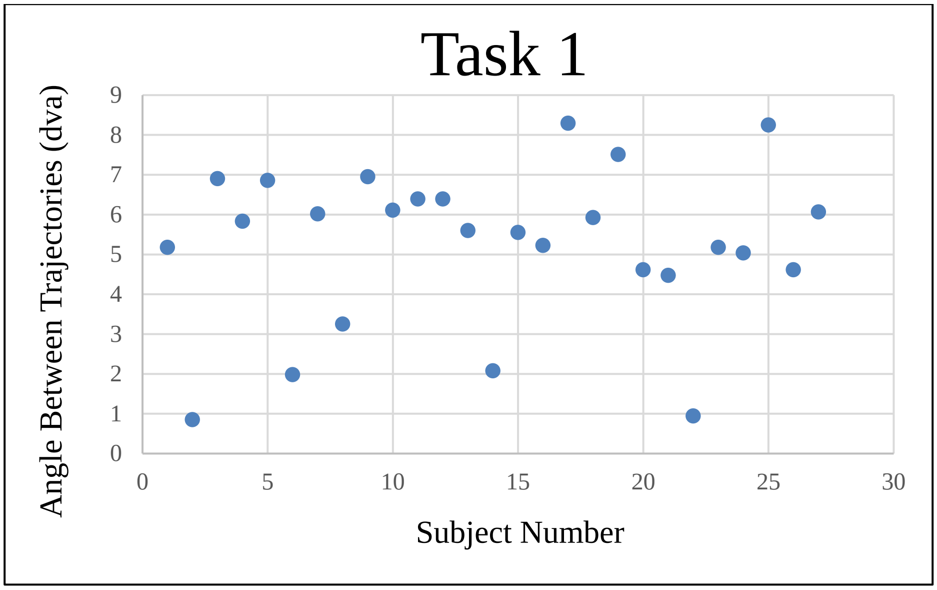

Figure 8: Results of Task 1

The x-axis represents the participant order in respect to when they were run through the experiment. The y-axis represents the degrees of visual angle (dva) between trajectories with leftward and rightward internal motion when perceived as vertical.

Task 2

All delay conditions showed significant effects of the illusion ($p < 0.01$). A univariate ANOVA was conducted to compare the effect of the different delay periods on the perceived trajectory in Task 2. A significant effect of delay on perceived trajectory was detected [$F(4,130) = 11.16$, $p>0.01$]. In a repeated contrast, the magnitude of the illusion was significantly greater for the 0ms delay than for the -250ms delay ($p = 0.004$), and the effect for the 250ms was significantly greater than for the 0ms delay ($p = 0.014$). However, for delays greater than 250ms, the magnitude of the illusion hit a plateau, with no significant increases in illusion magnitude for increasing delays ($p>0.55$, Figure 9).

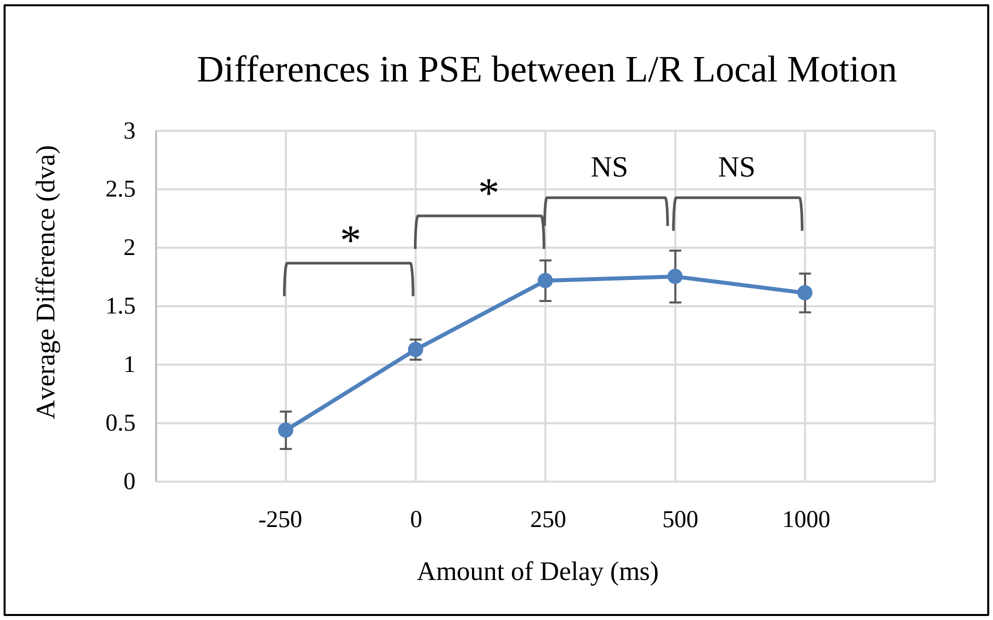

Figure 9: Results of Task 2

The data points depict the difference in the PSE (degrees of visual angle) between trials with leftward and rightward local motion. The magnitude of the illusion for all delay periods was significantly different from zero ($p < 0.01$). The brackets above, connecting adjacent data points, depict the significance (*), or lack thereof (NS) in the difference in PSE between delay periods. Error bars represent the standard error for each delay period.

Task 1 x Task 2

We assumed that the distortion of the perceived trajectory in Task 1 was due at least in part to the misremembered location of the trajectory's starting point, as measured in Task 2. Given this assumption, we hypothesized that the magnitude of the offset of the perceived trajectory in Task 1 would correlate, within subjects, with the difference between the PSEs for leftward and rightward internal motion for each delay condition in Task 2. The relationship between the two tasks cannot be definitively concluded at this point, but there appears to be a general trend with some of the comparisons nearing significance, and one reaching significance (250ms: $r = 0.42$, $p < 0.05$, Figure 10).

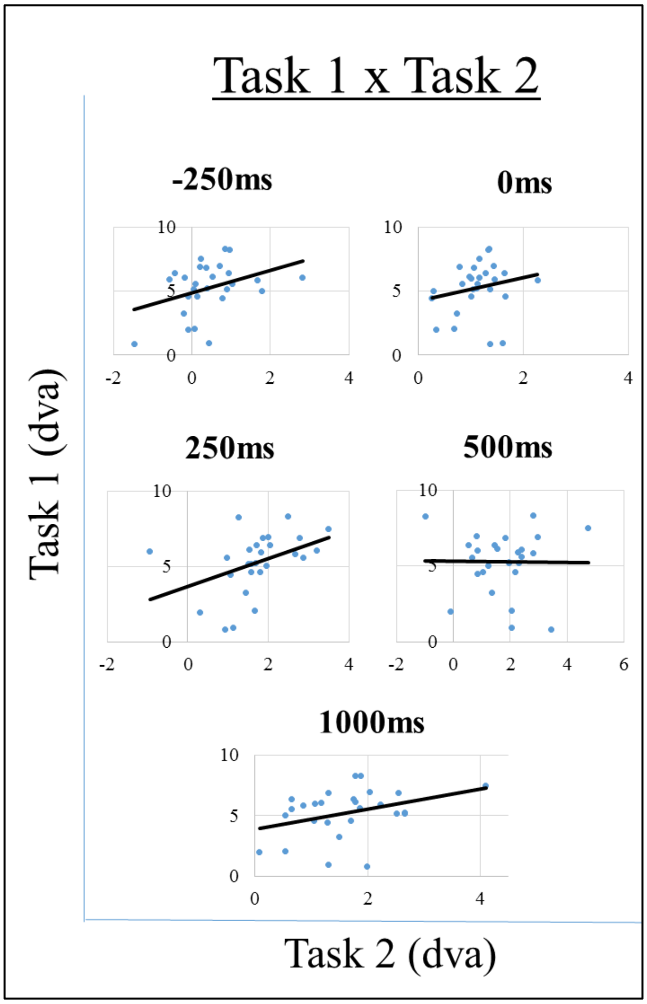

Figure 10: Correlations between Task 1 and Task 2

The y-axis represents the dva between trajectories with L/R internal motion in Task 1 to be perceived as vertical. The x-axis represents the difference in pixels between the PSEs (point where the flash appears 50% on either side of beginning of trajectory) of trajectories containing leftward and rightward internal motion in Task 2. The subplots are separated by delay period for Task 2. Although the correlation for the 250ms delay reached significance (250ms: $r = 0.42$, $p < 0.05$), correlations for other delays were either trending towards significance (-250ms: $r = 0.37$, $p = 0.055$; 1000ms: $r = 0.36$, $p = 0.065$) or were not significant (0ms: $r = 0.21$, $p = 0.29$; 500ms: $r = 0.01$, $p=0.95$).

Discussion

Discussion of Hypotheses

As hypothesized, all delay periods resulted in a significant perceptual effect of the illusion (p<0.01, Figure 9). This finding is important, as it exemplifies that our stimulus effectively induced the illusion regardless of delay period. Our results also indicate that the distance between the actual starting point and perceived starting point (i.e. the effectiveness of the illusion) significantly increases following longer delay periods, up until 250ms, with the illusion plateauing at a maximal effectiveness for delays of 250ms or longer (Figure 9). These findings suggest that although the illusion causes an immediate effect on the target's perceived location, the effect grows with delay such that the remembered location of the target's starting point shows greater effects of the illusion over time.

We also predicted that there would be a correlation between the magnitude of the illusory effects on the perceived trajectory of the double-drift stimulus (Task 1) and the perception (and memory) of its starting location (Task 2). Although in general the results showed a trend in this direction, the effect of the illusion in Task 1 was only significantly correlated with the 250ms delay condition in Task 2 (Figure 10). One possible reason for a lack of strong correlation was that Task 2 only measured the effects of the illusion on the perceived start of the target's trajectory. A stronger correlation might be found if one were to compare the perceived trajectory with the *vector between the perceived start and perceived end* of the trajectory. To test this prediction, we are running follow-up experiments to measures the perceived beginning and ending locations so that a perceived trajectory can be inferred. However, as described in the next section, it may also be that the perception of the orientation of a target's trajectory may be based on different neural mechanisms than those responsible for achieving the perception of an object's location. If that is the case, one would expect little to no correlation between the perception of an object's trajectory and its location.

Perception v. Action

The original inspiration to run this thesis study stemmed from the findings of Massendari et al. (2016) revealing that actions, specifically saccades, were not fooled by the double-drift illusion, unless there was a delay between when the stimulus disappeared from the screen and when the saccade began. If our findings had indicated that the perceptual effects of the illusion were also not significant unless there was a delay, this finding in relation to Massendari et al. (2016) would have suggested that perception and action likely rely on a shared neural mechanism. However, our findings indicate that perception is fooled with or without a delay, and when taken together with Massendari et al. (2016), suggest that there is a neural dissociation between perception and action. These results seem to provide support to Milner and Goodale's (1991, 1992) theory that the ventral and dorsal streams of visual processing are responsible for encoding perception and action, respectively. With that said, our perceptual task demonstrated that the error grew with increasing delays, and the magnitude of the effect at the earliest delay was significantly smaller than the rest. Therefore, Massendari et al. (2016) may not have had the statistical power to detect the same small mislocalizations at the earliest delays which would have also led to our delay-dependent results.

Lisi and Cavanagh (2015) investigated the relative extents that perception and action mechanisms were affected by the double-drift illusion, finding that perceptions were significantly affected while reflexive actions were not. However, their experiment tasks differed in more than just the type of response (perceptual vs. action) required. While the different characteristics of an object's motion (speed, location, distance traveled, direction) are perfectly correlated as per the laws of physics (e.g., a faster moving object will travel a greater distance in a given time than a slower one), the brain's subjective, perceptual assessments of these characteristics may not be, since it is possible that they are encoded using different neural mechanisms.

Indeed, Abrams and Landgraf (1990) demonstrated that the difference between an object's perceived spatial location at the start and end of a movement may differ from the perceived distance that it traveled. This finding indicates that we do not use knowledge of the distance traveled to determine the trajectory's endpoint, and vice versa. Smeets and Brenner (1995) found that the perceived velocity of an object can be dissociated from the changing perception of its location in space. Given these findings, it might be that the differences in illusion susceptibility measured in the perception and action tasks of Lisi and Cavanagh (2015) have less to do with a true difference between perceptual and action abilities, but were perhaps caused by the fact that one task (perception) required subjects to report on the orientation of a target's *trajectory* while the other (action) required subjects to move the eyes to the target's *location*. A more reliable comparison of perceptual and action abilities would require tasks that allow subjects to provide both perceptual and action reports on the target's trajectory, or on its location. Lisi and Cavanagh's (2015) perceptual task required participants to report whether the illusory target’s trajectory was tilted left or right with respect to vertical, whereas their action task required participants to guide saccades toward specific locations along the path of the stimulus. The study of Massendari et al. (2016) was similarly limited, as is the current study (with Task 1 providing a perceptual measurement of trajectory, and Task 2 providing a perceptual measurement of perceived location). Future studies to assess the illusion susceptibilities of perception and action should be designed in ways that avoid this confound.

Fröhlich Illusion

A possible confound of the current study, that could have contributed to the insignificant correlation between the results of Task 1 and 2, are the potential effects of an unintended Fröhlich illusion. The Fröhlich illusion (Fröhlich, 1923) is a motion-based illusion in which a suddenly appearing object in motion is perceived to appear in a location offset in the direction of the motion. The Fröhlich illusion is thought to occur because, by the time the observer is consciously aware of the stimulus’ sudden appearance, it has already travelled some distance along its trajectory. If the target moves along a diagonal vector, its perceived onset location will be in error in both the horizontal and vertical dimensions. Alternatively, if the target moves with a perceived vertical trajectory, then the error should only be along the vertical axis and should not affect the localization of the target’s starting point along the horizontal axis.

To successfully assess the effects of the double-drift illusion on perceived location, the confounding effect of the Fröhlich illusion needs to be eliminated. In an experiment like the current one, we attempted to accomplish this by adjusting the trajectory of the double-drift stimulus so that the perceived trajectory was vertical (with the horizontal component of the global motion offsetting that of the local motion). In this way, the perceived offset of the starting point due to the Fröhlich illusion would be biased in only the vertical dimension, leaving the perceived offset in the horizontal dimension unaffected.

However, our assumption that the effects of the Fröhlich illusion are based on perceived trajectory may be inaccurate. If, for example, the Fröhlich effect is driven only by the target's global motion, then it would confound the results of the current study. Therefore, a planned follow-up study will further investigate whether the Fröhlich effect can explain the pattern of results presented here. This study will use three global trajectories (tilted left, vertical, and tilted right), and either leftward or rightward local motion, or no local motion. Conditions without local motion should show only the effects of the Fröhlich illusion, without the confounding effects of the double-drift illusion. We will be compare the error in the perceived start of the trajectories for the conditions with internal motion to the counterpart condition without internal motion, which will allow us to de-confound the effects of the two illusions.

Summary

In the double-drift illusion, the perceived trajectory of a moving Gabor is biased by its internal local motion (Tse & Hsieh, 2006; Lisi & Cavanagh, 2015). It remains unclear whether this distorted trajectory is caused by erroneous perception of the current location of the stimulus, erroneous memory of its previous locations, or both. In the present experiment, we assessed how the perceived starting location of a double-drift trajectory changed over time. Participants were asked to compare the onset location to a flashed probe that could be presented before or after motion onset (-250, 0, 250, 500 or

1000ms). The local motion of the double-drift stimulus induced a small but significant distortion of the perceived starting location with probes presented 250ms before motion onset. The bias grew significantly with later probe presentations, reaching a plateau for delays of 250ms or longer. We predicted that the error in starting position perception would be correlated with the error in trajectory perception, but the correlation only reached significance for the 250ms delay. In ongoing experiments, we are measuring the distortion in position perception for both the top and bottom of the trajectory to infer a perceived trajectory based on the perceived target extremities. We predict that the trajectory drawn between the remembered endpoints will correlate with perceived trajectory orientation.

Appendix

Staircase Explanation

The trajectories across all trials and conditions had the same onset location which the location of the flash was staircased around. Each condition had two staircases; one approaching from the left, in which the initial flash was presented 100 pixels to the left of trajectory onset, and one from the right, in which the initial flash was 100 pixels to the right. The staircase shifted the flash location in one direction until it was perceived as switching sides of the trajectory's starting point, then the staircase began to shift the flash in the opposite direction (Figure 11).

Provided the participant judged the initial flash correctly, the flash in the next trial for this condition moved 64 pixels in towards the trajectory's onset location. For each successive trial in this condition, the flash moved another 64 pixels towards trajectory onset until the participant perceived the flash on the other side of the trajectory. Then the flash moved 32 pixels in the opposite direction, back towards the perceived onset location. Again, the flash shifted by 32 pixels in this direction for each successive trial, until the participant perceived the flash to switched sides of the trajectory.

When the participant responded that the flash had switched sides, it is called a 'reversal' because the staircase reverses directions. Following each reversal, the pixel step sized was cut in half until the step size reached 4 pixels. There were 16 total reversals, and we took the average of the final ten reversal locations (in pixels) to determine the point of subjective equality (PSE) for each staircase within condition. The

PSE indicates how far offset the perceived beginning of the trajectory moved due to the illusion.

We calculated the average PSE between the two staircases for each condition. Next, we calculated the difference between these average PSE locations for leftward versus rightward internal motion conditions, within a delay period. This difference represents how much internal motion affected target localization, such that the greater the difference was, the greater the effects of the illusion.

Staircase Example

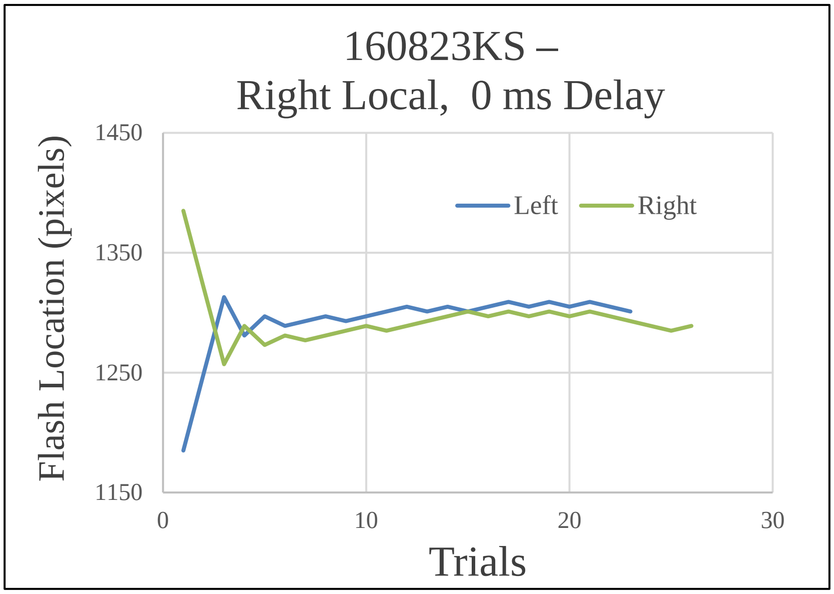

Figure 11: Staircase Results for One Participant in One Condition

This graph shows the data for one subject (160823KS) for the condition with right local/left global motion and a 0ms probe delay. The y-axis represents the location of the flash in pixels as it staircased around the actual trajectory onset location (1285 pixels). The x-axis represents the number of trials for this condition. The blue line depicts the staircase coming from the left of the onset location (1185 pixels) and the green depicts the staircase coming from the right (1385). Each peak marks a reversal, and each staircase continues until it reached 16 reversals.

Bibliography

Abrams, R. A., & Landgraf, J. Z. (1990). Differential use of distance and location information for spatial localization. Attention, Perception, & Psychophysics, 47(4), 349-359.

Aglioti, S., DeSouza, J. F., & Goodale, M. A. (1995). Size-contrast illusions deceive the eye but not the hand. Current biology, 5(6), 679-685.

Blanc-Goldhammer, D., Araujo Sanchez, M., Dassonville, P. (2016). Both Perception and Action Are Biased by Local Motion When Reporting the Location of a Moving Target. Visual Science Society Conference 2016, Abstract.

Brenner, E., & Smeets, J. B. (1996). Size illusion influences how we lift but not how we grasp an object. Experimental Brain Research, 111(3), 473-476.

Eagleman, D. M., & Sejnowski, T. J. (2007). Motion signals bias localization judgments: A unified explanation for the flash-lag, flash-drag, flash-jump, and Frohlich illusions. Journal of vision, 7(4), 3-3.

Frohlich, F. W. (1923). Uber die Messung der Empfindungszeit [Measuring the time of sensation]. Z Sinnesphysiol, 54, 58-78.

Goodale, M. A., & Milner, A. D. (1992). Separate visual pathways for perception and action. Trends in neurosciences, 15(1), 20-25.

Goodale, M. A., Milner, A. D., Jakobson, L. S., & Carey, D. P. (1991). A neurological dissociation between perceiving objects and grasping them. Nature, 349(6305), 154-156.

Lisi, M., & Cavanagh, P. (2015). Dissociation between the perceptual and saccadic localization of moving objects. Current Biology, 25(19), 2535-2540.

Massendari, D., Lisi, M., Collins, T., Cavanagh, P. (2016) A dissociation between the perceptual and saccadic localization of moving objects for reactive saccades but not for memory-guided saccades. Visual Science Society Conference 2016, Abstract.

Milner, A. D., Goodale, M. A., & Vingrys, A. J. (1995). The visual brain in action (Vol. 27). Oxford Psychology Series. Oxford University Press, Oxford.

Mishkin, M., Lewis, M. E., & Ungerleider, L. G. (1982). Equivalence of parieto-preoccipital subareas for visuospatial ability in monkeys. Behavioural brain research, 6(1), 41-55.

Mishkin, M., & Ungerleider, L. G. (1982). Contribution of striate inputs to the visuospatial functions of parieto-preoccipital cortex in monkeys. Behavioural brain research, 6(1), 57-77.

Müsseler, J., & Aschersleben, G. (1998). Localizing the first position of a moving stimulus: The Fröhlich effect and an attention-shifting explanation. Attention, Perception, & Psychophysics, 60(4), 683-695.

Pinel, J. P. (2014). Biopsychology with MyPsychLab. Pearson Education Limited.

Rossit, S., Szymanek, L., Butler, S. H., & Harvey, M. (2010). Memory-guided saccade processing in visual form agnosia (patient DF). Experimental brain research, 200(1), 109.

Smeets, J. B., & Brenner, E. (1995). Perception and action are based on the same visual information: distinction between position and velocity. Journal of Experimental Psychology: Human Perception and Performance, 21(1), 19.

Whitwell, R. L., Milner, A. D., Cavina-Pratesi, C., Barat, M., & Goodale, M. A. (2015). Patient DF's visual brain in action: visual feedforward control in visual form agnosia. Vision research, 110, 265-276.