

**TRANSSACCADIC UPDATING AND FEATURE
OVERWRITING**

A Thesis Presented for the
Master of Arts
Degree

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I would like to thank my family and my partner for being a great support system for me.

Further, I appreciate the guidance from my mentor, who has greatly fostered my
academic growth.

ABSTRACT

The present study investigated mechanisms of transsaccadic object updating. We have previously shown that the pre-saccadic representation of the saccade target object is overwritten by its post-saccadic representation when visual stability is established (Tas, Mordkoff, & Hollingworth, 2021). However, other studies have shown that the pre- and post-saccadic representations are instead integrated across saccades (e.g., Wolf & Schütz, 2015). An important difference between these studies was the task instructions. In our previous experiments, we asked participants to report either the pre- or the post-saccadic feature of the saccade target. However, studies which found integration effects asked participants to report the feature of the saccade target without specifying different states (pre-saccadic or post-saccadic) which may promote an integration mechanism. The present study tested this possibility. Participants executed a saccade to a colored disk. On half of the trials, the saccade target's color was changed by 15° during the saccade. After each trial, participants were asked to report the color of the saccade target object by clicking on the corresponding color on a color wheel (integration block). Participants also completed two blocks where they saw the saccade target either only pre-saccadically or only post-saccadically. In the current study, when we tested the fit of the response distributions of the integration trials, finding that data were best explained by a single distribution of responses at the post-saccadic color value. We also tested whether integration trials resulted in better performance compared to the best of the pre-saccadic only (PreOnly) or post-saccadic only blocks (PostOnly). We found no evidence for cue integration: Color reports were not significantly more precise in the integration block

compared to the best single performance. Together, these findings failed to show support for integration, but found support for overwriting in nearly 100% of the trials.

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CHAPTER ONE

INTRODUCTION

As we observe our environment, to gather detailed information about the objects in the environment, we execute saccades to focus our small range of high-resolution foveal vision on different objects in our surroundings (Irwin, 1992). However, our visual perception is suppressed during saccades, a process called saccadic suppression (Matin, 1974). Thus, each saccade captures two representations of the saccade target object: the pre-saccadic representation that is visible in our periphery before the initiation of the movement of the eyes, and the post-saccadic representation that is foveated on upon landing after the movement of the eyes. Despite this disruption in our visual input, we perceive the world as continuous. How do we update information across saccades and establish stability across over 100,000 saccades we make each day?

Some researchers have proposed that the peripheral and foveal representations are integrated in some form (Oostwoud Wijdenes, Marshall, & Bays, 2015; Stewart & Schütz, 2018), while others argue that transsaccadic updating occurs with an object-based masking process where the pre-saccadic representation is overwritten by the post-saccadic one (Tas, Mordkoff, & Hollingworth, 2021). According to transsaccadic integration accounts, the pre- and post-saccadic representations are merged into a single percept, resulting in a final representation whose value is somewhere between the pre- and post-saccadic feature. In contrast, object-mediated updating account states when the pre-saccadic representation is overwritten by the post-saccadic one, and as a result, the pre-saccadic feature value will be lost.

In the present study, we employed a method that allowed us to directly compare different mechanisms of transsaccadic updating by asking participants to report the color of the saccade target object. In some of the trials, the color of the saccade target changed transsaccadically, but participants were not informed of this change. We also included conditions where the saccade target was presented only pre-saccadically (PreOnly) or only post-saccadically (PostOnly), allowing comparison between these trials and the transsaccadic trials. These measures allowed us to directly test the different approaches to transsaccadic updating.

Transsaccadic Updating

We execute saccades to gain information about our environment. During a saccade, the processing of visual information is suppressed (Matin, 1974). Saccadic suppression is evident in tasks where the saccade target is displaced during the eye movement: Participants usually do not detect the displacement even when the saccade target is displaced up to one-third of the total distance of the saccade (Bridgeman, Hendry, & Stark, 1975). A common explanation for the saccadic suppression of target displacement is that most changes go undetected is that they are perceived as being an error of the oculomotor movement itself. In other words, there is an underlying assumption of visual stability, such that slight variations in the stimuli are perceived as error and go unnoticed until the changes become large enough to disrupt the assumption of visual stability. Once visual stability is disrupted, participants become more sensitive to changes that occur transsaccadically (Deubel, Schneider, & Bridgeman, 1996). Visual stability can be disrupted in many ways, such as disrupting spatiotemporal continuity by

removing the saccade target object for approximately 250ms during the eye movement, which exceeds the duration of the saccade such that the saccade target does not reappear until after the saccadic landing (Deubel et al., 1996). This object continuity manipulation results in significantly increased sensitivity to displacements of the saccade target object. Alternatively, stability can also be disrupted by making drastic changes to the surface features of the saccade target object such as size (Feldman & Tremoulet, 2006), luminance (Tas, Moore, & Hollingworth, 2012; Feldman & Tremoulet, 2006), shape (Demeyer, De Graef, Wagemans, & Verfaillie, 2010; Feldman & Tremoulet, 2006), and identity (Tas et al., 2012). When stability is disrupted, participants become more sensitive to the displacements of the saccade target object (Deubel et al., 1996). One explanation for this increased sensitivity is that under the conditions of instability, the pre- and post-saccadic representations are perceived as belonging to different objects, and therefore, participants are able to access the location of the pre-saccadic object and compare it with the location of the post-saccadic object (Deubel et al., 1996; Tas et al., 2021).

The suppression of information during a saccade leaves our visual system with two representations of the saccade target object: a peripheral pre-saccadic representation and a foveal post-saccadic representation. It is important to understand how the pre- and post-saccadic representations obtained from each saccade are combined across identical and slightly varied saccade target objects. Early theories of transsaccadic updating claimed the existence of a low-level fusion of detailed sensory information (McConkie & Rayner, 1976). This account holds that pre-saccadic information is transferred in low level sensory memory, such that the final percept is a completely fused image of the

information from the pre- and post-saccadic representations. Previous work has failed to support the use of low-level sensory or "photographic" representations across saccades when they examined whether participants could fuse sets of lines to form a merged representation of the individual images presented (O'Regan & Lévy-Schoen, 1983).

Alternatively, more recent work has shown support for a low-level integration of feature information across saccades rather than a fusion of two "photographic" representations (see Herwig, 2015 for review). This idea of integration can include averaging feature information of a saccade target object when the values are not the same value (Oostwoud Widjenes et al., 2015; Hübner & Schütz, 2017; Wolf & Schütz, 2015). Another form of integration is cue integration, which is a specific type of feature integration that occurs when the information from the pre- and post-saccadic objects are the same, and the redundancy results in improved responding (van Dam, Parise, & Ernst, 2014; Stewart & Schütz, 2018). Alternatively, there is also the overwriting approach, where the visual system overwrites pre-saccadic information with post-saccadic information transsaccadically (Tas et al., 2021).

Feature Averaging

Recent work in transsaccadic updating has shown support for a low-level integration of feature information about the target across saccades (Demeyer et al., 2010; Ganmor, Landy, & Simoncelli, 2015; Oostwoud Wijdenes, et al., 2015; Schut, Van der Stoep, Fabius, & Van der Stigchel, 2018; Wolf & Schütz, 2015).

In one such study, participants were presented with three stimuli of different colors at equidistant locations just above the fixation point, post-saccadic location, and

central location (Oostwoud Wijdenes et al., 2015). Participants were instructed to execute a saccade to a saccade target location while remembering the color of each of the three targets. The targets were peripheral targets, such that none of them were foveated on, but remained above the fixation point and saccadic landing point. The purpose of this manipulation was to ensure that the representations were not much stronger for some targets than others as a result of fixating directly on the target. Each of the targets changed color by a magnitude of 20° on the color wheel as soon as a saccade was detected. The authors used a small color change magnitude so that the participants would not be aware of the color change, and the color change itself would not disrupt stability. A color wheel was presented at the end of the trial, and participants were asked to report the last color that they saw by clicking on the corresponding location on the color wheel. The authors found that the color response distributions showed a single distribution with a mean at an intermediate value between the pre- and post-saccadic color values, indicating averaging of the pre-saccadic and post-saccadic color values. Further, the authors proposed that the integration is optimal, such that the pre-saccadic and the post-saccadic representations are weighted based on the reliability (or precision) of each representation, which resembles past work done in areas of transsaccadic integration and multisensory integration (also see Ganmor et al., 2015; Stewart and Schütz, 2018; Stewart & Schütz, 2019; Wolf & Schütz, 2015; van Beers, Sittig, & Gon., 1999; Ernst & Banks, 2002; Ernst & Bühlhoff, 2004; Niemeier, Crawford, & Tweed, 2003). To test optimal integration, the authors manipulated reliability by introducing visual noise to the

stimuli and showed that color response performance was biased in favor of the more reliable (less noisy) stimulus and had lower variability in the low noise condition.

While these results have been interpreted as providing evidence for feature averaging, there is a possible alternative explanation for these results. It is possible that pre-saccadic information was overwritten by post-saccadic information in some of the trials. With a color change magnitude of 20° , two response distributions (one for pre-saccadic and one for post-saccadic) would be close to each other and thus may appear as a unimodal distribution at an intermediate value. In other words, there may be an underlying bivariate structure in the data, but without such tests it is not possible to differentiate between feature averaging and overwriting.

Cue Integration

Another form of feature integration is cue integration, where the pre-saccadic and post-saccadic feature information is the same, and participants benefit from the redundancy (Ganmor et al., 2015; Hübner & Schütz, 2017; Stewart & Schütz, 2018, 2019; Wolf & Schütz, 2015). Early work defines cue integration as the optimization of the precision of participant responding as a result of multisensory information (Rohde, van Dam, & Ernst, 2015; Clark & Yuille, 1990; Ernst & Banks, 2002). In other words, we benefit from the weighted integration (integration of stimuli which are weighted based on their reliability) of redundant information from multiple modalities as compared to information from any modality in isolation (van Dam et al., 2014).

This idea of cue integration has been recently applied to transsaccadic updating, with researchers finding that responses improved in conditions where the pre- and post-

saccadic information were identical compared to conditions where they saw either in isolation (Stewart & Schütz, 2018). In this task, participants fixated at a central location until a saccadic target appeared. In the integration condition of this study, participants were instructed to execute a saccade when the colored disk appeared in their periphery. After landing on the disk, a color wheel would appear, and participants were instructed to report the color that they saw by clicking the corresponding location on the color wheel. Note that to test cue integration, participants were presented with the same stimulus both pre- and post-saccadically in the transsaccadic trials. These transsaccadic trials were then compared with trials where the pre-saccadic stimulus was presented in isolation (peripheral trials) and the post-saccadic stimulus was presented in isolation (foveal trials). In this task, cue integration would predict that representation of the target object would be significantly more precise in the transsaccadic trials compared to the peripheral and foveal trials. Supporting this idea of improved responding in the transsaccadic trials, the results showed that standard deviations in the transsaccadic trials were significantly lower than standard deviations in the peripheral or foveal trials (Stewart & Schütz, 2018). The authors interpreted these results as evidence that the pre- and post-saccadic information is being combined to improve performance.

Overwriting

In contrast to the studies showing evidence of integration, recent evidence has supported the object-based updating, or overwriting of pre-saccadic information with post-saccadic information (Tas et al., 2021). Object-mediated updating explains the process in which the visual system continues to take in information and updates object

information when a later representation of the object is perceived as the continuation of the earlier representation. That is, when object continuity is established, the later instances of the object updates, thus overwrites, the previous instances (Moore, Mordkoff, & Enns, 2007). Based on the object-mediated updating account, when our visual system takes in information for two representations of one object (a pre- and post-saccadic representation) that are perceived to belong together, then visual stability is established, and the pre-saccadic information is overwritten with the post-saccadic information.

To test overwriting, participants were presented with a colored disk and asked them to saccade to the disk. While the participants are executing a saccade, the color of the disk changed so that their eyes landed on a different color, and the change was either 15°, 30°, or 45° on a color wheel in clockwise or counterclockwise direction (Tas et al. 2021). These variations include the magnitude of change used by Oostwoud Wijdenes et al. (2015) at 20° and the magnitude of change used by Schut et al. (2018) at 30°. Unlike any of the prior studies measuring feature averaging and cue integration, object continuity was manipulated by including manipulation in half of the trials where the target object was briefly removed (i.e., blanked) from the screen to disrupt visual stability (Deubel et al., 1996). Because visual stability was not established in the trials with a blank screen, the two representations of the target object were not perceived as belonging together. Participants were then post-cued to report to either the pre-saccadic or the post-saccadic color value, by clicking a location on a color wheel. This manipulation varied from Oostwoud Wijdenes et al. (2015) and Schut et al. (2018), where participants were

not told to respond to a specific state of the target, but only to report the color that they remember seeing.

When visual stability was established, participants reported the post-saccadic color value in a large number of the trials where they were asked to report the pre-saccadic stimulus, resulting in bivariate color report distributions. The proportion of trials in which the pre-saccadic color value was decreased as the magnitude of color change increased, presumably because larger color changes led to some trials where visual stability was disrupted due to the color change alone. It is likely that the pre-saccadic information was not overwritten in all the trials because the participants had an incentive to report the pre-saccadic representation. The use of a task that requires pre-saccadic report resulted in a distribution of responses at the pre-saccadic value and a distribution of responses at the post-saccadic value, with most of the responses at the post-saccadic value. When visual stability was not established (i.e., a blank screen was presented), the pre-saccadic representation was preserved, such that participants were better able to report the pre-saccadic representations.

It is important to note that the studies testing feature integration and overwriting implemented different methods. For example, the work supporting feature averaging required participants to report the color that they perceived without distinguishing which state (pre- or post-saccadic) (Oostwoud Wijdenes et al., 2015). Alternatively, the study using color information to test overwriting required participants to separate the representations by post-cuing to specifically report the pre-saccadic value or the post-saccadic value (Tas et al., 2021). Further, the studies testing feature averaging (Oostwoud

Wijdenes et al., 2015) and cue integration (Stewart & Schütz, 2018) did not manipulate visual stability, while the study testing feature overwriting did (Tas et al., 2021). Studies examining feature averaging also only included a color variation of 20° (Oostwoud Wijdenes et al., 2015) or 30° (Schut et al., 2018), while the study finding evidence of overwriting used a range of color change magnitudes at 15°, 30°, and 45°. Further, the work supporting overwriting (Tas et al., 2021) tested the data for underlying bivariate structures, which was a test that was not included in the work supporting feature averaging. Considering these differences in both the experimental design and analyses, it is not possible to compare the findings of these studies and thus the different mechanisms of transsaccadic updating.

Current Study

The aim of the current study was to test all three approaches to transsaccadic updating: feature averaging, cue integration, and overwriting. To do that, in the following experiments, we combined the tasks used by Tas et al. (2021) and Stewart and Schütz (2018). The experiment had three blocks: transsaccadic, PreOnly, and PostOnly. In the transsaccadic block, participants were instructed to execute a saccade to a peripheral target object. Critically, on half of the trials the color of the target was subtly changed while participants were executing the saccade. The color change occurred during saccadic suppression, such that participants should not be able to perceive the resulting transient. At the end of each trial, the participants were asked to report the color of the target. The responses in this transsaccadic block were used to test the feature averaging and overwriting accounts by examining the response distributions and testing for underlying

bivariate structures that may indicate responses at the pre- and post-saccadic values rather than an intermediate value. To test for cue integration, we included two additional blocks, one of which presented a stimulus pre-saccadically only and the other which presented a stimulus post-saccadically only. Performance in these single blocks were then compared with performance in the transsaccadic block to test whether redundant information in the transsaccadic block resulted in more precise color reports.

If the pre- and post-saccadic features are integrated in the sense that their values are averaged, then participants' color report distributions should be centered around the midpoint of the pre- and post-saccadic color values. If, however, the pre-saccadic feature is overwritten by the post-saccadic feature, then the color response distributions should be centered around the post-saccadic value. Previous studies have shown that this type of object-based overwriting is probabilistic, and therefore, does not occur on every single trial (Tas et al., 2021), possibly due to color changes disrupting visual stability on a proportion of trials (Tas et al., 2012). In the following experiments we used a relatively small color change (15°), but it is still possible that this color change would disrupt visual stability. If this change does disrupt visual stability, it is possible that we will not observe overwriting in all the trials.

For the blank trials, either effect observed in the no blank trials (integration or overwriting) may be attenuated. When visual stability is disrupted, the representation of the pre-saccadic value is protected from being overwritten, therefore, participants should be able to report both pre- and post-saccadic values accurately. Therefore, if overwriting is observed in the no blank trials, disrupting stability would reduce overwriting.

Alternatively, if integration is observed in the no blank trials, then the disruption of visual stability may reduce integration.

If cue integration occurs, then responses should improve significantly in trials where the pre-saccadic and post-saccadic color values are identical when compared to trials where the stimulus is presented either only pre-saccadically or only post-saccadically. To test this, the standard deviations of the response distributions in the transsaccadic block were compared with the best of either the PreOnly or the PostOnly trials. If the representations are integrated optimally, then we expect to find significantly smaller standard deviations (i.e., more precise color reports) in the transsaccadic block than in the best of the single blocks. In the blank conditions, any observed effects of cue integration may be weaker because of the disruption of visual stability.

CHAPTER TWO

EXPERIMENT 1

Materials and Methods

Participants

We recruited 23 undergraduate students (age range 18-31, $M=21.22$) from the University of Tennessee-Knoxville for participation in this experiment in return for course credit. Data from six participants were eliminated from the analyses (two due to experience with similar task previously and four for inability to complete the study), resulting in 17 participants (15 female) in the final dataset. The tasks were reviewed and approved by the University of Tennessee Knoxville Institutional Review Board. All participants reported normal or corrected-to-normal vision and screened for color deficiency with an 8-plate Ishihara color deficiency test.

Stimuli

At the beginning of each trial, participants fixated on a white fixation cross that subtended 1.5 degrees of visual angle (dva) at the center of the screen. The pre-saccadic stimulus appeared at a randomized value between 5 and 7 dva on the left or right side of the fixation cross. The pre-saccadic and post-saccadic stimuli were circles that subtended 0.5 dva presented on a gray (RGB: 148, 148, 148) background. The color of the pre-saccadic stimulus was randomly selected from 360 possible values distributed within HSV color space. The saturation and lightness were set at 0.7. The color of the post-saccadic circle in the change trials was changed 15° clockwise or counterclockwise (randomly) from the pre-saccadic value. The color wheel used to collect the responses

was an annulus with an outer radius of 7 dva and an inner radius of 3 dva. The orientation of the color wheel was randomly rotated in each trial to avoid response biases.

Apparatus

The stimuli were all presented on a ASUS VG248 LED monitor with 1920 × 1080 resolution at a 60 Hz refresh rate. Participants were seated with a chin and forehead rest to ensure a distance of 94 cm from the screen. The position of the right eye was monitored using an Eyelink 1000 Plus eye tracker sampling at 1000Hz. The experiment was controlled with Experiment Builder.

Procedure

At the beginning of the experiment, the participant's right eye was calibrated with a 9-point calibration. The calibration was repeated after every block and within a block if necessary. Each trial was initiated by the experimenter once participants had fixated within 1.5 dva from the center for at least 200 ms to enable drift correction. At the beginning of each trial, participants were instructed to fixate on a cross in the center of the screen until the pre-saccadic stimulus appeared. Participants were instructed to execute a saccade to the pre-saccadic stimulus as soon as they detected the pre-saccadic stimulus. The pre-saccadic stimulus remained on the screen until the eye crossed a 1.5 dva boundary, and post-saccadic stimulus appeared once the eye crossed a 1.5 dva radius boundary around the post-saccadic stimulus. Waiting to present the post-saccadic stimulus until the boundary cross ensured that the post-saccadic stimulus would not be incorrectly triggered if participants made an erroneous eye movement or an anticipatory

saccade. Additionally, if the pre-saccadic duration was less than 100 ms, then the post-saccadic duration was set to 250 ms.

The experiment had three blocks: transsaccadic, PreOnly, and PostOnly. In the transsaccadic block, participants were presented with a colored disk for both the pre- and post-saccadic targets, and they were asked to report the color that they saw. There were two primary manipulations: manipulation of color change and of object continuity. In half of the trials, the color changed transsaccadically, such that the post-saccadic target was 15° (clockwise or counterclockwise) away from the value of the pre-saccadic value (color change trials). The manipulation of color allowed a test of feature averaging and overwriting. Further, in half of the trials, a 250 ms blank screen was presented during the saccade before the presentation of the post-saccadic stimulus as a manipulation of visual stability (Deubel et al., 1996).

In the PreOnly block, we presented a colored pre-saccadic stimulus, which was then replaced by an annulus once the eye crossed the boundary around the fixation cross. In the PostOnly block, the pre-saccadic stimulus was an annulus, and the post-saccadic stimulus was a colored circle. In the PostOnly trials, the post-saccadic stimulus was presented for the average duration of the previous four trials or for 250 ms if the pre-saccadic duration was less than 100ms to avoid durations that were too short or too long. Colors for both the PreOnly and PostOnly blocks were selected from a list of colors presented in the transsaccadic blocks change trials, since these trials are also used to test overwriting.

At the end of each trial, participants were asked to report the color that they saw by using their mouse to select a location on the color wheel (See Figure 3.1). In contrast to Tas et al. (2021), participants were not told to report the pre-saccadic or post-saccadic stimulus separately to prevent them explicitly detecting the color change. After the experiment, they were asked to report anything that they noticed about the experiment, which provided an opportunity to see if the participants noticed that the colors changed.

All participants started with the transsaccadic block, since the color values for the PreOnly and PostOnly block utilized the colors presented in the transsaccadic block. The order of PreOnly and PostOnly blocks was counterbalanced across participants. In the transsaccadic block, there were 8 practice trials and 300 experimental trials. In the final two blocks, there were 4 practice trials and 150 experimental trials per block. The entire experiment took an hour to complete.

Results

Saccades in this data set were determined by the eyes crossing a 1.5 dva boundary around the fixation cross. If the participant failed to make an eye movement 4 seconds after the pre-saccadic stimulus was presented, an error message was displayed notifying the participant that the eye movement was incorrect, and the trial was aborted and repeated. Trials with saccade latencies that exceeded 2 standard deviations above the average ($M=160.9$, $SD=76.9$) or less than 100ms were removed, resulting in the removal of 9.7% of the trials from analyses.

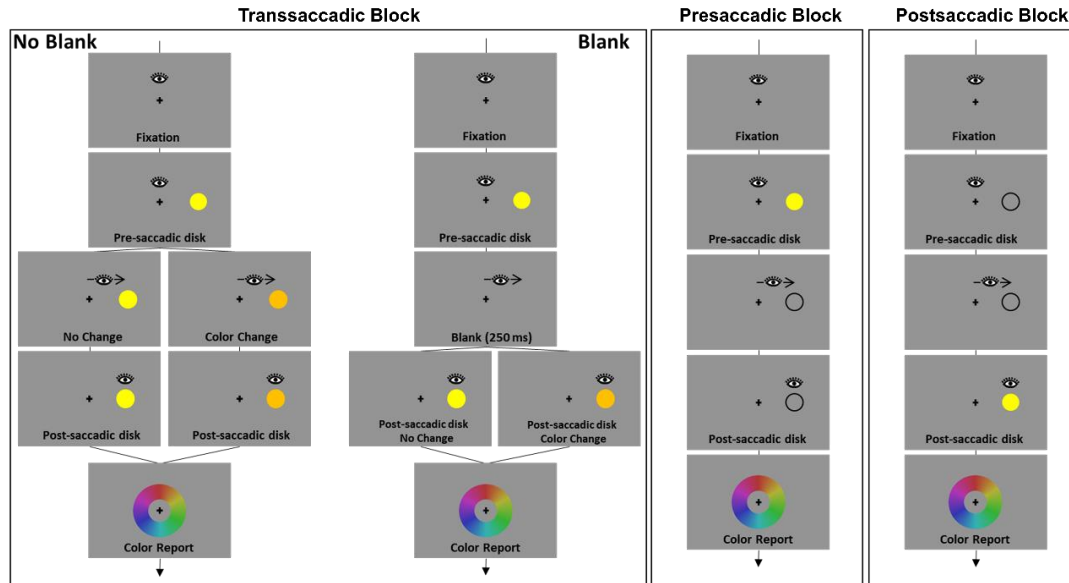


Figure 3.1. Task. Types of trial in each block. The representation of the eye in the diagram indicates where the eye is during each step of the trial. The left panel is an example of a no-blank and a blank trial in the transsaccadic block. The blank trials included a 250ms blank screen between the pre-saccadic stimulus and the post-saccadic stimulus. In the change trials, the colors shifted by $\pm 15^\circ$ on the color wheel. The middle and right panels show an example trial in the PreOnly block and PostOnly block, respectively. The stimuli are not drawn to scale.

Feature Integration and Overwriting

The data from the change trials of the transsaccadic block were fit to probabilistic mixture models to test if the data were better fit to a single gaussian model with a variable mean (Model 1), a single gaussian model fixed at 15° (Model 2), or a dual gaussian model with means fixed at 0° and 15° (Model 3). More specifically, the single gaussian model represents a model with one distribution of responses with mean, standard deviation, and probability of guessing set as free parameters (Suchow, Brady, Fougner, & Alvarez, 2013). In the analyses for the single gaussian model with mean as a free parameter, the target was defined as the pre-saccadic and the distractor was defined as the post-saccadic value. To test for complete overwriting, we also used a single gaussian model with the mean fixed at the post-saccadic value (15°) while the standard deviation and probability of guessing were free parameters. In the analyses for the single gaussian model with the mean fixed at 15°, the target was defined as the post-saccadic value. The dual gaussian model represents a model with two distributions with means fixed at the pre-saccadic value (0°) and the post-saccadic value (15°), while the standard deviation, probability of guessing, and the probability of reporting a distractor value were free parameters (Bays, Catalao, & Husain, 2009). In the analyses for the dual gaussian model, the target is defined as the pre-saccadic value and the distractor is defined as the post-saccadic value. The data were analyzed in MATLAB using MemToolbox (Suchow et al., 2013). The Bayes Information Criterion (BIC) was calculated to test how well each model explained the data (Schwarz, 1978). The model with the lowest BIC value is considered to provide the best explanation of the results.

Figure 3.2 shows the distribution of responses for the transsaccadic color change trials. In the no blank trials, the single gaussian model with mean as a free parameter (Model 1, $BIC=630.37$) and the dual gaussian model (Model 3, $BIC=630.53$) had nearly identical BIC values (see Table 3.1). However, the single gaussian model with a mean fixed at the post-saccadic value (Model 2, $BIC=628.27$) had the lowest BIC value and thus was the best model to explain the data. Therefore, for the no-blank trials, the most likely explanation of the data was complete overwriting. The probability of reporting the target value (pt) in the Model 2 was estimated to be 0.99, suggesting that when visual stability was established, the pre-saccadic value was overwritten by the post-saccadic value on 99% of trials.

One interesting observation from the data is that the mean value for the distribution in the color change no blank transsaccadic trials obtained from Model 1 ($M=12.55$) was 2.45° short of the post-saccadic value of 15° . Feature integration account would predict that the mean of the response distribution should be closer to the average of the pre- and post-saccadic values, which would be around 7.5° . Together with the finding that the data were best explained by a complete overwriting model (Model 2), these results suggest that the pre- saccadic color value was overwritten by the post-saccadic color value on almost every trial when visual stability was established.

For the blank trials, on the other hand, Model 2 had the largest BIC value ($BIC=636.52$), and BIC values of Models 1 and 3 were nearly equivalent ($BIC=635.74$ and $BIC=635.71$, respectively), suggesting that when visual stability was disrupted partial overwriting and feature averaging provided equally likely explanations.

Cue Integration

To test cue integration, we compared the standard deviations of the no blank no change trials in the transsaccadic block ($M=17.5$) to the best of the PreOnly trials and PostOnly trials ($M=17.6$), and we did not find a significant difference, $t(16)=0.19$, $p=.847$. In other words, participants did not significantly benefit from the transsaccadic presentation of stimuli. These results fail to support cue integration.

We also examined the standard deviations between the color change no blank transsaccadic trials ($M=21.4$) and the best of the PreOnly and PostOnly trials ($M=17.6$), finding that the best of the PreOnly and PostOnly trials had a significantly smaller standard deviations than the color change trials $t(16)=7.27$, $p<.001$, indicating that performance significantly improved in the PreOnly and PostOnly blocks when compared to the color change no blank transsaccadic trials, but not in comparison to the no change no blank transsaccadic trials. These results show evidence against cue integration. In fact, single trials resulted in more precise color reports compared to transsaccadic blocks with color change. It is possible that color change in these transsaccadic trials may have led to disruption of visual stability. As a result, the pre- and post-saccadic representations are separated as different objects, leading to less precise representation of color information.

Change Detection

At the end of the experiment, participants were asked whether they noticed anything during the experiment. Of the 17 participants, 14 participants reported noticing that the color changed during the task. Of those 14 participants who noticed, 13 expressed it verbally at some point during the experiment. The sensitivity to change indicates that,

while the magnitude of color change was small and the task did not require separate responses to the pre- and post-saccadic stimuli, participants were still sensitive to the transsaccadic changes. It is possible that participants easily detected the color change in the blank trials, due to disruption of stability on those trials. Because the current study employed a mixed design, it is not possible to know whether participants also detected color changes in the no blank trials.

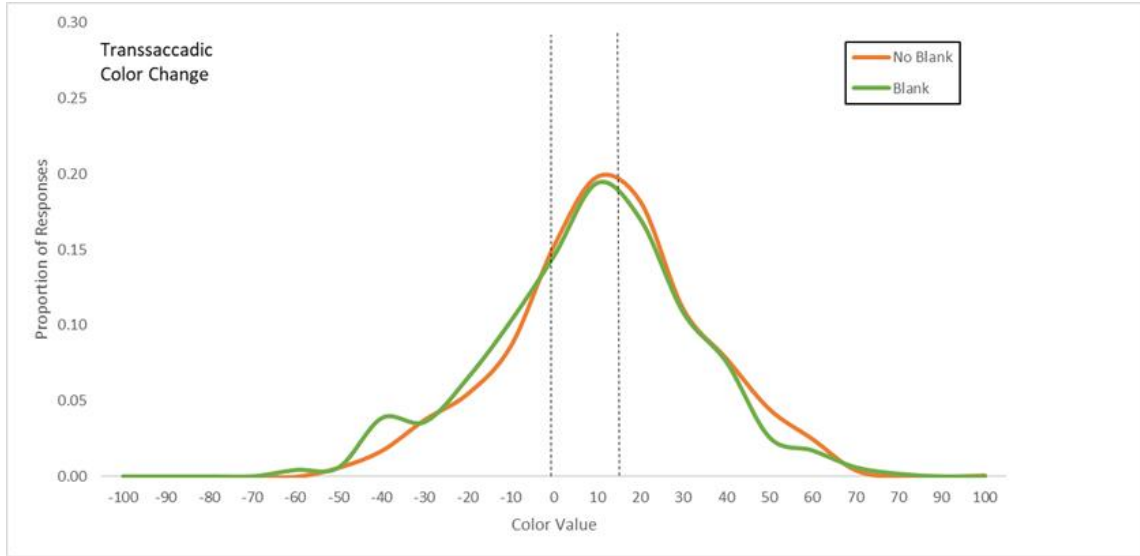


Figure 3.2. The figure shows the distribution of responses across the different color values with the orange line representing responses in the blank condition and the blue line representing responses in the no blank condition.

Table 3.1. The table below shows the values of the no blank and the blank condition for the four models used to test the data: a single gaussian model with a variable mean, a single gaussian model with the mean fixed at the post-saccadic value, and a dual gaussian model.

Condition Parameter	No Blank						Blank					
	μ	SD	$p_{guessing}$	p_{pre}	p_{post}	BIC	μ	SD	$p_{guessing}$	p_{pre}	p_{post}	BIC
Single Gaussian Variable Mean (Model 1)	12.55	21.97	0.001	0.999	-	630.37	9.28	22.86	0.002	0.998	-	635.74
Single Gaussian Mean at 15° (Model 2)	-	22.40	0.000	-	1.00	628.27	-	23.75	0.002	-	0.998	636.52
Dual Gaussian (Model 3)	-	21.35	0.001	0.81	0.19	630.53	-	21.86	0.002	0.62	0.38	635.71

CHAPTER THREE

EXPERIMENT 2

The results of Experiment 1 expanded on the previous study (Tas et al., 2021) by including a way to examine cue integration effects with the inclusion of a PreOnly block and a PostOnly block. The results of Experiment 1 supported overwriting and failed to find support for feature averaging and cue integration. Experiment 1 selected the color values for each of these blocks from the colors previously presented in the transsaccadic change trials. Experiment 2 is identical to the methods of Experiment 1, but colors were selected from the transsaccadic no change trials for presentation in the PreOnly and PostOnly trials. Because the primary goal of examining cue integration is to compare the performance of the PreOnly and PostOnly blocks with the transsaccadic no change trials, testing the PreOnly and PostOnly blocks with the colors from the no change trials may provide a more direct comparison. This direct comparison should remove the possibility that failure to support cue integration in Experiment 1 was a result of using different color values in the PreOnly and PostOnly block than in the no change transsaccadic trials. Further, selecting colors from the no change trials enabled us to examine whether the results may differ as a result of repeating no change color values from the transsaccadic block in the PreOnly and PostOnly blocks rather than repeating colors from the change trials of the transsaccadic block in the PreOnly and PostOnly blocks.

As in Experiment 1, if feature information is averaged across transsaccadic change trials, then the color report distributions should be centered at an intermediate value between the pre- and post-saccadic color values. Alternatively, if the pre-saccadic

color information is overwritten by the post-saccadic color information, then the color report distributions should be centered at the post-saccadic value. Similarly, if the overwriting is probabilistic, then participants may report the pre-saccadic value in some trials, such that there is an underlying bivariate structure in the data. For the blank trials, either effect observed may be attenuated by the disruption of visual stability by improving participants' ability to report the pre-saccadic color value.

If cue integration occurs, then performance in the no change no blank transsaccadic trials should be significantly better than performance in the PreOnly or PostOnly blocks. Further, if providing a more direct comparison by using the no change transsaccadic colors in the PreOnly and PostOnly blocks supports cue integration, then the standard deviations in the no change transsaccadic trials should be significantly lower than the standard deviations in the best of the PreOnly or PostOnly blocks.

Materials and Methods

Participants

We recruited 31 undergraduate students (age range 18-30, $M=19.65$) from the University of Tennessee-Knoxville for participation in this experiment in return for course credit. Of these participants, data from three participants were removed from analyses due to issues with calibration, one for self-reported difficulty completing the task or seeing the stimulus, and one for technical difficulties causing the program to crash during the experiment. The final sample included 26 participants.

Procedure

The stimuli and procedure were the same as in Experiment 1, except for the differences noted. For 16 of the participants, the tracker waited for 30ms after the eye left the fixation cross to present the post-saccadic display. Second, in Experiment 1 in blank trials, the program waited until the detection of the eye in the post-saccadic target location before presenting the target. In Experiment 2, this boundary was removed for 9 of the participants, therefore, the post-saccadic stimulus was presented immediately following the blank screen. Third, contrary to Experiment 1, the pre-saccadic and post-saccadic durations were equated for all pre-saccadic duration values within the same trial. More importantly, in Experiment 2, the colors used in the PreOnly and the PostOnly blocks were selected from a list of colors presented in the transsaccadic no change trials.

Results

As in Experiment 1, trials with saccade latencies that exceeded 2 standard deviations above the average ($M=175.9$, $SD=95.9$) or less than 100ms were removed, resulting in the removal of 6.4% of the trials from analyses.

Feature Integration and Overwriting

Color response distributions in the color change trials of the transsaccadic block are plotted in Figure 4.1. In the no blank trials, there was not a large difference between a single gaussian model with the mean as a free parameter (Model 1, $BIC=659.44$) and the dual gaussian model (Model 3, $BIC=659.63$). Replicating Experiment 1, the single gaussian model with a mean fixed at the post-saccadic value (Model 2, $BIC=657.41$) had the lowest BIC of all of the models. In other words, the data were again best explained by

Model 2. When visual stability was established, the pre-saccadic information was overwritten by the post-saccadic information 99.9% of the time. See Table 4.1 for a visual representation.

Replicating Experiment 1, we found that the mean value for the Model 1 in the color change no blank transsaccadic trials ($M=12.73$) is 2.27° away from the post-saccadic value of 15° . Feature integration would predict that the mean of the Model 1 would be at a centered value between the pre- and post-saccadic values, or around 7.5° . Based on our findings that the mean of Model 1 is close to the post-saccadic value and the data were overall better explained by Model 2, the data support an overwriting account. These findings show that, similar to Experiment 1, the pre-saccadic information is overwritten with the post-saccadic information in nearly 100% of the trials in Experiment 2.

Results In the blank trials, Model 1 and Model 3 had very similar BIC values ($BIC=660.35$ and $BIC=660.40$, respectively). Similar to Experiment 1, Model 2 ($BIC=659.22$) had the lowest BIC value. These results indicate that in the blank trials, the best model to explain the data is Model 2. When visual stability was disrupted, the pre-saccadic information was overwritten by the post-saccadic information 99.6% of the time.

Cue Integration

To test cue integration, we compared the standard deviations of the transsaccadic no blank no change trials to the best of the PreOnly trials and PostOnly trials. In contrast to what cue integration would predict, standard deviations in the best of the PreOnly and

PostOnly ($M=21.38$) were significantly smaller than the standard deviations in the transsaccadic no blank no change trials ($M=22.58$), $t(25)=-2.43$, $p=.022$. As in Experiment 1, we failed to find support for cue integration, as our data do not indicate improved responding in the transsaccadic no blank no change trials when comparing them to the single conditions. Standard deviations in the color change no blank transsaccadic trials ($M=22.21$) were also not significantly different from the best of the PreOnly and PostOnly trials, $t(25)=1.95$, $p=.062$. Thus, similar to Experiment 1, the results showed no evidence of cue integration.

Change Detection

Of the 26 participants, 14 participants reported noticing that the color changed during the task. Of those 14 participants that noticed, 11 also expressed it verbally at some point during the task. These results replicate Experiment 1 and suggest that participants were able to detect a 15° color change during the experiment, possibly due to the presence of blank trials.

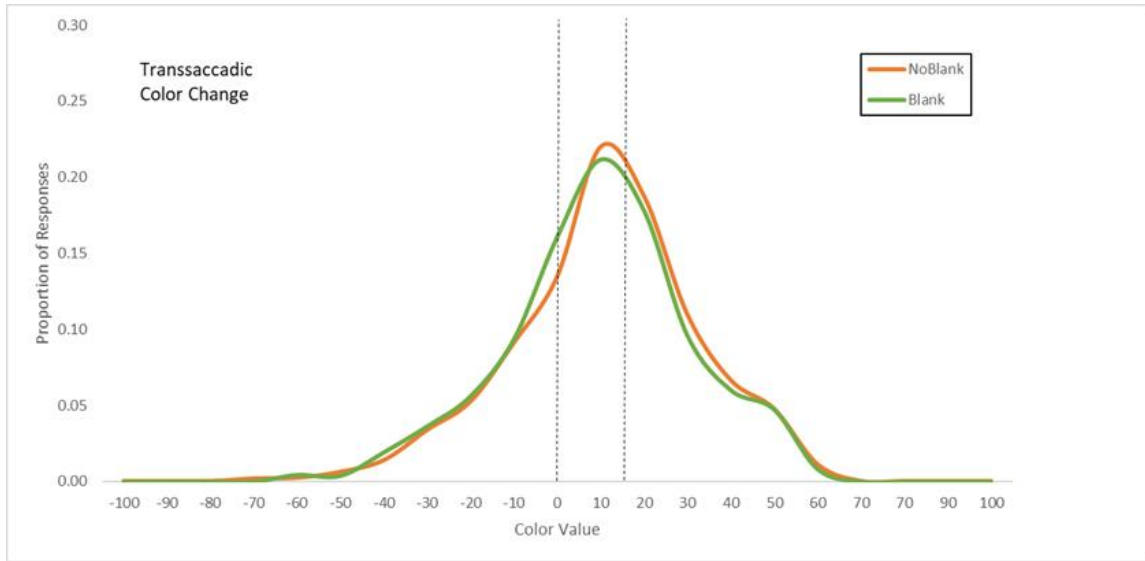


Figure 4.1. The figure shows the distribution of responses across the different color values with the orange line representing responses in the blank condition and the green line representing responses in the no blank condition.

Table 4.1. The table below shows the values of the no blank and the blank condition for the four models used to test the data: a single gaussian model with a variable mean, a dual gaussian model, a standard mixture model fixed at the post-saccadic value, and a swap model.

Condition Parameter	No Blank						Blank					
	μ	SD	$p_{guessing}$	p_{pre}	p_{post}	BIC	μ	SD	$p_{guessing}$	p_{pre}	p_{post}	BIC
Single Gaussian Variable Mean (Model 1)	12.73	22.21	0.001	0.999	-	659.44	11.17	22.01	0.004	0.996	-	660.35
Single Gaussian Mean at 15° (Model 2)	-	22.55	0.001	-	0.999	657.41	-	22.53	0.004	-	0.996	659.22
Dual Gaussian (Model 3)	-	21.61	0.001	0.81	0.19	659.63	-	21.14	0.005	0.74	0.25	660.40

CHAPTER FOUR

DISCUSSION

The results of the two experiments failed to support feature averaging and cue integration but provided support for overwriting. Unlike Tas et al. (2021) which found probabilistic overwriting, our data showed overwriting in nearly 100% of trials.

Some previous work using color has found evidence of feature averaging across saccades (Oostwoud, Wijdenes et al., 2015; Stewart & Schütz, 2018). In such cases, the distribution of responses appeared to be unimodal, such that there was one distribution of responses between the pre-saccadic value and the post-saccadic value. The key difference in this study was that the data were not tested for a bivariate structure. It is possible that their findings supported probabilistic overwriting like the findings of Tas et al. (2021), such that there were two distributions of responses at the pre- and post-saccadic values rather than a single distribution at an intermediate value. The results of the present study did not indicate that either approach was better fit to explain the data, as indicated by similar BIC values for each model.

One potential reason that our findings were not similar to the findings of Oostwoud Wijdenes et al. (2015) is that most participants in our experiments were sensitive of the color change and reported noticing two different colors. As discussed above, such disruption of visual stability in the transsaccadic block might have discouraged integration. Future work needs to exclude the blank trials to clarify whether this disruption is responsible for the different results.

Previous work has also found evidence to support cue integration across saccades, such that when participants are presented with the same stimulus pre-saccadically and post-saccadically, performance improves significantly (Stewart & Schütz, 2018). The current study included PreOnly and PostOnly blocks to test cue integration and did not find improved color reports in the transsaccadic trials with no color change as compared to the best of the PreOnly or PostOnly trials. Further, when the single trials were compared to the color change no blank transsaccadic trials, the standard deviations for the single trials were significantly smaller than the color change no blank trials in Experiment 1 and the no change no blank trials in Experiment 2. These results indicate that color report performance was not improved by the transsaccadic presentation of target information, even in the trials where the transsaccadic trials presented the same color pre- and post-saccadically. Across both experiments, we did not find any evidence to support cue integration.

While the findings of this study are not in line with the findings of previous cue integration studies, there are a number of methodological differences that could be the cause of the discrepancies. Many of the prior studies were examining cue integration among multiple modalities (Rohde et al., 2015; Clark & Yuille, 1990; Ernst & Banks, 2002). While our task was more closely related to Stewart and Schütz (2018) who also found evidence of cue integration, we included color change trials and blank trials in the transsaccadic condition. As previously discussed, while the magnitude of the color change was small, the inclusion of both the color change and the blank trials is likely the reason that participants were sensitive to the color changes in the transsaccadic block

across both experiments. Even for the comparison with the no blank trials, it is possible that responding was impacted by an awareness that not the saccade target information changed transsaccadically in some of the trials, which may impact reduce the likelihood of transsaccadic integration.

The results of the present study mostly align with the overwriting account. Previous studies showed that pre-saccadic information is overwritten with post-saccadic information on a majority of trials when visual stability is established (Tas et al., 2021). In the present study, our results were best explained by a unimodal model with the mean fixed at the post-saccadic value, which indicated that the pre-saccadic information was overwritten by the post-saccadic information in nearly 100% of the trials.

It should be noted that while Tas et al. showed evidence for probabilistic overwriting, the present study showed evidence for complete overwriting. While aspects of the present methods resembled the prior work supporting overwriting, there were some key differences that could have contributed to the differences in results. For instance, Tas et al., (2021) required that participants hold both the pre- and post-saccadic representations separately, so that they could report whichever was post-cued. While probabilistic overwriting would be supported by a bimodal distribution of responses, it is possible that the bimodal distribution is less likely to be observed in a situation where participants are not required to report the pre-saccadic information or to separate the pre- and post-saccadic features. If the pre-saccadic features are overwritten by the post-saccadic features in nearly all of the trials, then one would expect to see a unimodal distribution at the post-saccadic value. It is also possible that they strategically reported

the post-saccadic values, even when both representations were available to them. To examine this, the blank trials would need to be removed, such that visual stability is not disrupted, and the visual system cannot hold both representations separately.

Limitations

The present study showed that the pre-saccadic color value was overwritten by the post-saccadic color value on every trials. A possible alternative explanation for complete overwriting is that because participants were never asked to report the pre-saccadic value, they did not have a reason to report it in any of the trials. Thus, they may have always reported the more reliable post-saccadic color because it was perceived foveally. Further, while the color change magnitude was small in this experiment and participants were asked to report the color of the object without specifying its state (pre- or post-saccadic), the inclusion of blank trials likely disrupted visual stability, resulting in representing the pre- and post-saccadic objects as separate objects. Disruption of visual stability may also have limited the possibility of integration. To be able to accurately test integration, it is important that participants do not detect the color change, as part of the purpose of this experiment was to examine whether an awareness of color change might inhibit integration transsaccadically. In other words, integration may be less likely when participants are aware of transsaccadic changes.

Future Directions

A primary concern in this study was that the inclusion of blank trials disrupted visual stability, which might have affected the data as discussed above. This disruption of visual stability leads to participants perceiving the pre- and post-saccadic targets as

different objects rather than assuming that the post-saccadic object is a continuation of the pre-saccadic object, which means that typically undetected changes occurring transsaccadically become easier to detect. In this study, participants were able to detect changes in color, which is likely a result of the blank trials disrupting visual stability. To eliminate the alternative explanation that the failure to find integration effects are due to this visual instability, future studies should replicate the present findings with a version of this experiment without the blank trials.

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VITA

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