DOES GLOBAL CONTEXT AFFECT MEMORY FOR POSITION IN THE ONSET REPULSION EFFECT?

by

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Abstract

The onset repulsion effect (ORE) refers to the tendency to misremember the first appearance of a moving object as being back behind its true onset position, that is, in a direction opposite to the path of motion (Actis-Grosso & Stucchi, 2003; Thornton, 2002). While the ORE has been replicated many times, the underlying cause for such a backward shift is still unclear. The present study was designed to (i) test whether the ORE can be observed in an online environment, and (ii) examine whether the global context of a motion event (e.g., the number of motion segments or the presence/absence of shape-cueing) modulates patterns of responding. In three separate experiments, observers were asked to watch a smoothly moving target and to subsequently indicate its starting, stopping and, if relevant turning points. In some conditions, shape cues were provided via both instructions (e.g., complete the sides of the triangle/rectangle) and visual feedback. In all conditions a robust ORE was measured, indicating that the effect can be observed in an online environment, where viewing conditions are not controlled. However, the global context of the motion event had very little influence on the pattern of error. This contrasts with Representational Momentum – the tendency to misremember the stopping point of an event –which is known to be modulated by context (Freyd & Finke, 1984; Vinson & Reed, 2002). The current findings suggest that the ORE is likely determined by low-level perceptual mechanisms, with less susceptibility to higher-level contextual influences.

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Chapter 1: Introduction

Our visual experience of the world often consists of objects that dynamically change over time and in our everyday lives we successfully interact with moving objects. We are able to cross the street taking into consideration the passing cars, we can catch objects that are thrown at us, as well as avoid obstacles while moving. This suggests, that our visual system is well adapted to our dynamic world. However, there have been reported cases, at least in the laboratory, suggesting that our judgments for the localization of a moving object are not always veridical. By studying such localization errors it may be possible to further understand the mechanisms underlying the perceptual processing of object motion.

In this chapter, a brief description of the various localization errors found in the literature is given. The emphasis of the present study, however, is allocated to a particular type of localization error; the *onset repulsion effect* (*ORE*). As well as describing the ORE in detail, the plan for the current experiments is outlined. A discussion of the processing levels of motion and the importance of global context on visual perception and memory is also provided.

Localization Errors of Moving Objects

Offset Localization Errors - Representational Momentum

Various studies have shown that people tend to misestimate the vanishing position of a moving object as being further ahead in the direction of motion (*representational momentum*; Freyd & Finke, 1984; Hubbard, 2006; Thornton & Hubbard, 2002). Freyd and Finke (1984) attributed the effect to the mental representations of a physical object, meaning that there are some memory distortions in observers' representations of the exact position of the physical target.

Hubbard (1998), argued that the effect is due to the process of internalization of the physical principles of the objects. Another explanation provided is that the forward displacement of the offset position of the moving object is due to the delays between the perception of the motion and the action (response) and thus, for a big error to be avoided, observers point to the location that the object would have by the time the motor response is made (Hubbard, 2005). For some display types, such forward displacements may also be accounted for by the smooth pursuit of the eyes that track the moving target (Kerzel, 2000; Kerzel, Jordan & Müsseler, 2001). A schematic example is given in Figure 1.

Onset Localization Errors - Fröhlich Effect

Similar to *representational momentum*, there is a tendency for people to report the onset of a moving object at a position ahead of the true starting point, in the direction of motion (*Fröhlich effect*; Fröhlich, 1923; Müsseler & Aschersleben, 1998). Originally, Fröhlich (1923), considered the effect as a manifestation of the processing limits of conscious awareness. Later discussion centered around other mechanisms, such as delays in the allocation of attention (Müsseler & Aschersleben, 1998) or metacontrast masking of the initial appearance of the moving object (Kirschfel & Kammer, 1999) as explanations for the effect. A schematic example is given in Figure 1.

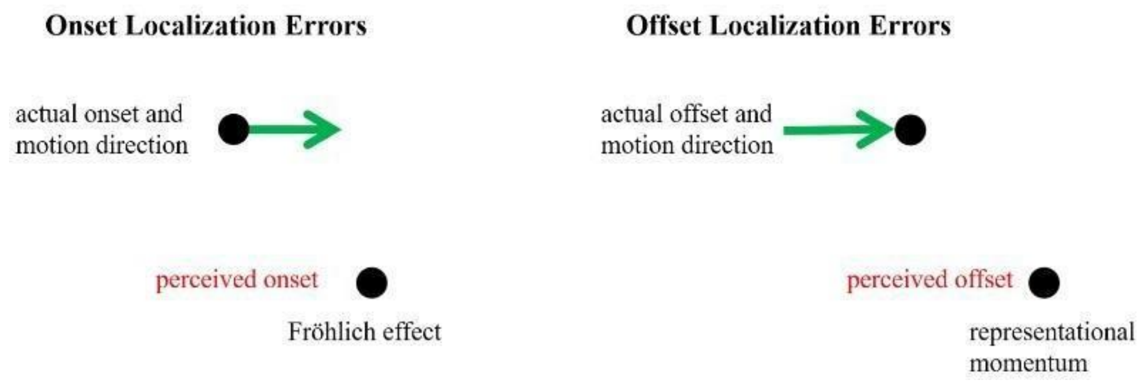

Figure 1: Schematic representation of *representational momentum* and the *Fröhlich effect*. The green arrows represent the direction of motion. The upper black dots represent the actual onset/offset position of the moving object, while the lower black dots represent the perceived onset/offset position of the moving object. In the *Fröhlich effect,* the onset position of the target is localized in a position further ahead of the direction of motion. With *representational momentum*, the offset position of the object is localized in a position further ahead of the actual vanishing point.

The flash-lag Effect

In the *flash-lag effect* (Nijhawan, 1994), a flashed object which is physically aligned with a continuously moving object is consistently judged to lag behind. Active extrapolation is one of the mechanisms that have been suggested as an explanation for this effect, as there is a latency in neural activity after light enters the eye (Berry, Brivanlou, Jordan, & Meister, 1999; Johnston & Lagnado, 2015; Nijhawan, 1994). Sheth, Nijhawan, and Shimojo (2000), suggest that as there is a neuronal delay between the two objects in the visual system, so some sort of compensation should take place. Also, shifts in the allocation of attention have been suggested as a possible cause of the *flash-lag effect* (Baldo & Klein, 1995). Figure 2 provides a schematic representation of the *flash-lag effect*.

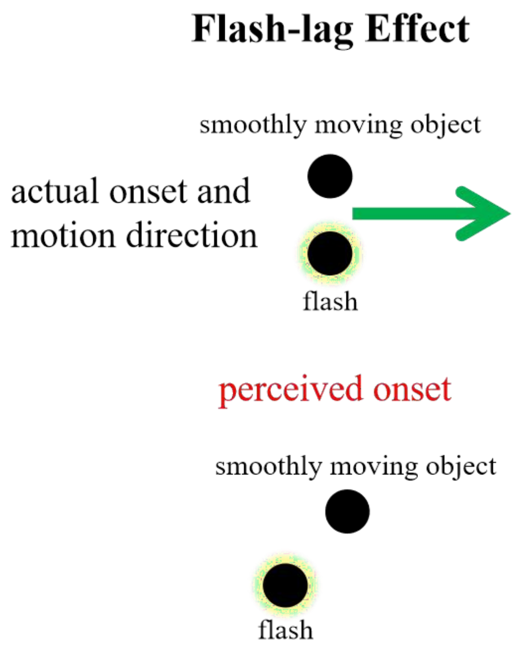

Figure 2: Schematic representation of the *flash-lag effect*. A flash Adjacent to a continuously (smoothly) moving object is perceived to lag behind it.

Motion-Induced Position Shifts (MIPS)

Motion-induced position shifts (*MIPS*), are a class of motion illusions mainly driven by the object's local motion characteristics, as the local motion within the stimulus creates a global mislocalization of the whole object (e.g., Caniard et al., 2011, 2015; De Valois & De Valois, 1991; Ramachandran & Anstis 1990). One possible cause of such illusory displacement might be the attempt of the visual system to extrapolate the position of the object, after compensating for neuronal delay (e.g., van Heusden, Rolfs, Cavanagh, & Hogendoorn, 2018; Yamagishi, Anderson, & Ashida, 2001). Allocation of attention and metacontrast masking have additionally been suggested as explanations for this kind of illusory displacements (Kirschfeld, 2006). Figure 3 gives a schematic representation of the *MIPS*.

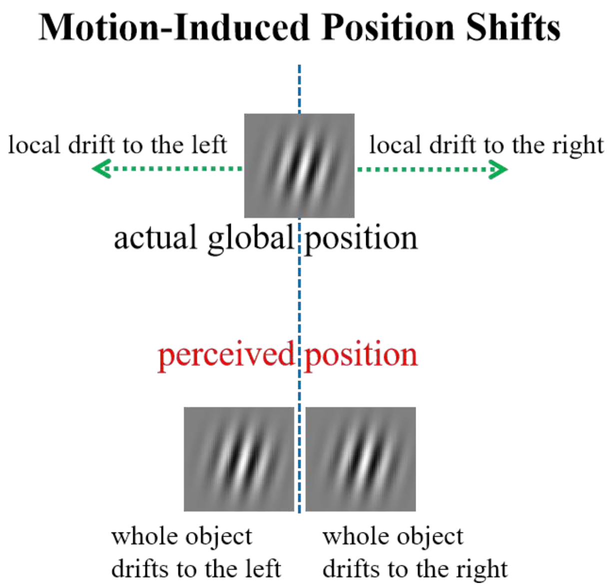

Figure 3: Schematic representation of the *motion-induced position shifts* (*MIPS*). The blue dashed line represents the actual global position of the object, while the green dashed arrows represent the local motion drifts to the left and to the right. When there is local motion within the Gabor patch to the left, the whole object is perceived to be in a leftward position, while when there is local motion to the right, the whole object is perceived to be in a rightward position. When there is no local drift, the object is perceived to be in its veridical position.

The Onset Repulsion Effect

In addition to errors where perceived onset is localized further ahead in the direction of motion, there have also been cases where observers localize the onset position of a moving object behind the true starting point, relative to the direction of motion (*onset repulsion effect* or *ORE*; e.g., Actis-Grosso & Stucchi, 2003; Hubbard & Motes, 2005; Thornton, 2002). Usually, such errors occur with slower velocities than the ones where the *Fröhlich effect* is observed (Actis-Grosso & Stucchi, 2003; Müsseler and Aschersleben, 1998).

While localizing a moving object as being further ahead of its actual position can be explained by both neuronal and attentional mechanisms, errors that fall behind the actual position of the moving target do not yield such an explanation, simply because the moving object has never physically been in that perceived position. Thus, the existence of such errors has been a challenge to the activation models, described above. A more detailed description of the *ORE* will be given in a later section of this chapter. Figure 4 provides a schematic representation of all onset and offset localization errors.

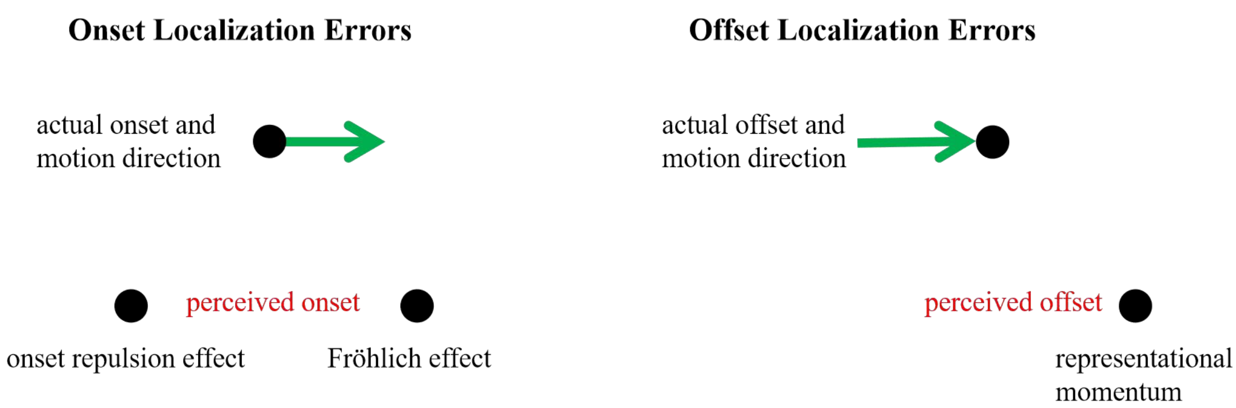

Figure 4: Schematic representation of the onset and offset localization errors. The green arrows represent the direction of motion. The upper black dots represent the actual onset/offset position of the moving object, while the lower black dots represent the perceived onset/offset position of the moving object. In the *onset repulsion effect*, the object is localized in a position further behind the direction of motion, while in the *Fröhlich effect* it is localized in a position further ahead of the direction of motion. In the *representational momentum*, the offset position of the object is localized in a position further ahead of the actual vanishing point.

Localization Errors and Levels of Perceptual Processing

Having briefly sketched a number of localization errors, there are several questions that arise from reviewing the literature. Is the nature of the relevant motion processing driven by low-level or high-level mechanisms? Can some localization errors be attributed to low-level processing while others to higher-level processing? Does contextual information affect judgments of localization of moving objects, and if so, are all of them affected in the same way?

For example, there have been various studies showing that *representational momentum*, as a phenomenon, can be highly affected by global motion characteristics, contextual information, and conceptual knowledge (Freyd & Finke, 1984; Reed & Vinson, 1996; Vinson & Reed, 2002), suggesting that higher-level processing is involved with this effect. These results are in accordance with Pylyshyn's (1981) notion of *representational momentum* being a product of the observers' tacit knowledge about the motion of different objects, thus constituting a cognitive processing effect.

MIPS, on the other hand, appear to be dependent both on low and higher level mechanisms. For example, there is both fMRI (e.g., Fischer, Spotswood, & Whitney, 2011; Maus, Fischer, & Whitney, 2013) and psychophysical (e.g., Mather & Pavan, 2009; Tse, Whitney, Anstis, & Cavanagh, 2011; Watanabe et al., 2002, 2003) evidence for the crucial involvement of higher visual areas. However, the effect is not eliminated or reduced even following repeated exposure or with instructions to overcome the shifts by providing active control over the global position of the object (Caniard et al., 2011). In fact, the size of the illusory position shift appears to increase under active control, compared to standard passive viewing (Caniard, Bülthoff, & Thornton, 2015). Additional evidence for a more low-level explanation for *MIPS* came from a recent fMRI study by Kohler, Cavanagh and Tse (2017), who found evidence that representations of the motion were modulated in the primary visual cortex, suggesting that motion encoding of *MIPS* is already happening very early in the visual processing stream, underlining the importance of early activation and low-level perceptual processing in addition to higher-level mechanisms and visual areas.

The *flash-lag effect* also seems to persist under different kinds of manipulations, suggesting that the relationship between the continuously moving object and the flashed object has a limited effect on the presence of the phenomenon and that low-level perceptual mechanisms are responsible for such an effect (Hubbard, 2014). Also, active observation seems to reduce the effect only after a certain amount of trials and familiarization with the task (Ichikawa & Masakura, 2010).

As far as the *ORE* is concerned, there is a limited number of studies that try to establish the nature of the effect by employing information about the general, global context of the dynamic event. For example, Hubbard and Motes (2005) have explored the influence of a window boundary on the localization of a moving target. Additionally, Actis-Grosso and Stucchi (2003), explored various factors that lead to different types of localization errors (type of stimulus, motion duration, type of response, availability of a reference system).

Although no satisfactory theoretical explanation yet exists when it comes to localization errors of moving objects (Müsseler & Kerzel, 2018), and no study has yet provided solid evidence regarding the exact nature of these errors, Merz, Soballa, Spence, and Frings (2022) have proposed the *speed prior account model*, attempting to provide a unified explanation for all localization errors. Based on this model, estimations for both the onset and the offset positions of a moving object are made using previous experience to update the sensory input, leading to reduced uncertainty and more precise judgments for the position of the moving objects. Furthermore, the *speed prior account model* has provided evidence that localization errors are modality-independent, by testing the effect with both visual and haptic stimuli. According to the model, the expected errors should be antithetical, meaning that if the onset position is localized as being further ahead of the direction of motion, then the localization of the offset position should be judged to be behind the trajectory of motion and vice versa. However, data from previous studies directly challenge the model predictions (Thornton, 2002).

Exploring the Onset Repulsion Effect (ORE)

Thornton (2002) introduced the *ORE* as one localization error of a moving target that, contrary to other localization errors, is manifested behind the motion trajectory. In his study, he showed that the effect persists under different velocities, however, it is modulated by target speed. Specifically, the effect reduces as target speed increases, shifting to an error ahead in the direction of motion with very high velocities, that is, turning into a *Fröhlich effect*. Also, the addition of a fixation point did not eliminate the ORE, suggesting that eye movements do not play a significant role in the magnitude of the effect. Additionally, he used both smooth and implied motion. While the effect was obtained for both motion types, smooth motion yielded a much stronger effect. Finally, directionality effects were also reported in the study, with right-to-left and upward motion paths leading to stronger errors than the left-to-right and downward paths. These directionality effects only occurred when the task involved a single response to localize the onset position of the target, not when observers were asked to indicate both the onset and the offset positions.

Hubbard & Motes (2005) showed that placing a window boundary where the target is supposed to appear can play an important role in the memory for the onset position of a moving target. That is, when the onset position of the target was close to a window boundary, observers tended to localize it as further ahead in the direction of motion, whereas, when it was further away from the boundary, observers reported a localization error that fell further behind the trajectory of the motion path. When the target appears too close to the boundary, it is argued that the target's trajectory is limited within that boundary, and observers are unable to extend it further away from the boundary, so no backward error in the onset localization can occur. This limitation, however, is lifted when the target appears further inside the window.

Predictability of the onset position of the target seems to be a factor that modulates the robustness of the *ORE*, meaning that when a moving object is expected to appear in a certain position, the error tends to be reduced or to be manifested further ahead in the direction of motion. The argument here is that the positional uncertainty leads the observers to notice the target with some delay from its initial appearance (Müsseler & Kerzel, 2004). However, in a later study, Müsseler, Stork & Kerzel, (2008) showed that the aforementioned results were not replicated, as a *Fröhlich effect* was obtained in all conditions, with just a tendency for the *ORE* to occur in the unpredictable conditions. One interesting finding, however, was the different results obtained by using different indication methods; mouse pointing, and relative matches (using a probe), where no effect of predictability with the latter method was reported.

Kerzel (2002; 2003b) studied the onset localization of a moving target using both indication methods and both slow and fast velocities. His results indicated that with slow velocities and pointing indications, the onset position of the moving target is judged to be behind the motion trajectory, whereas, with fast velocities and relative matching indications, the opposite error in localization is observed. Interestingly, when the velocity increased and a pointing method was used, no error was observed, and, similarly, when the velocity decreased and a relative match was used, no error was observed. One possibility for the different errors obtained by the two different indication methods is the different response modalities employed by the cognitive system. When motor responses are expected, it is possible that, in order to avoid large errors, the brain overcompensates for the movement of the target.

Kerzel and Gegefurtner (2004), introduced a temporal variation in measuring the *ORE*. They found that when observers were asked to indicate the onset position of the moving target as soon as the target appeared on the screen, the error was increased compared to when they were asked to do the same immediately after the target had completed its motion path. This finding suggests that the ORE is susceptible to attentional mechanisms and that the motion itself functions as a distractor to the localization task. With slower velocities, the competition between the distractor (motion) and the task (target localization) is bigger compared to faster velocities, and thus, a bigger error is observed.

Actis-Grosso and Stucchi (2003), have proposed a low-level model based on the active extrapolation mechanism (Nijhawan, 1994). This model suggests that the visual system compensates for the delayed neuronal activation by placing the onset position of the moving object backwards to the motion trajectory.

The underlying mechanism of the *ORE* is not yet known. Based on the aforementioned studies it is not clear whether the ORE is a low-level perceptual phenomenon that employs bottom-up processes or a high-level one that is modulated by various experimental manipulations. Also, most of the provided explanations given for the previously described localization errors do not seem satisfactory for this type of error.

For example, in order for a misestimation explanation to be satisfactory, the object has to have physically occupied the position where observers localize it. While this happens with the other types of localization errors, it is simply not the case where the *ORE* is observed. Instead, some sort of misapplied inhibition could be a more appropriate explanation for the *ORE*. Neuronal inhibition occurring early during the stimulation process yields response to a visual trace and creates a backward perceptual bias (Jancke, 2000; Jancke et al., 1999). Inhibitory mechanisms operate on a local level, and based on such an explanation, one could argue that the

ORE, contrary to *representational momentum*, is an effect modulated by local motion events and not global manipulations and characteristics of the motion path.

Another hypothesis attributes the localization error not due to imprecise perception of the moving object, but due to position distortions arising from the memory decay. This hypothesis also suggests that the onset position of the target is indicated relative to its offset position, and thus, boundary extension is observed (Hubbard & Ruppel, 1999). Finally, the displacement of the moving target cannot be accounted for by the smooth pursuit of the eyes, as in *representational momentum* and the *Fröhlich effect* (Kerzel, 2003a), as the displacement is manifested opposite to the direction of the motion path, rather than in the direction of the motion path.

The present study

The experiments of the present study were designed to investigate whether *ORE* is modulated by global motion characteristics, similar to the *representational momentum*, or whether it depends solely on local motion processes. This was investigated by providing a general global context in the object's motion path (e.g. the moving object was creating a shape) or by increasing the complexity of the motion path. In the following section, the role of context in visual perception and memory is briefly discussed in order to highlight the reason why employing such an approach might be of importance in investigating localization errors. In addition, the experiments presented in this study were designed to further disentangle local motion factors. However, before moving to the description of the methodology of the study, it is crucial to present, at least in short, the importance that the overall context plays in visual perception, as the main goal of the present study is to investigate whether contextual effects might affect the *ORE*.

The Importance of Context in Visual Perception and Memory

While studying simple conditions is helpful for investigating and understanding visual phenomena, isolating them from their overall context might compromise our understanding of the underline mechanisms that characterize them. Various studies have provided strong evidence about the importance of context information in both visual perception and memory.

Central to the Gestalt approach, for example, is the notion that “the whole is something else than the sum of its parts” (Koffka, 1935, p. 176), meaning that distinct perceptions may arise from (essentially) the same local stimulation. In order for the visual system to extract meaning out of an image/scene, information about various regions of the image/scene must be taken into consideration, such as depth cues, positions, and reflectances (Albright & Stoner, 2002). Duncker (1929), has underlined the importance of the frames of reference in his experiments on *induced motion*, where relative motion between an object and a frame of reference (or between two objects) can lead to distorted motion perception. The lightness and colour of an object strongly depend on its immediate surround as well as the grouping configurations within the visual field (Adelson, 1993; Gilchrist et al., 1999; Murgia, Prpic, Santoro, Sors, Agostini, & Galmonte, 2016; Agostini & Proffitt, 1993; Nascimento, Pastilha & Brenner, 2019; Todorović, 2010) and both global and local characteristics contribute to the final percept. In visual search paradigms, global scene statistics or the presence of objects that are closely related to the target, tend to facilitate the eye movements, resulting in more efficient target detection (Castelhano &

Heaven, 2011; Mack & Eckstein, 2011; Torralba, Oliva, Castelhano, & Henderson, 2006; Võ & Henderson, 2011; Võ & Wolfe, 2015; Wolfe, 2015).

Both spatial and temporal context is an important aspect of memory retrieval. Providing contextual information has been reported to enhance memory recollection. For example, when both the encoding and the retrieval happen under matching environmental conditions, memory is improved (Godden & Baddeley, 1975; Smith, 1994; Smith & Vela, 2001). The same spatiotemporal findings are reported in more recent studies using virtual reality environments (Shin, Masís-Obando, Keshavarzian, Dáve & Norman, 2021). Emotional context modulates memory in a similar way, suggesting that people tend to remember more aspects of an event when the encoding and the retrieval of the information are happening in the same emotional context or if they share a similar emotional context (Erk et al., 2003; Erk, Kleczar & Walter, 2007).

In addition, priming can evoke contextual influences by activating associations in memory and/ or representations (Gulan & Valerjev, 2010; Tulving & Schacter, 1990). Priming effects have been meticulously studied over the years, mostly in visual search paradigms. Treisman (1992), as well as Malikovic and Nakayama (1994), have systematically shown that human perception is highly influenced by features that have been previously seen or that are repetitive in a task, leading to improved performance in the search task. Contrary to other researchers that used simple primes based on specific features of an object, such as color or shape, Chun and Jiang (1998) used more complex forms of priming, indicating that even a whole stimulus configuration can be the subject of priming. These findings were supported by other studies suggesting that priming effects can be based on objects as well as on features (Campana, Pavan, & Casco, 2008; Hillstrom, 2000; Huang, Holcombe, & Pashler, 2004; Kristjánsson, Ingvarsdöttir, & Teitsdöttir, 2008).

Summary and Outline

The main purpose of the study presented here was to further investigate the perceptual processing of motion by the visual system by addressing the nature of the *ORE*.

This chapter provided an introduction to the various localization errors found in the literature, with the *ORE* being the focus of attention, as well as a brief discussion on the importance of studying visual phenomena under their general global context.

The next chapter presents the methodological aspects of the study, while in the following chapter there is a description of the three experiments comprising the study. The final chapter puts forward a general discussion about the findings of the study as well as addresses the limitations and proposes some areas for further research. A supplement section is also provided, containing additional information about the study (ethical approval statement, observers' consent forms, additional statistical analyses).

Chapter 2: General Methodology

Overview of experimental methods.

The empirical part of this thesis comprised of three experiments. Full methods sections for each experiment are provided in the next chapter. Here, a brief overview is provided to highlight common aspects of the design and analysis.

Each experiment involved 12 participants per group, with the number of groups varying by experiment. The sample size was chosen to match the primary study being replicated (Thornton, 2002). A priori power analysis confirmed that a minimum of four participants should be sufficient to detect the presence of an ORE, based on an observed effect size of $d = 2.1$, assuming *alpha* = 0.95 and required power of 0.8. The larger planned sample size takes into account the online data collection, where we expected more noisy data, and should also provide more stable estimates that can be used in the between-group analysis. A new set of participants was used for each condition, and people who had participated in one condition were excluded from participating again in a new one.

The experiments conducted during this study were designed to test whether the ORE is modulated by characteristics of the global event structure – number of segments, underlying shape, vanishing position – or is only determined by the local motion at the point of onset. Previous models of localization errors typically focus on how local motion characteristics, such as velocity (Kerzel & Gegenfurtner, 2004) and predictability (Müsseler & Kerzel, 2004) affect the ORE. Task manipulations, such as spatial cuing (Hubbard & Ruppel, 2011; Müsseler & Kerzel, 2004) and response modality (Kerzel & Gegenfurtner, 2004) have also been studied. However, little or no research has explored the influence of event complexity and/or global structure (see Actis-Grosso & Stucchi, 2003; Hubbard & Motes, 2005 for exceptions). Thus, the primary goal of the study was to determine whether the ORE is modulated by more global aspects of a dynamic event.

The specific objectives of the present study were to (a) replicate the findings reported in Thornton (2002), but this time in an online environment (Experiment 1), (b) introduce additional motion segments to increase the complexity of the global event (Experiment 1), (c) explore whether global shape cues interact with local motion processes (Experiment 2), and (d) disentangle local motion factors (Experiment 3).

The current chapter provides a general overview of the empirical part of the study. A general description of the experimental methodology, the tasks and the visualization of the observers' responses are given in the following sections of this chapter. A detailed description of the tasks as well as the stimuli used in each experiment is given in Chapter 3. Descriptions about the procedure, the results of each experiment as well as well as a short discussion of these obtained results are given in separate sections of the same chapter. The findings of the present study are further discussed in the *General Discussion* section (Chapter 4). The informed consent forms for each experiment are available in the *Supplement* section, together with additional statistical tables.

Building the Tasks Using JavaScript

All tasks used in this study were built using JavaScript. Overall, seven different tasks were created (3 for Experiment 1, 3 for Experiment 2, 1 for Experiment 3). The basic logic and design of all tasks were essentially the same. All tasks were developed by applying minor manipulations to the initial task, described next.

A canvas of 800px width and 600px height was set at a middle gray color ("RGB (150,150,150)"). The target could move inside that canvas, where a 400px width and 300px height window was created by placing a thin black border ("RGB (0,0,0)"). A small black dot ("RGB (0,0,0)") with a radius of 6px served as the target object. The speed of the target, constant in all seven tasks, was set at 30 px/sec (measurement taken on a 15.5″ monitor). The onset position of the target was random on each trial. Apart from the center of the window, the black dot could appear at any position on the screen. For the first motion path, the target could move either from right-to-left or from left-to-right. The second motion path could be either upwards or downwards in direction. The third motion path could be either in a right-to-left or in a left-to-right direction, similar to the first path. The length of each motion path was set to be random, within the limits of the 400 x 300px window (minimum distance = 50px), and the starting direction was also randomized.

For all experiments, the basic task was the same. Once the target object disappeared, the mouse needed to be used to localize both the start and the stop position of the target, in that order. Additional instructions (and responses) were required in some conditions, which are detailed in the following chapter.

All tasks were uploaded to a participant recruitment website (Prolific.co) under the general title *"Memory for Motion"*. For each observer, a unique identification code was randomly created as soon as they entered the website. This unique ID code was then used on the data file that was stored in the secure server of the *University of Malta*, upon completion of the task. Before observers were able to start doing the task, they were provided with an informed consent form and some general information about the purposes of the study, as well as with instructions about the specific task. If observers agreed on the terms of participation, they could proceed to the *maltacogsci.org* website, where the task was hosted. Once again, they were provided with specific instructions on how to do the task. After reading the instructions, they had to click on the *"Start"* button placed in the middle of the screen. Immediately after, a message saying *"Move the mouse into the center circle and click to progress"* was visible. Upon clicking on the circle they could move on to the first trial. After completing each trial, the same message was given and observers had to click into the circle to continue to the next one. On each trial, on the top right of the screen, observers could see the number of the specific trial, and on the top left, they could see how many clicks they had done. Both texts were written in red ("RGB (255, 0,0)"). On each trial, the number of clicks was always set at zero, up until the first response, and then it was incremented by one. Figure 5 shows an example of the task phases. All tasks are available on the maltacogsci.org website.

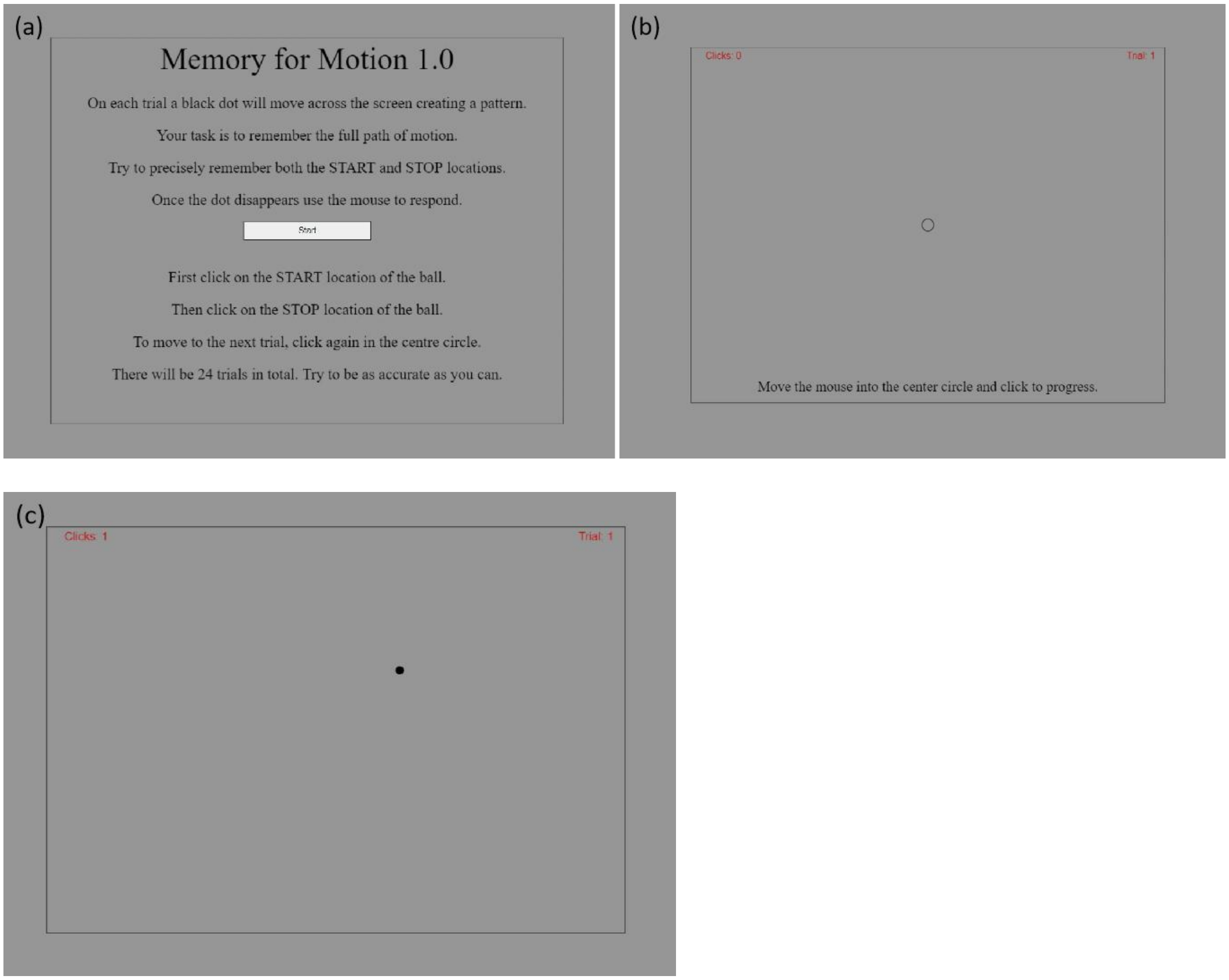

Figure 5: An example of the phases of the task. (a) instructions, (b) task initialization, and (c) after first response.

Visualization of Obervers' Responses

Since the whole study was held online, reassurance that the observers who participated in each task were actually following the instructions was necessary. For that reason, another series of code that helped with the visualization of every trial for each observer was created. The code was again written in JavaScript, and data visualization was done by implementing the plotly open-source library. Thus, observers who did not perform the task were excluded from the data analysis and were replaced.

The obtained data from each participant were merged in a comma-separated values (csv) file and uploaded into the code file. As different conditions needed a different kind of treatment on the code, several versions were created. After the file was uploaded, estimations about the onset, offset, and turn errors could be performed. Furthermore, information about the specific conditions of each trial could be extracted. Finally, observers' responses were mapped into a chart and were directly compared to the actual positions of the target. Figure 6 shows an example of the information that was obtained from the visualization code.

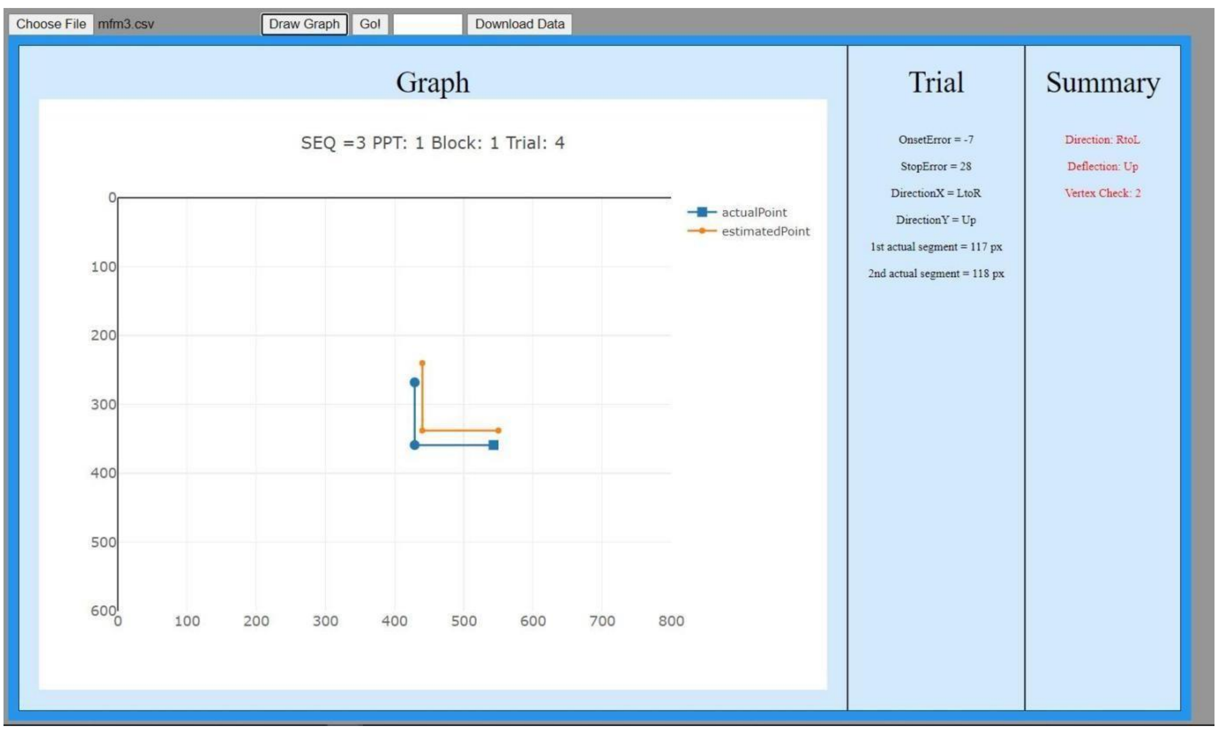

Figure 6: An example of the visualization of observers' responses. The blue line represents the actual motion path of the target, while the orange line its perceived path. The rectangular tick mark represents the onset position of the target. On the right, information about the localization errors, direction, and actual segment length is given.

Data Analysis

Data analysis was conducted only for the errors that fall along the path of motion and not for the ones orthogonal to the path of motion. Positive displacements indicate errors along the path of motion and negative displacements indicate errors that fall in a direction opposite to the path of motion. Although observers were asked to indicate both the onset and the offset positions of the moving target (in Experiment 2 they indicated the turn position as well), the conditions of the offset position of the motion were not controlled, and thus statistical analysis was mainly focused on the onset positions. All reported values are given in pixels, as observers' viewing conditions were not standard and conversion to visual angle could not be done. However, the software controlled the effect of the refresh rate of individual monitors, so that trials lower or higher than 60Hz could be eliminated.

To ensure that findings were not based on extreme outliers, data were plotted for motion conditions. Only two mild outliers were detected in Experiment 1, and none in Experiment 2, and thus adequate data analysis and interpretation were not endangered. The box plots that depict the overall distribution of observers' responses for each experiment are given in the *Supplement* section.

All data were analyzed using *JASP* open-source statistics program. *One-Sample t-tests* were conducted to establish that the localization errors were significantly different from zero and *One-Way Analyses of Variance* (*ANOVA*) were conducted to dictate any main effects (Experiment 1 and Experiment 2). In Experiment 3, where a within-participants design was used, a *Repeated Measures One Way Analysis of Variance* was conducted instead, for main effects and interactions. Preliminary analysis on the effects of the direction of motion for the first segment

(R-to-L or L-to-R) revealed no significant effects, thus, data are presented collapsed across this factor in the *Results* sections of the Experiments (Chapter 3).

Chapter 3: Experiments

Experiment 1

In Experiment 1, observers were asked to watch a small black dot (radius = 6px) moving on the computer screen. On each trial, the dot appeared at a random position and moved at a constant speed (30 px/sec), initially either left-to-right or right-to-left. In different conditions, the motion path could contain additional segments (described below) before disappearing. Observers were free to move their eyes and were instructed to follow the entire path of motion. After the black dot vanished, they used the mouse to indicate both its onset location and its offset location, as accurately as they could and in that particular order. The main questions of interest for this experiment were whether the findings of Thornton (2002) could be replicated in an online environment as well as whether a more complex motion path could affect the localization of the onset location of a moving object.

Methods

Participants

A total of 36 observers (12 in each condition) was recruited from an online participant recruitment website (*Prolific.co*) and were given compensation for their participation in this experiment. All were right-handed, English-speaking, and naive to the purpose of the research. Three observers were replaced as they did not follow instructions and either indicated the point of offset before indicating the point of onset or they were clicking on the same point for both onset and offset.

Equipment

All the experiments conducted for this study were held online, so no special equipment or laboratory space was used. Observers used their own monitors to participate in the study. The only requirement for participation was for the observers to use a desktop or a laptop with a mouse and not a touch screen device (tablet, mobile phone).

Stimuli

On each trial, a small black dot moved from one position on the screen to another. As the study was conducted online, there was no control for the observers' viewing distance. Before the start of each trial, a small circle was visible in the middle of the screen, which observers had to click on to continue with the experiment. Each observer participated only in one of the three conditions of the experiment.

In the first condition, the black dot was moving horizontally either from left to right or from right to left, and then vanished. In the second condition, we introduced a second, vertical segment to the initial motion path that could either be upwards or downwards. In the third and final condition, an additional segment was introduced to the path of motion, with the dot now completing a *Z-pattern* path (Figure 7).

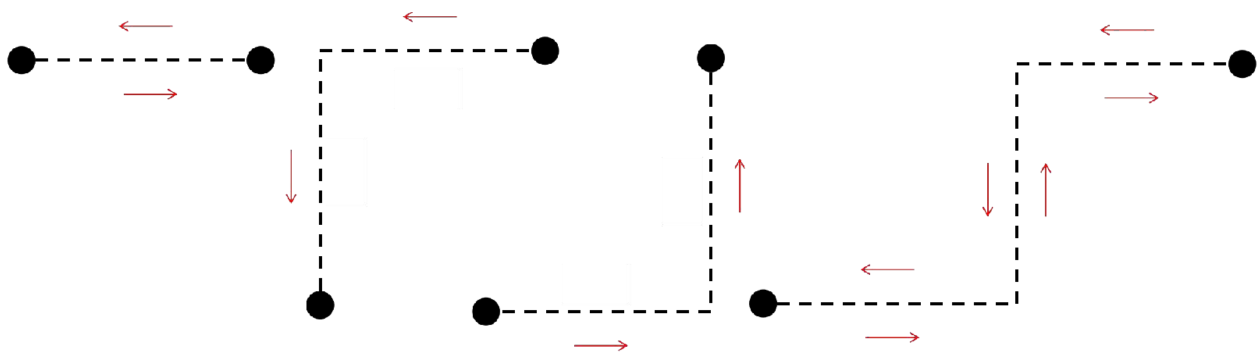

Figure 7: Schematic representation of the three conditions of Experiment 1. From left to right: 1-segment motion path, 2-segment motion path (R-to-L and down), 2-segment motion path (L-to-R and up), 3-segment motion path (R-to-L and down/ L-to-R and up). The dashed lines represent the motion path. The red arrows represent the directions in which the black dot could move.

Task

The task of the observers was always the same. After reading the instructions given, they had to use their mouse to click on the circle that was placed in the center of the screen. Afterwards, the back dot appeared at a random location and, depending on the condition, moved smoothly until it reached the required vanishing position. Observers were instructed to track the motion path and indicate as accurately as possible both the onset and the offset position of the moving dot, as soon as it vanished from the screen in that particular order. To move to the next trial they had to click on the center of the screen once again.

Procedure

A description of the task with specific instructions was given to all observers. When they first entered the online platform in order to participate in the experiment, an informed consent form with information about the study, the task, and a declaration about personal data protection were available for them to read and download. Once they agreed to participate in the study, a unique identification code was created and they were presented with the instructions screen of the experiment, where they could read again about the task.

Observers participating in the first condition had to complete 24 trials whereas observers in the other two conditions had to complete 36 trials. The presentation order of the type of motion path (left-to-right, right-to-left, up, down) was completely random across observers.

Results

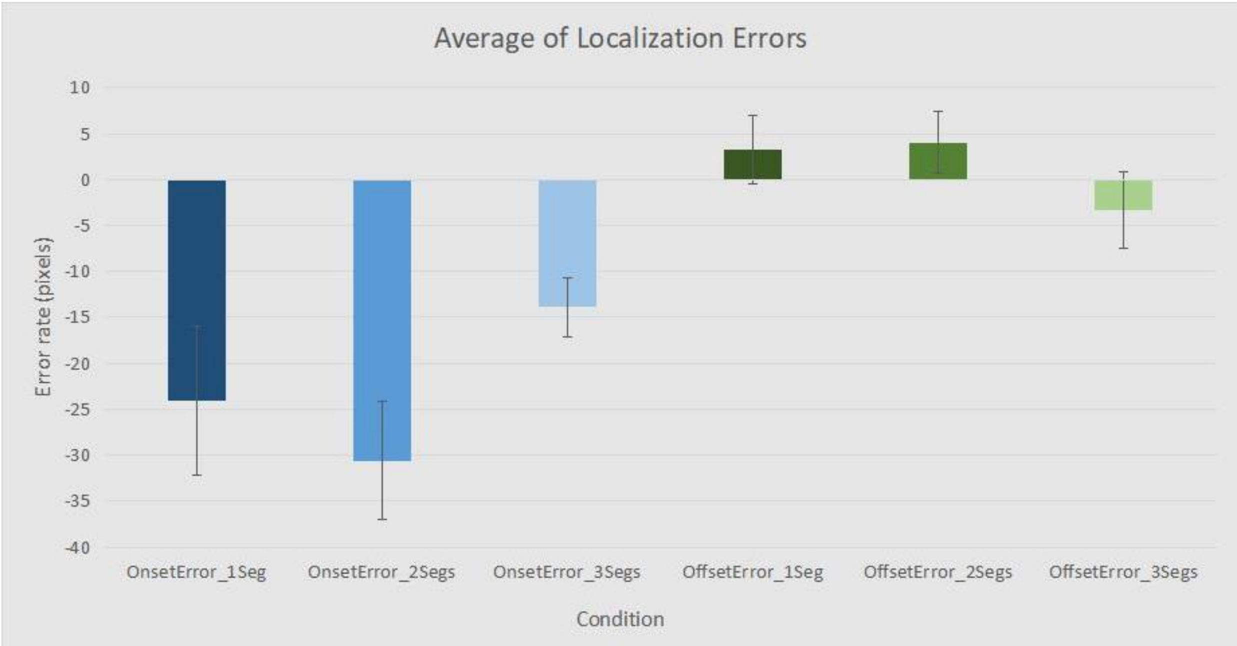

Figure 8: The average of onset and offset localization errors for each condition. Negative values indicate that localization of the onset position of the target falls behind the path of motion. Motion complexity does not eliminate the ORE. Error bars represent the standard error of the mean.

Figure 8, shows the average error for both onset and offset positions of the target in all three conditions. Localization for the onset position of the moving target was consistently opposite to the direction of motion, indicated by the negative values. As shown in Table 1, for the perceived onset positions, one-sample t-tests confirmed a significant difference from zero for all conditions. No such significant differences were obtained for the perceived offset position, indicating a rather veridical perception for the offset position. A One Way Analysis of

Variance for the perceived onset position indicated that there was no main effect of motion complexity: F (2,33) = 1.824, p = 0.177, η^2 = 0.100. Although the perceived onset position does not differ statistically among the conditions, a reduced onset error for the *3-segment motion path* can be observed (-13.88px, in comparison to the 1 segment path with an error of -24.05px and to the 2-segment path with an error of -30.63px).

One Sample T-Test

	t	df	p	Cohen's d	95% CI for Cohen's d Lower	95% CI for Cohen's d Upper
ORE_1Seg	−2.970	11	0.013	−0.857	−1.511	−0.176
ORE_2Segs	−4.761	11	< .001	−1.374	−2.160	−0.558
ORE_3Segs	−4.364	11	0.001	−1.260	−2.013	−0.476
RM_1Seg	0.860	11	0.408	0.248	−0.332	0.818
RM_2Segs	1.196	11	0.257	0.345	−0.246	0.921
RM_3Segs	−0.811	11	0.435	−0.234	−0.803	0.345

Note. For the Student t-test, effect size is given by Cohen's *d*.
Note. For the Student t-test, the alternative hypothesis specifies that the mean is different from 0.
Note. Student's t-test.

Table 1: Localization errors tested against zero. Onset localization errors are statistically significant, whereas offset localization errors are not.

Discussion

The results obtained in Experiment 1 confirmed the findings of previous research that observers show a consistent tendency to mislocalize the onset position of a moving object further behind its true onset location (Actis Grosso, Stucchi, & Vicario, 1996; Thornton, 1999; Thornton, 2002). Results also suggest that the ORE as a phenomenon can indeed be observed in a non-controlled laboratory environment.

Motion complexity does not seem to eliminate the onset localization errors, however, with more complex paths, there may be a tendency for the error to decrease. One of the proposed explanations for the ORE, also proposed as an explanation for other types of localization errors, takes into consideration possible inefficiencies in memory (Freyd & Finke,1984). This hypothesis states that although the onset point is accurately represented, it becomes distorted due to the delay until a response is made. However, if the error was to be attributed to memory decay, then one should expect the mislocalization error to increase with more complex paths, not to decrease.

A much more plausible hypothesis, that could incorporate the obtained results, is the one of miss-applied inhibition at the point of onset. Inhibitory "rebound" signals are used by the visual system to maintain a reliable history of the motion of an object and they tend to create a backward perceptual bias (Francis and Kim, 1999; Jancke, 2000; Jancke et al., 1999; Kim & Francis, 1998). The inhibitory signals though operate at a local level, thus with more complex motion paths, which take longer to complete, traces of these inhibitory signals tend to decay, concluding in smaller localization errors. Furthermore, no directionality effects were observed, similar to the initial study by Thornton (2002) in the condition where observers had to indicate both the onset and the offset positions of the moving target.

Experiment 2

The results obtained in Experiment 1 indicate that the ORE can indeed be observed even in an online study, where viewing conditions and screen size cannot be controlled. Furthermore, they suggest that the ORE is not affected by increases in motion complexity.

Experiment 2 was designed in order to investigate whether ORE can be affected by asking the observers to indicate the turning position of the moving target in addition to its onset and offset positions. Furthermore, in this experiment, observers were primed before the start of the task, to expect that the motion path, if it were to be complete, would form a specific shape. Shape priming either invoked a triangle or a rectangle. After each trial, observers were provided with visual feedback on what the shape would have looked like if the target had completed the motion path. Priming was a means to provide additional information about the motion path, and thus, enhance the global configuration of the moving target. If ORE is modulated by global motion characteristics and contextual cues, then both the additional indication point and the priming/feedback should modulate the effect.

Methods

Participants

A total of 36 observers (12 in each condition) were recruited from *Prolific.co* and were given compensation for their participation in the experiment. All were right-handed, English-speaking, and naive to the purpose of the research. Nine observers were replaced as they did not follow instructions and were either constantly indicating the point of offset before indicating the point of onset or they did not perform the task at all, clicking at random positions on the screen.

Task

The task of the observers was always the same. After reading the instructions, they had to use their mouse to click on the circle that was placed in the center of the screen. Immediately after, a black dot (radius = 6px) appeared at a random location and, depending on the condition, moved smoothly (30 px/sec) until it reached the required vanishing position. Observers were instructed to track the motion path and indicate as accurately as possible the onset, the turn, and the offset positions of the moving dot, as soon as it vanished from the screen in that particular order. To move to the next trial they had to click on the center of the screen once again.

Stimuli and Procedure

For this experiment, we used the two-segment motion path of Experiment 1. A black dot moved from one position on the screen to another. Before the start of each trial, a small circle was visible in the middle of the screen, which observers had to click on to continue with the experiment. Each observer participated in only one of the three conditions of the experiment.

In the first condition, the black dot was moving in a right-to-left/left-to-right and then in an Up/Down direction and then vanished. In the second and third conditions, the motion path was identical to the first condition, with the only difference being that observers were cued with instructions before the experiment that the black dot would complete two sides of a particular shape (condition 2: triangle and condition 3: rectangle). After each trial, and before they could move on to the next one, they were provided with feedback on what would the shape look like had the motion been complete (Figure 9).

The procedure was exactly the same as in Experiment 1. Observers had to complete 36 trials in all three experimental conditions.

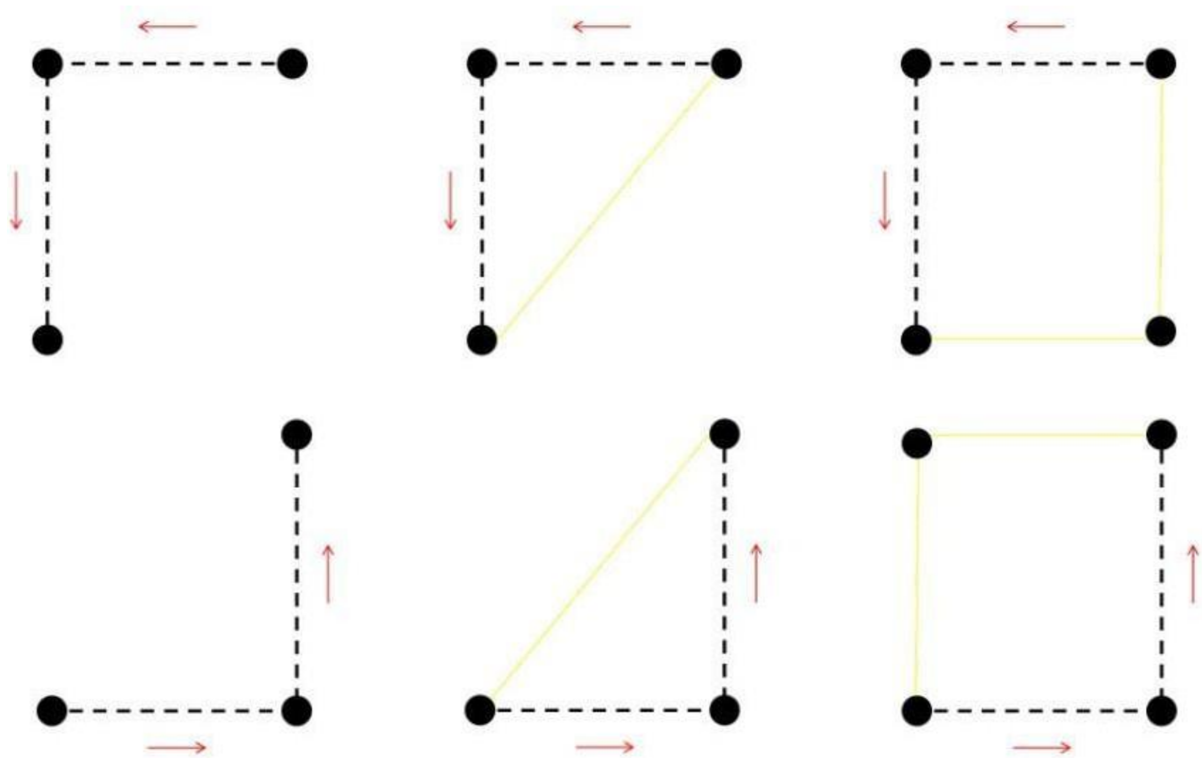

Figure 9: Schematic representation of the three conditions of Experiment 2. From left to right: 2-segment motion path without feedback, 2-segment motion path with triangle as feedback, 2-segment motion path with rectangle as feedback. The dashed lines represent the motion path. The red arrows represent the directions in which the black dot could move. After each trial, observers were provided with feedback on how the shape would look like had the black dot completed its motion path. The yellow lines represent the feedback type.

Results

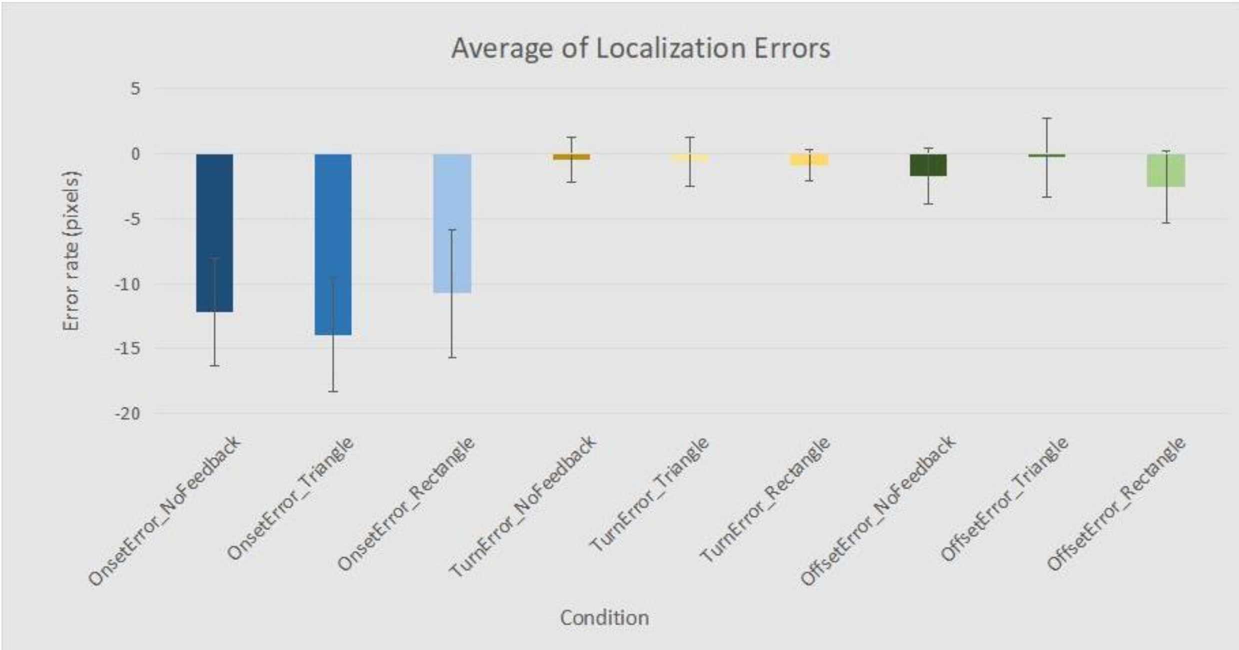

Figure 10: The average of the onset, turn, and offset localization errors. Priming about the global context of the motion path has a limited effect on ORE. Error bars represent the standard error of the mean.

Figure 10 shows the average error for onset, turn and offset positions of the target in all three conditions. For onset errors, one-sample t-tests revealed a significant difference from zero for the *No Feedback* and *Triangle Feedback* conditions. The difference was marginal (p=0.51) for the *Rectangle Feedback* condition, where results seem to marginally fail to reach significance. No significant differences were obtained for the perceived turn and offset positions, indicating a rather veridical perception for both turn and offset positions (Table 2). A One Way Analysis of Variance for the perceived onset position confirmed that there was no main effect of motion complexity: $F\ (2,33) = 0.020$, $p = 0.980$, $\eta^2 = 0.001$.

One Sample T-Test

	t	df	p	Cohen's d	95% CI for Cohen's d Lower	Upper
ORE_NoFeedback	−2.962	11	0.013	−0.855	−1.508	−0.174
ORE_Triangle	−3.197	11	0.008	−0.923	−1.591	−0.227
ORE_Rectangle	−2.189	11	0.051	−0.632	−1.243	0.003
TurnError_NoFeedback	−0.270	11	0.792	−0.078	−0.643	0.490
TurnError_Triangle	−0.313	11	0.760	−0.090	−0.655	0.479
TurnError_Rectangle	−0.750	11	0.469	−0.217	−0.785	0.361
RM_NoFeedback	−0.805	11	0.438	−0.232	−0.801	0.347
RM_Triangle	−0.099	11	0.923	−0.028	−0.594	0.538
RM_Rectangle	−0.910	11	0.382	−0.263	−0.833	0.319

Note. For the Student t-test, effect size is given by Cohen's *d*.
Note. For the Student t-test, the alternative hypothesis specifies that the mean is different from 0.
Note. Student's t-test.

Table 2: Localization errors tested against zero. Onset localization errors for the *No Feedback* and the *Triangle* conditions are statistically significant. Onset localization error in the *Rectangle* condition does not differ from zero. Turn and offset localization errors are not statistically significant.

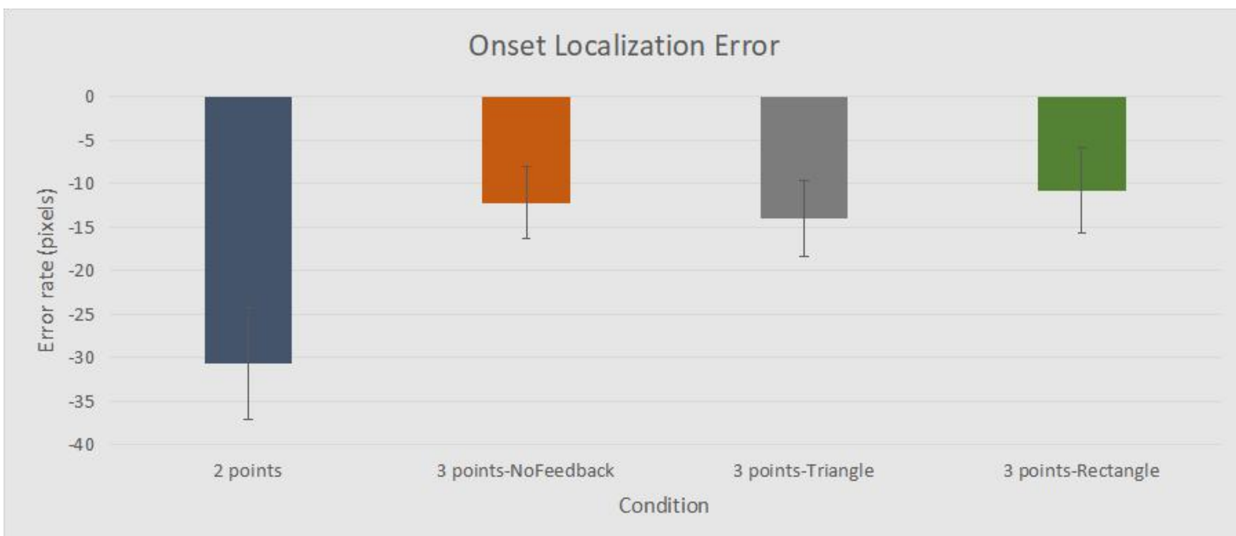

Figure 11: Comparison with condition 2 (2-segment motion path) of Experiment 1. Having an additional localization point does not seem to affect the magnitude and the direction of the onset error. Only the *Rectangle* condition is statistically different from condition 2 of Experiment 1. Error bars represent the standard error of the mean.

Figure 11 compares the average error for the onset position in Experiment 2 with the closet matching condition from Experiment 1, in which two segments were drawn, but only the start and stop locations were obtained. The localization error of the onset position of the moving target in Experiment 2, where observers were asked to also indicate the turn position of the target, was reduced, compared to Experiment 1. A One Way Analysis of Variance revealed a main effect of motion complexity: $F(3, 44) = 3.386$, $p = 0.026$, $\eta^2 = 0.188$. However, post-hoc analysis indicates a statistically significant difference only between the *No Feedback*-2 point motion path (Experiment 1) and the *Rectangle Feedback*-3 point motion path (Experiment 2): $t = -2.792$, $p = 0.046$, *Cohen's d* = -1.003.

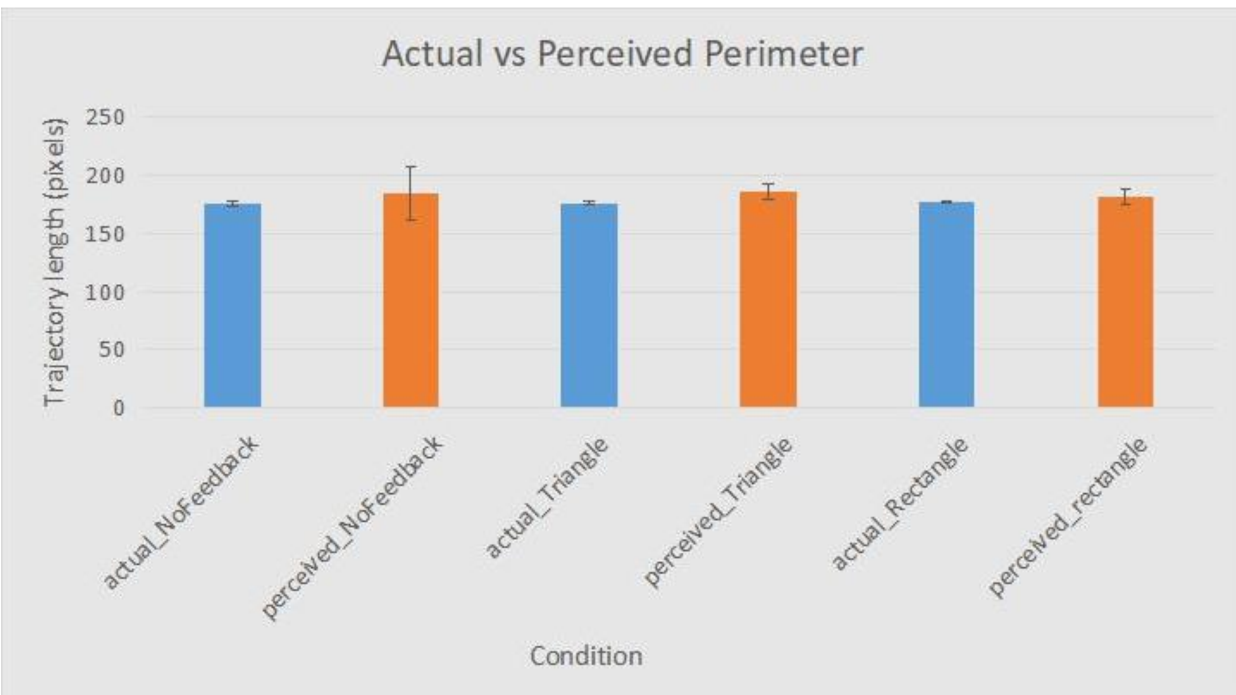

Figure 12: Actual and perceived perimeter of the motion path for each condition. Although observers overestimate the length of the motion path, the results are not statistically significant.

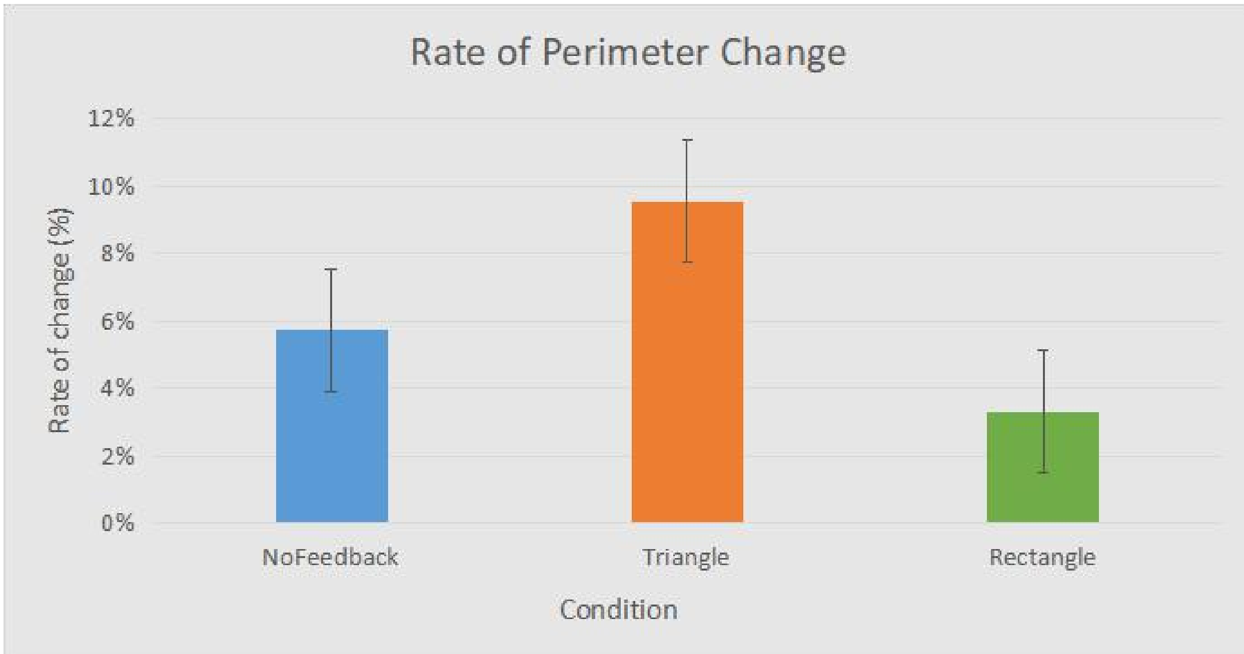

Figure 13: The difference between the actual and the perceived motion path length, given in percentage change.

Since data were acquired from all three points of the motion segments (onset, turn, and offset), a direct comparison between the actual and the perceived perimeter of the motion paths could be performed, both in terms of absolute values and in terms of percentage change. To do so, firstly the absolute value of the actual perimeter of the path was calculated, and then the same was done for the perceived perimeter, based on the observers' responses. The percentage change was calculated by dividing the difference of the two values by the actual value, multiplied by 100 [(difference/actual)*100]. Figure 12 shows the absolute values of the actual and the perceived perimeter, while Figure 13 shows the percentage of change between the actual and the perceived perimeter. Although the plotted data suggest that observers consistently overestimated the size of the motion paths, indicating that they perceived a longer trajectory of the moving object, there was no statistically significant difference between the actual and the perceived perimeter of the motion paths: $F(2,33) = 0.144$, $p = 0.867$, $\eta^2 = 0.009$ (absolute numbers) and $F(2,33) = 0.204$, $p = 0.817$, $\eta^2 = 0.012$ (percentage change).

Discussion

The results of Experiment 2 revealed a persistence for the localization of the onset position of the target to be placed further behind the path of motion. When observers have additional information about the shape that the moving target is supposed to complete, the error seems to be reduced but not eliminated. Also, even without feedback about the context of the motion, the addition of an extra indication point (the turn position of the target) seems to have an effect on the amount of the observed error.

However, the important finding of this Experiment is that even with priming about the global context of the motion path, the *ORE* is still statistically significant. This finding could be informative in the sense that the *ORE* is a phenomenon that is mainly driven by local stimulation (Francis & Kim, 1999; Jancke, 2000; Jancke et al., 1999; Kim & Francis, 1998) and that, probably, global manipulations of the motion path have a limited influence on it. Finally, the perceived length of the motion path was overestimated in all three experimental conditions, further suggesting that the *ORE* is produced by local stimulations and not influenced by the offset position of the moving target. The same increase in the perceived length of the motion path has been reported by Hubbard and Motes (2002). These findings seem to contradict the idea of the boundary extension effects (Hubbard & Ruppel, 1999), as a decrease in the perceived motion path should be observed instead.

Experiment 3

Experiments 1 and 2 indicate that ORE persists under more complex motion paths and appears to be almost unaffected by priming. The aim of Experiment 3 was to further investigate global factors (recency effect, global shape influences) and their effect on the ORE. Contrary to the previous experiments, a within-participants design was used. If the ORE is modulated by global aspects of the motion, a bigger error in the onset localization when both onset and offset positions suggest an error in the same direction on the x-axis would be expected, as well as when participants will expect a shape to form. Thus, both a recency effect and the global shape cues could influence observers when they try to localize the onset position of a moving target.

Methods

Participants

A total of 12 observers was recruited from *Prolific.co* and were given compensation for their participation in this experiment. All were right-handed, English-speaking, and naive to the purpose of the research.

Task

After reading the instructions, observers had to use their mouse to click on the circle that was placed in the center of the screen. Immediately after, the black dot (radius = 6px) appeared at a random location and, depending on the condition, moved smoothly (30 px/sec) until it reached the required vanishing position. Observers were instructed to track the motion path and indicate as accurately as possible both the onset and the offset positions of the moving dot, as soon as it vanished from the screen in that particular order. To move to the next trial they had to click on the center of the screen once again.

Stimuli and Procedure

For this experiment, we used the three-segment motion path of Experiment 1, which creates a *Z-pattern* path (*Open Shape* condition), as well as another novel stimulus, which creates the three sides of a rectangle (*Closed Shape* condition). A schematic representation of the two conditions is given in Figure 14. The comparison between these two types of stimuli could be informative for two reasons. Firstly, context information is very different in the two conditions. In the *Closed Shape* condition, the shape that is being created is coherent and discrete, whereas in the *Open Shape* condition the motion path does not create clear associations with shape information. Secondly, in the *Closed Shape* condition both the onset and the offset positions suggest an error in the same direction on the x-axis, while in *Open Shape* conditions they do not.

A black dot moved from one position on the screen to another. Before the start of each trial, a small circle was visible in the middle of the screen, which observers had to click on to continue with the experiment. Each observer viewed both conditions of the experiment (36 trials), which were completely randomized.

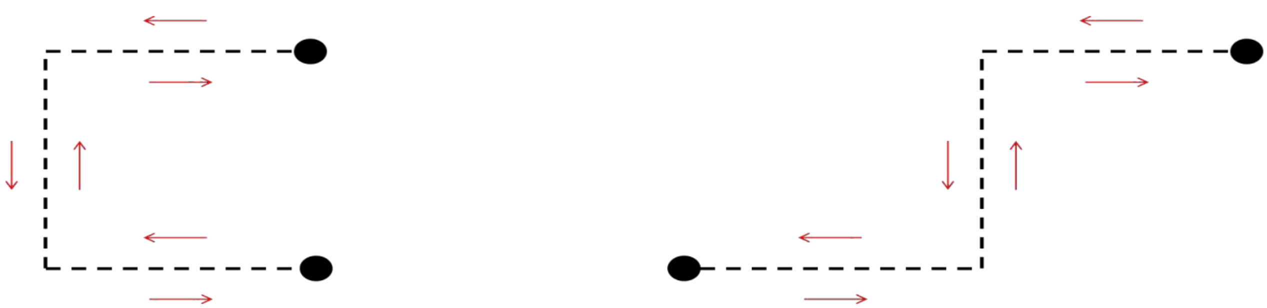

Figure 14: Schematic representation of the two conditions of Experiment 3. From left to right: Closed Shape, Open Shape. The dashed lines represent the motion path. The red arrows represent the directions in which the black dot could move.

Results

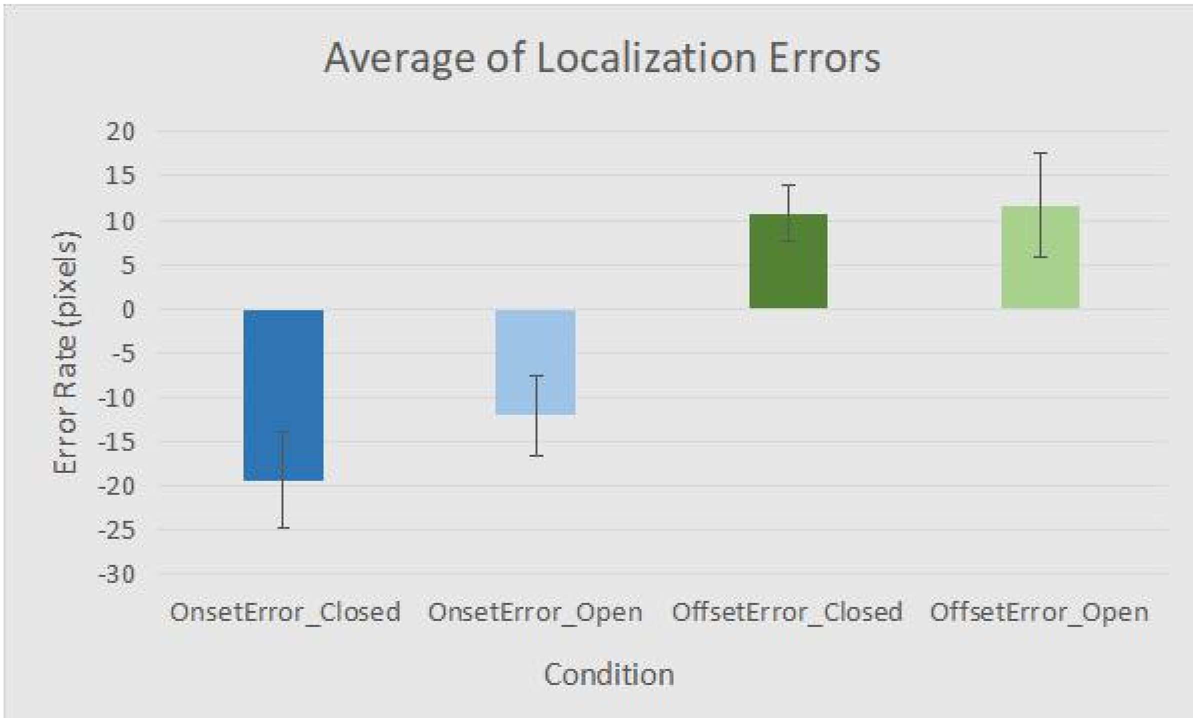

Figure 15: Average of onset and offset localization errors. When the moving target completes a *Closed Shape* path, ORE is significantly bigger than when it completes an *Open Shape* path (Z-pattern). Error bars represent the standard error of the mean.

Figure 15 shows the average error for both the onset and the offset position of the target in the two conditions. One-Sample t-tests confirmed a significant difference from zero for both the *Open* and the *Closed shape* conditions, as far as the onset position of the target is concerned. No such statistical significance was obtained for the *Open shape* condition regarding the offset position of the target, whereas the offset position of the target on the *Closed shape* condition did differ from zero. The results can be seen in Table 3. Furthermore, a Paired Samples t-test revealed a significant difference between the *Closed* and *Open shape* conditions for the onset position of the target: $t(11) = -2.421$, $p = 0.034$, *Cohen's d* = -0.699. A Repeated Measures Analysis of Variance revealed a main effect of the error type: $F(1,11) = 11.043$, $p = 0.007$, $\eta^2 =$

0.438. No main effect of shape type: $F(1,11) = 2.127$, $p = 0.173$, $\eta^2 = 0.010$ and no interaction between the error type and the shape type: $F(1,11) = 1.287$, $p = 0.281$, $\eta^2 = 0.006$.

One Sample T-Test

	t	df	p	Cohen's d	95% CI for Cohen's d Lower	95% CI for Cohen's d Upper
ORE_closed	−3.600	11	0.004	−1.039	−1.734	−0.314
ORE_open	−2.634	11	0.023	−0.760	−1.394	−0.100
RM_close	3.429	11	0.006	0.990	0.277	1.673
RM_open	1.967	11	0.075	0.568	−0.056	1.169

Note. For the Student t-test, effect size is given by Cohen's *d*.
Note. For the Student t-test, the alternative hypothesis specifies that the mean is different from 0.
Note. Student's t-test.

Table 3: Localization errors tested against zero. Onset localization errors are statistically significant. Offset localization errors in the *Closed Shape* condition is statistically significant, whereas it is not in the *Open Shape* condition.

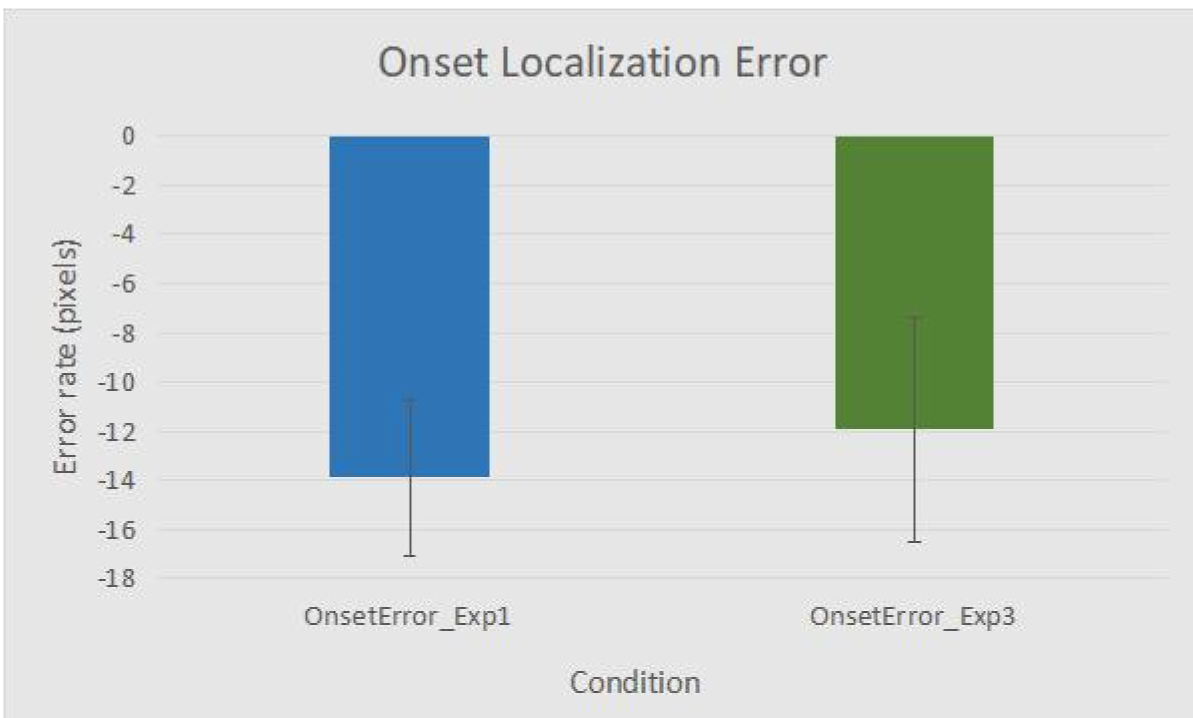

Figure 16: Comparison with condition 3 (3-segment motion path) of Experiment 1. ORE does not depend on the viewing conditions (between and within-participants design). Error bars represent the standard error of the mean.

Comparing the error for the onset position obtained in this experiment to the equivalent condition of Experiment 1 (*Open Shape* condition), no difference between them can be observed (Figure 16): $t(22) = -0.353$, $p = 0.728$, *Cohen's d* = -0.144, and ORE seems to be persistent under various viewing conditions (within or between-participants designs).

Discussion

The results obtained in Experiment 3 are consistent with the ones of Experiment 1 and Experiment 2. Motion complexity does not seem to eliminate the localization error that falls opposite to the direction of the path of motion and information about the global context of the motion path had little, if not no effect. However, in the *Closed Shape* condition observers were systematically reporting a larger error when localizing the onset position of the moving target than in the *Open Shape* condition.

Usually, mislocalizations of the offset position of a moving target fall along the path of motion (*Representational Momentum* - Freyd & Finke, 1984; Hubbard, 1998). In our *Closed Shape* condition, onset and offset localization errors fall in the same direction on the x-axis. Thus, one could argue that the offset position of the target has influenced the memory for the initial position of the target, resulting in a bigger error (*recency effect*). In fact, such an effect seems to influence various visual perception tasks. For example, when people are asked to search for a target in the same display consecutively, they tend to be faster the second time (Körner & Gilchrist, 2007). Additionally, research by Broadbent and Broadbent (1981), suggests that recency effects play an important role on deciding which one between two test items were on the test list. In a more recent study on ensemble perception, results suggest that averaging spatial orientation was influenced by the most recent frames that were presented to the observers (Yashiro, Sato, Oide, & Motoyoshi, 2020).

Furthermore, Hubbard and Ruppel (1999), have suggested that the onset position of a moving target is indicated relative to its offset position, leading to a backward shift in the localization task. However, in Experiment 1, Experiment 2, and in the *Open Shape* condition of Experiment 3, the localization of the offset position of the moving target was almost veridical. Thus, one could argue that the local event of the onset mislocalization of the target influenced the localization judgment of the offset position and not vice versa.

Chapter 4: General Discussion

Summary of the Findings

The study presented here was designed to further explore the nature of the *ORE*. This chapter provides a brief summary of the three experiments described above, a general discussion of the main findings, as well as some limitations of the nature of online studies that concern perceptual phenomena. Finally, some insights for further exploration of the *ORE* are suggested.

Experiment 1 was designed to replicate the original findings reported in Thornton (2002), regarding the localization errors that fall behind the true onset of a moving object, but this time in a non-controlled online environment. The results obtained in this experiment, suggest that the ORE can indeed be observed regardless of the viewing conditions, as a robust effect was present in all experimental conditions.

Additionally, Experiment 1 aimed to further investigate the *ORE* with longer and more complex motion paths. Motion complexity did not eliminate or reverse the *ORE*, however, it produced a slightly smaller effect.

Experiment 2 aimed to investigate whether the global context of the dynamic event can influence the ORE, or whether it is a phenomenon that is mainly driven by more local motion characteristics. This was achieved by introducing two additional indication points in the localization task, and by providing cues about the characteristics of the observed dynamic event (the target is moving as if it was about to complete a specific shape). The findings of Experiment 2, suggest that the global context and the additional information about the characteristics of the dynamic event, play little role in modulating the *ORE*. Only in the *Rectangle* condition, the ORE marginally failed to reach significance (p = 0.051). This, however, could be due to the experiment being held online, a matter that will be further discussed in another subsection of this chapter. The shape cueing used in this experiment has more cognitive characteristics, as it required observers to think about a specific shape while performing the task. This might be an additional argument in favor of the ORE being a low-level perceptual phenomenon, as there have been various reports on the way cognition influences pure perceptual/visual phenomena (Firestone & Scholl, 2016; Gilchrist, 2020; Pylyshyn,1999).

Experiment 3 was designed to further disentangle the global factors of the dynamic event. Contrary to the previous experiments, Experiment 3 was run using a within-participants design. The target completed a 3-segment path and which could either be a Z-pattern (*Open shape* condition) or an incomplete rectangle (*Closed shape* condition). In the second case, observes could be influenced by the structure of the motion path (global structure) or by the fact that the direction of the onset and the offset localization errors fall in the same direction on the x-axis, so that some sort of a recency bias could produce a bigger error for the onset position. The results suggest that in both motion structures the *ORE* is persistent, but it is much more robust when the motion created a more confined path (*Closed shape* condition).

Levels of Perceptual Processing

One of the main questions that drove this study concerned the nature of the *ORE*. The obtained results were consistent among the three experiments, suggesting that the ORE is indeed a robust and persistent effect. The different manipulations of the global dynamic event had only a small effect on the ORE, something that could possibly mean that the mechanisms underlying the effect are low-level and perceptual in nature. Having that in mind, as well as various studies on localization errors, we come to the point where we need to discuss whether all localization errors fall under the same level of perceptual processing and whether we can indeed create a unified model to explain and predict the localization of a moving object.

In the introductory chapter of this study, it has been stated that different kinds of localization errors involve different levels of perceptual processing. For example, research on *representational momentum* has revealed that this phenomenon employs and operates on higher levels of processing. Contextual information has a huge impact on *representational momentum* both in terms of appearance and in terms of robustness (Freyd & Finke, 1984; Reed & Vinson, 1996; Vinson & Reed, 2002). However, errors like those that occur in the *flash-lag effect* or in the *Fröhlich effect*, suggest that they operate on a lower, perceptual level (Hubbard, 2014; Ichikawa & Masakura, 2010). The results of the present study, also suggest that localization errors that fall further behind the path of motion are mainly determined by low-leve,l perceptual processing. The fact that longer and more complex motion paths (Experiment 1) or shape cueing (Experiment 2) did not modulate the *ORE* provides additional evidence for this type of effect being a low-level effect and perhaps not a cognitive one. The results of Experiment 3 were in accordance with the previous ones as well. Adding to that, the experiments conducted in this study do not suggest that the *ORE* is a matter of memory failure, and thus not a subject to a cognitive process. However, the memory influences on localization errors will be further discussed later in this chapter.

The question that stems from the aforementioned statements is whether we can actually create a unified model for all the localization errors, both onset and offset. The *speed prior account model* (Merz, Soballa, Spence, & Frings, 2022), is one of the most recent attempts toward a unification of all localization errors. As mentioned in the introductory chapter, the model is based on prior experience in order to update the sensory input and result in more precise responses, minimizing uncertainty. Although the model may provide a promising context in which to consider localization errors, a few issues should be discussed.

First of all, the *speed prior account model* predicts antithetical onset and offset localization errors. Both in the initial study (Thornton, 2002) and the present study, the data seem to contradict this notion. Especially in the present study, the error at the onset position of the target was always significant and in the same direction, but the perception of the offset position of the target was always veridical. The absence of an offset localization error might have been due to the fact that in the present study there was no control for the vanishing position of the moving target, as the effect being studied here was the *ORE*. Nevertheless, such results could be problematic for the model.

Secondly, and as was mentioned before, different types of localization errors seem to operate on different perceptual levels. So, the problem that arises here is how could it be possible to use the same model to predict and explain phenomena that have different underlying mechanisms? At this point, however, one could argue that all localization errors are a matter of mental representations and that both cognitive and perceptual representations influence each other in the sense that conceptual and perceptual processes operate under common mechanisms and/or that cognition is based on perception (Barsalou, 1999; Pecher, Zeelenberg, & Barsalou, 2004). Also, one can also argue that localization errors can indeed be under the same model, as the important aspect is not the processing level, but representational awareness (Lamme, 2003; Raftopoulos & Mueller, 2006), which is something that could be a unifying component for all localization errors.

Despite its weaknesses, the *speed prior account model* does provide a useful attempt to unify the localization errors of dynamic stimuli and further exploration of the role of prior experience in the perception of the onset and offset positions of the moving object is needed. For example, in order to avoid any possible learning biases, it could be useful to test different stimulus speeds in mixed and not in blocked trials.

Limitations of the Present Study

As happens with all studies, the present one has some limitations that should be taken into consideration. First of all, due to the restrictions of the current situation, the present study was designed to be held online in order to ensure the safety of both the observers and the experimenters, as well as to make sure that it would not be interrupted had another serious wave of the pandemic emerged. This automatically means that viewing conditions were not controlled, thus visual angle and precise measurements of the monitors used by each observer cannot be given. Adding to that, there was no direct control over each individual during the duration of the task, and the ability to review (partially) whether they were performing the task correctly was possible only post hoc.

Another limitation could possibly be the between-participants design that was used in Experiment 1 and Experiment 2. A within-participants design could have been more sensitive to the changes among the experimental conditions, and thus reveal more information about the nature of the ORE. However, this design was selected in order to reduce the number of trials for each observer and thus the experiment length, making it more suitable for an online study.

Future Research

The present study was an attempt to further explore the nature of the *ORE* as well as the influence of global context on this effect. The data obtained in the previously described experiments provide some additional evidence that the *ORE* is an effect that is mainly driven by low-level perceptual mechanisms and that global context appears to be of little importance for the robustness of the effect. However, the question regarding the nature and the quality of the *ORE* still remains unanswered and additional research needs to be done to address the matter more thoroughly.

In order to test memory influences in a more direct and holistic way, we could design an experiment where response time would vary after the initial presentation of the dynamic stimulus. In addition, masking and filler trials could prove useful manipulations.

In Experiment 3 of the present study, the moving target could perform an *Open Shape* motion path or a *Closed* one. The ORE was larger when the motion path completed a *Closed Shape*. Although we attribute this to some sort of recency bias, as both onset and offset are in the same position on the x-axis, one could argue that the perceived trajectory of the *Open Shape* motion path is longer than the *Closed Shape*. Studies of *representational momentum* provide evidence for both a decrease in the forward displacement with increased motion paths (Hubbard & Ruppel, 2002; Choi & Scholl, 2006) and for motion path length having no influence on the displacement (De Sá Teixeira & Oliveira, 2011; McGeorge, Beschin & Della Sala, 2006). Thus, it would be interesting to further investigate whether the perceived motion length has any influence on the robustness of the *ORE* and even on the direction of the onset localization of the target.

Furthermore, it may be useful to further explore contextual influences on the *ORE*. For example, one could test the influence of the frames of reference (Duncker, 1929) both in terms of directionality of the effect and in terms of robustness. Additionally, the effect of occluders blocking the target as it smoothly moves could be studied. Such a study could reveal more information about the magnitude of the global influences on the dynamic event.

As mentioned in the *Introduction* section of the study, dynamic stimuli are very often present in our everyday life and people seem to have no problem responding to them. Since the actual environment is richer than the laboratory, context-wise, it is crucial to conduct research trying to simulate it with more realistic objects and frameworks. By employing virtual reality, this task could be achieved in a more controlled manner, without compromising the methodological reliability of the research.

Conclusions

The present study was an attempt to further investigate the localization errors that fall further behind in the direction of a moving target. The experiments conducted in this study suggest that the ORE is a phenomenon that is mainly driven by low-level perceptual mechanisms, as all the manipulations on the global aspects of the dynamic event failed to minimize or change the direction of the localization error. These findings have also initiated the discussion on how qualitative different the various localization errors are and whether it could be possible to create a unified model for all of the localization errors, given their differences in the processing level. However, this study was only an attempt to explore the nature of the ORE and further research is necessary in order to be able to make any definite conclusions.

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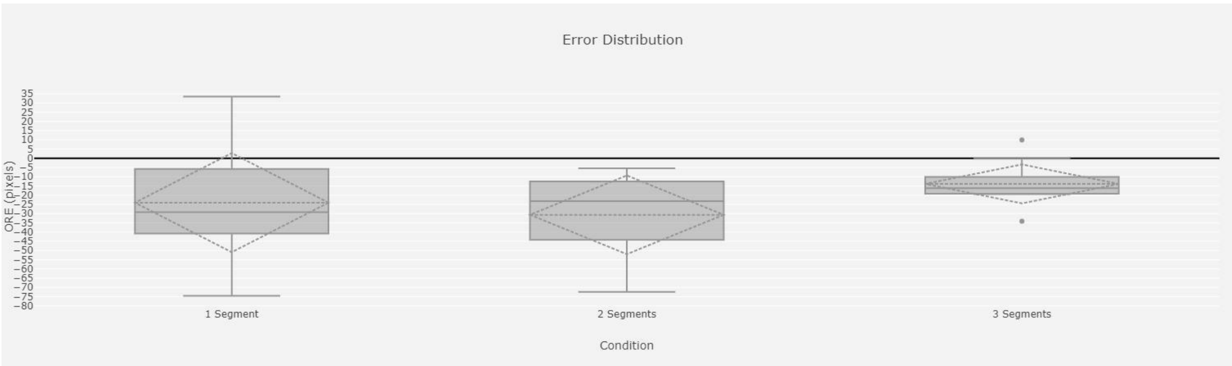
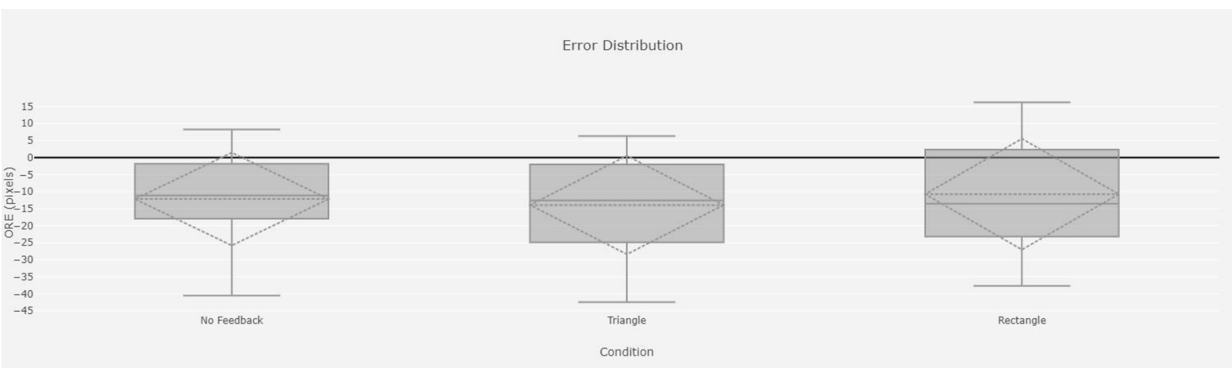
Supplement

A. Overall Distribution of Observers' Responses



The box plots that depict the overall distribution of observers' responses for the onset position of the target in Experiment 1. Only two mild outliers were detected and thus regular data analysis was not endangered.



The box plots that depict the overall distribution of observers' responses for the onset position of the target in Experiment 2. No outliers were detected and thus regular data analysis was not endangered.

B. ANNOVA Tables

Experiment 1

One Way ANOVA

	Sum of Squares	*df*	Mean Square	*F*	*p*	η^2
Number of Segments	1707.934	2	853.967	1.824	0.177	0.100
Residuals	15453.340	33	486.283			

Note: Type III Sum of Squares

Descriptive Statistics

Number of Segments	*M*	*SD*
1	-24.045	28.050
2	-30.628	22.284
3	-13.884	11.022

Note: *M* and *SD* represent mean and standard deviation, respectively

Experiment 2

One Way ANOVA

	Sum of Squares	*df*	Mean Suare	*F*	*p*	η^2
Feedback Type	61.114	2	30.557	0.127	0.881	0.008
Residuals	7917.915	33	239.937			

Note: Type III Sum of Squares

Descriptive Statistics

Feedback Type	*M*	*SD*
No Feedback	-12.175	14.238
Triangle	-10.748	17.005
Rectangle	-13.934	15.097

Note: *M* and *SD* represent mean and standard deviation, respectively

Experiment 3

Repeated Measures ANOVA

	Sum of Squares	*df*	Mean Suare	*F*	*p*	η^2
Error Type	8670.547	1	8670.547	11.043	0.007**	0.438
Residuals	8636.713	11	785.156			
ShapeType	206.428	1	206.428	2.127	0.173	0.010
Residuals	1067.540	11	97.049			
ErrorType*ShapeType	125.804	1	125.804	1.288	0.281	0.006
Residuals	1075.649	11	97.786			

** $p < .01$

Note: Type III Sum of Squares

Post Hoc Comparisons - Error Type

			95% CI for Mean Difference					
		Mean Difference	Lower	Upper	*SE*	*t*	*Cohen's d*	*p*
ORE	RM	-26.880	-44.684	-9.077	8.089	-3.323	-0.959	0.007**

** p < .01

Note: Cohen's d does not correct for multiple comparisons

Note: Results are averaged over the levels of: Shape Type

Descriptive Statistics

Shape Type	*M*	*SD*
ORE_closed	-19.316	18.587
ORE_Open	-11.931	15.690
RM_Closed	10.802	10.912
RM_Open	11.712	20.630

Note: *M* and *SD* represent mean and standard deviation, respectively