THE EFFECTS OF DIRECTION OF MOTION, LENGTH OF SPATIAL DISTANCE, AND DIFFERENCES IN VELOCITY ON TEMPORAL INTERVAL ESTIMATES OF VISUAL STIMULI

By

LYNNETTE M. MICHALUK

Bachelor of Arts in Psychology
Oakland University
Rochester, Michigan
1999

Master of Science in Psychology
Oklahoma State University
Stillwater, Oklahoma
2005

Submitted to the Faculty of the
Graduate College of the
Oklahoma State University
in partial fulfillment of
the requirements for
the Degree of
DOCTOR OF PHILOSOPHY
May, 2009

THE EFFECTS OF DIRECTION OF MOTION, LENGTH OF SPATIAL DISTANCE, AND DIFFERENCES IN VELOCITY ON TEMPORAL INTERVAL ESTIMATES OF VISUAL STIMULI

Dissertation Approved:

Dr. David G. Thomas

Dissertation Adviser

Dr. Bruce J. Ackerson

Dr. John M. Chaney

Dr. Melanie C. Page

Dr. A. Gordon Emslie

Dean of the Graduate College

ACKNOWLEDGMENTS

I would like to express my gratitude to my advisor, Dr. David G. Thomas, for his continued support and encouragement in this research. I would also like to thank my committee members, Dr. Bruce J. Ackerson, Dr. John M. Chaney, and Dr. Melanie C. Page for their effort and time. I would also like to thank my co-advisor, Dr. Charles I. Abramson for his support and interest in this research, and Dr. James W. Grice for his advice. Finally, I wish to thank my family.

TABLE OF CONTENTS

LIST OF TABLES

Table Page

LIST OF FIGURES

Figure Page

CHAPTER I

INTRODUCTION

BACKGROUND

The vast majority of psychophysical research involving velocity, distance, and duration fails to take into account the effects of each of these dimensions in the perception of the others; therefore, it is often necessary to make intuitive predictions in one area of research based on the results from the others. Because of this lack of integration in the literature, Representational Momentum (RM), or the representation in the cognitive and motor systems of the physical momentum of objects (Kerzel, 2005), will first be defined and described and typical RM studies reviewed in this paper. Next, the effects of implied and actual motion and direction of presentation of visual stimuli on temporal interval estimates in the kappa effect will be discussed, as will the possible role that RM played in the results of each study. Third, the importance of length of spatial distance and duration, as well as direction of motion of visual stimuli, on temporal interval estimates will be examined, although there is very little research available in this area. In addition, an attempt to justify merging judged displacements of moving stimuli typical in RM studies with temporal interval estimates of moving stimuli will be made. Finally, the study will be explained in detail, and results of the experiment will be discussed.

Operational Definition of Representational Momentum

Some researchers suggest that all human beings develop a sense of "intuitive physics", and that this intuitive knowledge leads to representational momentum, or RM (Freyd & Finke, 1984; Hubbard, 1990; 1997). There are several definitions of 'representational momentum' in psychology; in this paper, it is defined as the representation in the cognitive and motor systems of the physical momentum of objects (Kerzel, 2005). Representational momentum is very similar to impetus theory. Impetus theory was first discussed in the 6th century to further explain incomplete Aristotelian theories of projectile motion; its development continued through the 14th century (Kozhevnikov & Hegarty, 2001). In impetus theory, objects maintained motion by gaining an internal force at the time they were set in motion. Most impetus theories have two defining characteristics: (a) the object's internal force ebbs as time passes, thus the object stops, and (b) impetus determines the direction of movement, whether ascending, sideways, or circular. These characteristics often lead to erroneous judgments of the trajectory or of the speed of moving stimuli in representational momentum tasks. In Newtonian physics, however, objects "remain at rest or in constant motion unless acted upon by an external force" (Kozhevnikov & Hegarty, 2001, p. 441). The researchers state that in circumstances where Newtonian physics and impetus theories predict different outcomes, people rely on heuristics closely related to impetus theory.

This 'intuitive' knowledge of physics leads to predictable displacements in judgments of movement of visual stimuli. Typical examples of representational momentum tasks include estimates of the stopping point of visual stimuli, of the rate or direction of falling objects dropped from moving objects (such as airplanes), and of the trajectory of launched objects (Riener, Proffitt, & Salthouse, 2005). Note that all of these examples involve the perception of motion, and that thus far, there are no studies of the effects of RM on temporal interval estimates. Representational Momentum likely plays an important role in temporal estimates when movement of visual stimuli is involved, however, to date there are no studies that directly address this issue.

As previously mentioned, Kozhevnikov and Hegarty (2001) state that in circumstances where Newtonian physics and impetus theories predict different outcomes, people rely on heuristics closely related to impetus theory, the characteristics of which often lead to erroneous judgments of the trajectory or speed of moving stimuli in representational momentum tasks. To test the effects of these heuristics, Kozhevnikov and Hegarty (2001) had physics novices and experts judge the final position of vertically moving targets and found that judgments of both novices and experts were displaced in accordance with impetus theory. However, when the same two groups took a survey that required explicit knowledge of Newtonian physics, the experts answered the questions correctly, while novices still answered in terms of impetus theory. The researchers suggest that people may rely on RM resembling impetus theory beliefs because it may bestow a survival advantage. For example, it is advantageous to quickly determine what path a moving object will take, and when conscious deliberation is not possible, we tend to rely on the notion that objects lose their ‘energy’ or impetus. When conscious deliberation is possible, people with knowledge of physics correctly apply the principals of physics in their judgments of the movement of objects, while people with no formal knowledge of physics may still rely on impetus theory or RM, despite its outdated notions.

CHAPTER II

REVIEW OF LITERATURE

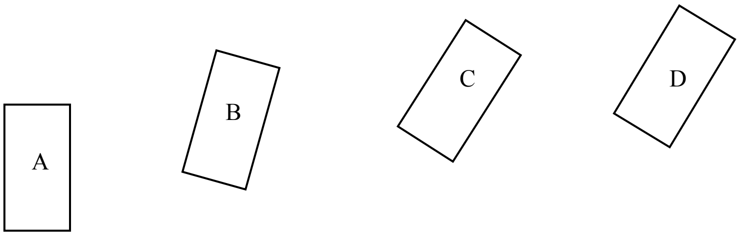
Representational Momentum Literature Review

In this section, studies examining the importance of representational momentum (RM) in visual displacement estimates will be discussed. In addition, an attempt will be made to clarify the relationship between visual displacement estimates in RM and the influence of motion and direction on temporal interval estimates. Furthermore, it is suggested that RM literature should also involve temporal estimates. First, the relationship between distance, time, and space are briefly discussed, as is the importance of each of these factors in the perception of the others. Next, RM studies are reviewed, and theoretical explanations for RM are described.

Representational Momentum Studies

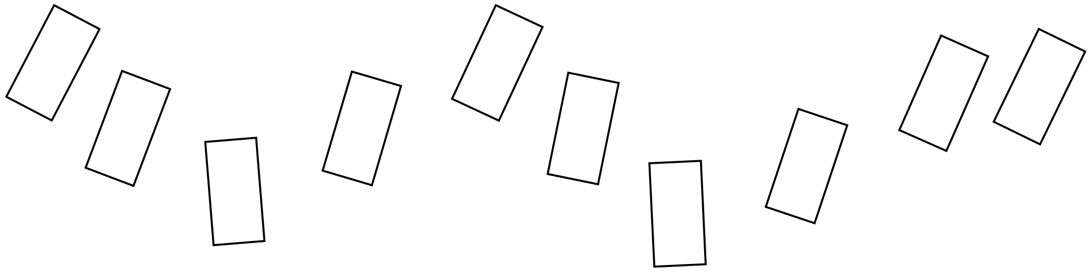
In an early study of RM, (Freyd & Finke, 1984) three stationary rectangles appeared on a screen one after another, with a 250 ms interstimulus interval (ISI), on a screen rotated either clockwise or counterclockwise on its center axis, to appear as if they were moving (see Fig.1). In other words, rectangles appeared one after the other in the center of the screen; only their orientation changed. A fourth rectangle (D in Fig.1) was then shown and participants indicated whether the fourth rectangle was in the same position, ‘ahead’ of, or ‘behind’ the previous rectangle. Participants were much more likely to respond ‘same’ for rectangles in the ‘ahead’ position than in the other conditions, meaning that the position of the final rectangle was extrapolated forward. A second experiment utilizing the same conditions examined the effect of ISI on judgments; ISIs were 500 ms and 750 ms. Although participants were still more likely to respond that the rectangle in the ‘ahead’ position was the same as the previous rectangle, the effect became less obvious as ISI increased, and was not statistically significant in the 750 ms condition. Freyd and Finke (1984) proposed that their results suggest that the representation in memory of an object changes along the path of the object’s implied motion. They add that these effects were strongest in short ISI conditions and weakened as ISI lengthened because as ISI lengthened, the effect of implied motion was reduced.

Figure1. Stimuli (A – C) and test target (D) in Freyd and Finke (1984).



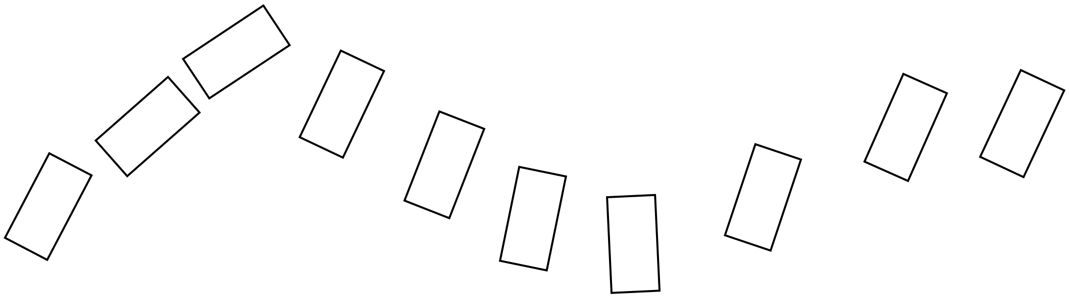
Because Freyd and Finke’s (1984) experiment involved only monotonic transformations, Verfaillie and d’Ydewalle (1991) examined the effects of more complex events on what they referred to as ‘anticipation processes’, rather than RM. In their first experiment, there were two implied motion conditions: the first was the same as that employed by Freyd and Finke (1984), and the second added more complex implied motion to the standard paradigm (see Fig. 2), although the final three rectangles (including the test rectangle) were in the same position in each condition. Interstimulus intervals were 240 ms in each condition. Results indicated that when stimuli were presented monotonically as in Freyd and Finke, judgments were displaced in the ‘ahead’ position, however, in the complex implied motion condition, judgments were accurate, and no forward displacement occurred. Verfaillie and d’Ydewalle explain these results in terms of the higher order representation of the occurrence of events. Specifically, in the monotonic condition, implied rotation in a single direction is presented, thus, the final position for the target rectangle is extrapolated forward. However, when complete direction change is presented as in the complex implied motion condition, implied rotation velocity will be zero at some point in time, therefore, there is no forward memory shift. They add that the final judged position of a target varies depending upon the complexity of the inducing display over the long term, because if this were not the case, then forward memory shifts should have occurred in each condition, because the position of the final three rectangles was the same in each condition.

Figure 2. Stimuli in complex implied motion condition, Experiment 1 (Verfaillie & d’Ydewalle, 1991).



To further test the idea that pattern presentation over time is responsible for forward memory shift, Verfaillie and d'Ydewalle (1991) conducted a second experiment, utilizing the complex implied motion condition from their first experiment and a second implied motion condition that included fewer implied rotations (according to the authors), thus less direction change (see Fig. 3 for stimuli in the less-direction change condition). Results indicated that as in Experiment One, judgments were accurate for the complex implied motion condition. However, in the 'few implied rotations' condition, judgments were displaced in the 'ahead' direction.

Figure 3. Stimuli in 'few implied rotations' condition, Experiment 2 (Verfaillie & d'Ydewalle, 1991).



These results replicate the findings from Experiment One for complex implied motion. Verfaillie and d'Ydewalle (1991) add that results in this experiment also provide evidence for their conclusions in Experiment One that final judged position of a target varies depending upon the complexity of the inducing display over the long term. The researchers note that position of the final three rectangles was identical in all three conditions, yet forward displacement occurred only in the simple monotonic implied rotation and ‘few implied rotations’ conditions. In addition, it was not the complexity of the event itself that determined judged memory for the final stopping point of a rectangle; rather, it was the anticipated end result of the representation in memory of the complex event over time. Verfaillie and d’Ydewalle add that the ability to anticipate the future trajectory of a moving object (Representational Momentum) suggests that anticipation is a necessary and integral part of the structure of the perceptual system.

Kerzel (2002) found similar results in a recent study examining the effects of varying both direction and motion of a moving target. He notes, as did Verfaillie and d’Ydewalle (1991), that in the majority of RM studies, implied or actual motion and direction changes are highly predictable. According to Kerzel (2002), the judged forward displacement effect found in most RM studies may be the result of nothing more than the repeated presentations of the same visual stimuli over a given period of time, particularly since direction of rotation (i.e. clockwise or counterclockwise) in early studies was a between-subjects variable. Therefore, each participant only saw either clockwise or counterclockwise implied or actual motion. Kerzel suggested that after viewing the same stimuli over repeated trials, participants may have begun to learn the position of each rectangle at any given time, and thus may have been able to predict the final position of the rectangle *before* the onset of stimuli.

In a study on the effects of predictability on judged displacement of visual stimuli, Kerzel (2002) treated direction of rotation as *both* a between-subjects and a within-subjects variable. Therefore, one group of participants viewed the implied rotation of stimuli in only one direction, while stimuli were presented to the second group in each direction. Kerzel also points out that in previous studies the final position of the rectangle was the same for all participants, which may also have contributed to forward displacement. Therefore, final position of the rectangle was also either fixed or was varied randomly. The interstimulus interval was 156 ms for all conditions, and each participant received 360 trials. Kerzel (2002) stated that predictability of the final rectangle position should have declined when direction change and variation of final rectangle position were within-subjects variables. Based on this logic, participants who received trials which varied in both direction of presentation and in final rectangle position should have shown the least forward displacement, if prior knowledge regarding the stimuli contributes to displacements. As expected, forward displacement was most evident when stimuli were presented to a single participant in only one direction and the final rectangle position was fixed, and was also evident to a lesser extent when stimuli were presented to a single participant in only one direction, but final rectangle position varied. However, when stimuli were presented to the same participant in different directions, forward displacement occurred only when the final rectangle position was fixed. When a single participant saw both direction change and the final rectangle position was random rather than fixed, no forward displacement occurred. Kerzel (2002) concluded that "the assumption that the forward shift was…due to representational momentum needs to be modified - if not abandoned - in light of the present data (p. 76)".

It is important to mention that in most RM studies, participants typically receive 95 or more trials (Freyd & Finke, 1984; Hubbard, 1990; 1997; 2001; Hubbard & Motes, 2002; Verfaillie & d'Ydewalle, 1991), thus Kerzel's conclusion that predictability is necessary for forward displacement to occur likely has some merit. I believe it is necessary to mention that the effect is referred to as "representational momentum" and not “representational direction change”. In other words, for forward displacement to occur, there must be a sense of implied momentum, which is not likely to occur if implied or actual motion seems artificial, as in the complex implied motion condition utilized by Verfaillie and d’Ydewalle (1991), or when the implied direction of rotation changes over 360 trials, as in Kerzel (2002). Rather, for RM to occur, motion must seem natural.

Perceived Gravity and Representational Momentum

Hubbard (1990) has examined the effects of direction of motion and perceived gravity on the judged vanishing point of targets. Participants viewed targets traveling vertically, horizontally, and diagonally. ‘Direction of motion’ influenced judgments of target vanishing points, and judged displacements occurred in both the ‘direction of motion’ as well as in ‘downward’ directions. Furthermore, ‘direction of motion’ and ‘downward’ displacements were largest in the horizontal conditions, intermediate in diagonal conditions, and finally, ‘direction of motion’ displacement was least evident in the bottom-to-top vertical condition. In addition, ‘direction of motion’ displacement was nearly as large for horizontal conditions as it was in the top-to-bottom condition. Hubbard (1990) suggests that a gravity effect (i. e., downward motion) as well as an effect of direction of motion combined to produce displaced judgments. In particular, when the force of gravity was parallel to the direction of target motion, more forward displacement occurred, as in the top-to-bottom vertical condition. However, when the force of gravity was *not* parallel to the direction of target motion, as in the bottom-to-top condition, less ‘direction of motion’ displacement occurred. Thus, in horizontal conditions, the combination of gravity and direction effects combined to produce judgments that were displaced both in the direction of motion as well as downward, while in diagonal conditions, there were stronger direction of motion than downward displacements.

To further examine the effects of gravity on judgments of the vanishing point of ascending and descending targets, Hubbard (2001) varied the height at which ascending and descending targets disappeared in a picture plane, with targets traveling at slow or fast speeds vanishing at one of five different heights in the plane (two above midpoint, one at midpoint, and two below midpoint). For targets that disappeared in the top half of the screen, ‘direction of motion’ displacement was non-existent for slow moving ascending targets, small for fast moving ascending targets, slightly higher for slow-moving descending targets, and higher still for fast-moving descending targets. For targets that disappeared in the bottom screen half, ‘direction of motion’ displacement occurred in all conditions; most displacement occurred in the fast-moving descending condition, slightly less in fast-moving ascending and slow-moving descending conditions, and least in the slow-moving ascending condition. Hubbard (2001) explained that these results support the idea that implied gravitational attraction influenced the representation of the target’s vanishing point. He added further that from everyday experience we learn that ascending projectile objects decelerate on ascent and descending objects accelerate as they fall. Moreover, the higher an ascending object climbs, the more it slows, and the further a projectile object falls, the faster it falls. Therefore, both ascending and descending objects have slower velocities when traveling at higher levels in the picture plane.

Theoretical Explanations of Representational Momentum

Hubbard (2001) states that several factors influence memory for the final position of moving objects, including the momentum of a moving object, participants' conceptual knowledge of the object, projected motion of the target, velocity of visual stimuli, and the impact of friction on the target. Because so many factors influence the perception of time, motion, and space in memory, more researchers are beginning to examine the movements of targets in many contexts, rather than presenting them to participants in isolation as was common in early research. Others are studying the role of the perceptual and motor systems in RM. Theoretical explanations considered in this section include Hubbard's (2001) proposal that RM is the result of the cognitive representation of objects in memory and Kerzel's (2005) theory that RM occurs because of limitations in the perceptual processing of velocity.

Hubbard (1990; 1997; 2001) concludes that a cognitive representation of gravity is utilized when making judgments of moving objects. In other words, previous experience with moving objects suggests that gravity should influence their stopping points in predictable ways. In a study of the effects of direction of presentation of visual stimuli in the kappa effect (Cohen et al., 1955) found that judged durations were longest for stimuli presented from top-to-bottom and most accurate for stimuli presented from bottom-to-top. The researchers explained their results in a manner similar to Hubbard: Results in their study may have been due to intuitive knowledge acquired about the natural motion of objects. Hubbard (1990) adds that these experiences come to be represented as cognitive heuristics, which then systematically influence judged displacements of moving stimuli.

Kerzel (2005) believes that RM may not simply be a cognitive construct. He believes forward displacement may result in part from “predictive mechanisms at the perceptual and motor levels.” Kerzel proposes that it is possible that attention is focused on the future position of a moving target in order to facilitate motor system responses to the target position. Thus, RM may be the result of the representation in both the cognitive and the motor systems of the physical momentum of objects. Kerzel points out the brain’s visual system requires approximately 100 ms to process visual information. Because of this processing delay, moving targets change position before it is possible to be consciously aware of the new location. The visuomotor system ‘makes up for’ the time needed for neuronal processing of perceptual information according to Kerzel. If this were the case, performance would be faster and more efficient. Kerzel (2005) adds that this explanation fits data from previous research well. For example, he notes that in both Freyd and Finke’s (1984) and in Hubbard’s (1990; 1997; 2001) research, participants’ eye movements were unrestrained, and judgments in all experiments required motor responses. In Freyd and Finke’s (1984) studies, effects lessened as ISI increased. They suggested that this occurred because longer ISIs did not lead to a sense of implied motion, therefore, judged displacements of rectangles to the ‘ahead’ position were not as apparent. According to Kerzel’s theory however, forward displacement with longer ISIs was not as apparent because smooth-pursuit eye movements do not occur in response to implied movement. With faster ISIs, the stationary target may have appeared to move and smooth pursuit eye movements occurred, resulting in more ‘ahead’ judgments. Thus the visuomotor system anticipated the future position of the target, resulting in forward displacement of the rectangle. This explanation also pertains to Hubbard’s (1990; 1997; 2001) results.

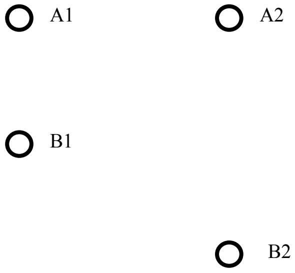
To summarize, in typical RM studies, when implied or actual motion of visual stimuli appears as natural motion, judged displacements of the vanishing point of the stimuli occurs, such that participants estimate that the final stopping point is displaced in the direction of the implied or actual motion. Researchers suggest (Freyd & Finke, 1984; Verfaillie & d’Ydewalle, 1991; Hubbard, 1990; 1997; 2001; Hubbard & Bharucha, 1988; Hubbard & Motes, 2002; Kozhevnikov & Hegarty, 2001) that this effect occurs because of intuitive knowledge of natural motion and gravity and of limitations of the human perceptual processing system. To date, there is no research specifically examining the possibility that RM may also play a role in temporal estimates; however, two studies carried out in our lab on the kappa effect (Michaluk et al, in preparation) provide a starting point, and as such will be examined in detail next.

Study One - Kappa Effect Study

Background - Kappa Effect Study

Figure 4.

Visual stimuli in the kappa effect.



In the initial kappa effect study, the impact of differences in spatial distance as well as type of motion of visual stimuli on the kappa effect was examined. The kappa effect is a well-studied phenomenon in which two spatial distances of different lengths are paired with temporal intervals of equal durations which are presented in succession, (see Fig. 4 for illustration of visual stimuli). Previous research has shown that participants judge the temporal interval paired with the longer spatial distance to be longer in duration as well (Abe, 1935; Adkins, 1972; Cohen & Cooper, 1962; Cohen et al., 1955; Collyer, 1977; Huang & Jones, 1982; Ono, 1966-67, 1976; Ono & Maruyama, 1969-70; Parks, 1967; Price-Williams, 1954; Russo & Dellantonio, 1989; Yoblick & Salvendy, 1970).

In most studies of the kappa effect, visual stimuli marking spatial distances are flashed in succession to mark the onset and offset of temporal intervals, which may lead to a sense of implied motion. For example, in most studies, the onset of the first temporal interval is marked by the flashing of A1, followed at the offset of the interval by the flashing of B1. The second temporal interval is then presented in the same manner (A2 – B2).

Results of many studies show that motion of visual stimuli paired with temporal intervals *lengthens* their perceived duration compared to static visual stimuli paired with equal temporal intervals (Brown, 1995; Cohen & Cooper, 1962; Ono, 1969-70; Predebon, 2002). For example, in studies by Brown (1995) and Predebon (2002) visual stimuli paired with temporal intervals moved in irregular patterns across computer screens in one condition; in another, the same durations were paired with stationary stimuli. Temporal interval estimates in both studies were longer for moving stimuli than for stationary stimuli. In addition, both Ono (1969-70) and Cohen and Cooper (1962) studied the effects of actual motion of stimuli on the kappa effect. In Ono's study, participants drew short and long spatial distances paired with equal temporal durations as directed by the researcher. Cohen and Cooper had blindfolded participants estimate the duration of the first and second half of a vehicle ride, with both durations being the same, but speed in the first half was slower than in the second half. In both studies, longer distances, and therefore faster movement, were associated with longer temporal estimates. Despite these findings, changes in perception of temporal intervals in kappa effect studies have been attributed to differences in spatial distance with little regard for the possible role of motion.

Method - Kappa Effect Study

As noted earlier, many factors interact to influence the perception of time, movement and space (Hubbard, 2001). Therefore, in the kappa effect study, the effects of differences in spatial distance alone, in addition to spatial distance in combination with either implied or with actual motion were examined. To study the influence of differences in spatial distance alone on temporal intervals on the kappa effect, visual stimuli marking spatial distances were presented prior to the onset of intervals and remained present throughout the interval (predefined) in half the trials for each motion (no, implied, and actual) condition. Spatial distances were marked only during temporal intervals in the other half of trials (not predefined).

Only one previous study has examined the influence of direction on the kappa effect, and this used only implied motion (Cohen et al., 1955). Results in Cohen et al. showed the kappa effect was most evident in the top-to-bottom condition and least evident in the bottom-to-top condition. Therefore, stimuli in this kappa effect study (Michaluk et al., in preparation) were presented from top-to-bottom in order to maximize results (see Table 1 for complete list and description of conditions). In addition, the first, or standard, distance/duration was fixed at 2 ¼ in. (5.72 cm) in length and 1500 ms in duration. The second, or test, distance/duration was always 4 ½ in. (11.44 cm) in length, but durations were 1425 ms in half the trials and 1500 ms in the other half. Durations were chosen based on data from a pilot study showing that participants adjusted the second temporal interval to be on average 5% *shorter* than the actual interval of 1500 ms, meaning that adjustments were approximately 1425 ms. Two durations were used primarily to prevent practice effects. Finally, each participant received four trials. Two trials were of equal temporal duration and two were of unequal duration. In addition, each participant received two predefined and two not predefined trials, but only one type of motion: no motion, implied, or actual.

Table 1.

Conditions in the Kappa Effect Study

Condition number	State at start	Sample	Test	Duration defined by:
1[1] No motion, not predefined	Blank screen	A1 and B1 on and off simultaneously	A2 and B2 on and off simultaneously	AB flash at onset to AB flash at offset
2 No motion, predefined	A1, B1, A2, B2 all visible as yellow, brighten to orange	A1 and B1 brighten simultaneously then dim	A2 and B2 brighten simultaneously then dim	AB brightening to AB dimming
3 Implied motion, not predefined	Blank screen	A1 on, then off; B1 on, then off	A2 on, then off; B2 on, then off	A onset to B offset
4 Implied motion, predefined	A1, B1, A2, B2 all visible as orange, brighten to yellow	A1 brightens, then dims; B1 brightens, then dims	A2 brightens, then dims; B2 brightens, dims	A brightening to B dimming
5 Actual motion, not predefined	Blank screen	A1 on, moves to B1, stops, disappears	A2 on, moves to B2, stops, disappears	Onset at A to offset at B
6 Actual motion, predefined	A1, B1, A2, B2 all visible as yellow, orange circles begin at A1 and A2	A1 brightens, moves to B1, then dims	A2 brightens, moves B2, dims	Brightening at A to dimming at B

[1] It is impossible to have both no predefined distance and no motion. In this condition, the first time the lights flash on and off, the distance is predefined but that distance does not remain in the participant's view during the temporal interval.

Hypotheses and Results- Kappa Effect Study

Based on previous findings, the first hypothesis stated that the kappa effect would be present in all motion conditions whether or not stimuli were predefined, and that it would be most evident when implied or actual motion was present. As predicted, in both no- and implied motion conditions temporal estimates were approximately 5% longer than actual intervals when paired with long spatial distances, thus, differences in spatial distances alone led to longer perceived duration of temporal intervals. However, in actual motion conditions, the kappa effect was reversed, and temporal estimates were on average 20-25% *shorter* than actual intervals for durations paired with longer spatial distances (see Table 2).

Table 2.

Single Sample t-tests for Both Durations and Adjustments in the Kappa Effect Study

Motion[a]	Adj/Dur[b]	*N*	*M*	*SD*	*t*	*df*	*p* - level
NM	1/E	59	-.04	.10	-2.93	58	.005*
AM	1/E	59	-.05	.10	-3.84	58	.001*
M	1/E	49	.22	.28	5.52	48	.001*
NM	2/E	59	-.03	.07	-3.61	58	.001*
AM	2/E	59	-.03	.08	-2.74	58	.008*
M	2/E	49	.22	.27	5.62	48	.001*
NM	1/U	59	-.03	.08	-2.63	58	.011*
AM	1/U	59	-.03	.09	-2.40	58	.020
M	1/U	49	.23	.32	5.13	48	.001*
NM	2/U	59	-.01	.06	-1.42	58	.161
AM	2/U	59	-.01	.07	-1.11	58	.271
M	2/U	49	.23	.28	6.04	48	.001*

[a] Motion = NM for no motion, AM for apparent motion, and M for actual motion. [b] Adj/Dur combinations = 1 for adjustment 1, 2 for adjustment 2, E for 1500/1500 ms intervals, and U for 1500/1422 ms intervals. * Statistically significant at *p* = .017.

The second hypothesis stated that apparent or actual motion of visual stimuli would affect the perceived duration of equal temporal durations marked by different spatial distances. Results from the first planned comparison showed that there were no significant differences between the no motion conditions and the apparent motion conditions for either first or second adjustments for either duration (see Table 3). Therefore, for this comparison, hypothesis two was not supported, and apparent motion of visual stimuli did not affect the perceived duration of equal temporal durations marked by different spatial distances. However, results of the second planned comparison showed significant differences in both first and second adjustments for both durations between the no motion conditions and the actual motion conditions (see Table 3). In the no motion conditions, first and second adjustments were generally *equal* to or *shorter* than the actual temporal interval by approximately 5% for equal and for unequal intervals, while in the actual motion conditions, both first and second adjustments were approximately 22% *longer* than equal and unequal temporal intervals. Therefore, hypothesis two was supported for comparison 2, but not in the expected direction.

Table 3.

Planned Comparisons for Each Motion Condition, for First and Second Adjustments and Both Durations in the Kappa Effect Study

Conditions[a]	Adj/Dur[b]	*df*	*F*	η^2	*p* - level
M vs. NM	1/E	1	59.05**	.265	< .001
AM vs. NM	1/E	1	0 .23	.228	.634
M vs. NM	1/U	1	49.48**	.232	< .001
AM vs. NM	1/U	1	0.00	.001	.971
M vs. NM	2/E	1	65.85**	.287	< .001
AM vs. NM	2/E	1	0.02	.000	.900
M. vs. NM	2/U	1	57.90**	.261	<.001
AM vs. NM	2/U	1	0.00	.000	.998

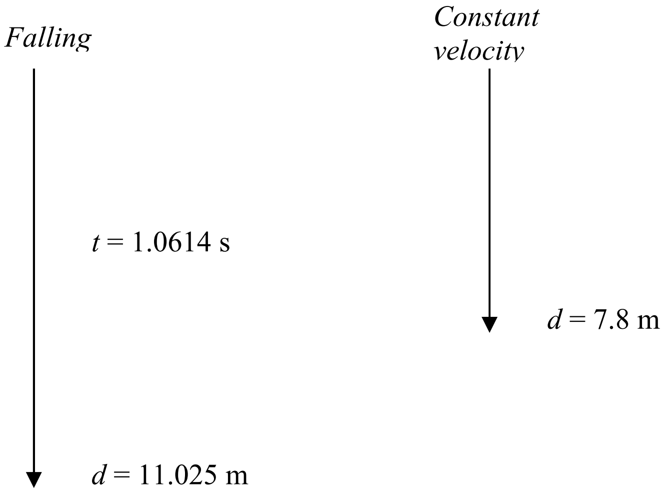
[a] Motion conditions = NM for no motion, AM for apparent motion, and M for actual motion. [b] Adj/Duration condition combinations = 1 for adjustment 1, 2 for adjustment 2, E for 1500/1500 ms intervals, and U for 1500/1422 ms intervals.

Discussion – Kappa Effect Study

There are two likely explanations for the reversal of the kappa effect in actual motion conditions in this study. First, participants may have inadvertently attempted to match the *speed* of the visual stimuli of each spatial distance rather than the duration as instructed. Because the first distance was shorter, stimuli moved much more slowly than the longer spatial distance. Participants may have increased the temporal interval (thereby decreasing the speed) in an attempt to match the speed of each distance. A second explanation is that the top-to-bottom direction of movement of spatial stimuli used to define spatial distances influenced adjustments. Visual stimuli marking temporal intervals always began at the top of the screen and moved downwards, which may have led to the appearance that stimuli were falling, and thus accelerating, an explanation consistent with RM theory (Freyd & Finke, 1984; Hubbard, 1990; 1997; 2001; Hubbard & Bharucha, 1988; Hubbard & Motes, 2002; Kozhevnikov & Hegarty, 2001; Verfaillie & d'Ydewalle, 1991). It is important to note that stimuli in the short distance may have appeared to move at a constant rate, while that in the long distance seemed to fall. Stimuli in this study remained in the top half of the screen, and results from Hubbard's 2001 study of the effects of varying height of disappearance of objects in the screen suggest that velocity may have changed the perceived duration of intervals. Specifically, in Hubbard's study, displacements were largest for fast-moving descending stimuli.

It is not possible to determine from these results whether participants attempted to match the velocity of stimuli rather than temporal intervals; therefore, this question was examined further in the follow up direction study which will be discussed in more detail below. The second explanation relies on participants' perceptual knowledge of gravity.

Figure 5. Distance traveled in 1.5 s by moving objects.



An object starting at rest that falls for 1500 ms will travel 11.025 m in that time (see Fig. 5) according to the acceleration of gravity. At its midpoint (5.5125 m), the object has fallen for t = 1.0607 s and is falling at the rate of 5.2 m/s. However, an object moving in any direction at a constant velocity of 5.2 m/s will move only 7.8 m in the same 1500 ms. In this study, the visual perceptual system may have applied a top-down processing algorithm and interpreted moving stimuli to be falling, and therefore accelerating. Thus, the brain computed the duration of movement as 1.28 s rather than as 1.5 s, because that is the duration required for a true falling object to travel 7.8 m. For both durations to be perceived as equal, the second duration would need to be lengthened by 17% to make the duration seem to be 1.5 s. In the kappa effect study, first adjustments in movement conditions were approximately 22%, slightly more than 17%. While this explanation fits the data well, it fails to explain why participants believed the temporal interval associated with the shorter distance was much longer than that paired with the longer distance, even though visual stimuli may have seemed to fall in both cases.

It is likely that this occurred because stimuli paired with the short distance moved much more slowly and thus appeared to be moving at a constant rate, while that paired with the longer distance appeared to fall due to increased speed of stimuli in the long distance. In other words, participants may have perceived visual stimuli in the short spatial distance to be moving at a constant rate and the stimuli paired with the long spatial distance as falling, because stimuli moved much more quickly when paired with long spatial distances. If this occurred, participants would have perceived the short spatial distance as 1.5 s in duration, and the long as 1.28 s. In this case, average temporal adjustments of 20-25% would have lengthened the second perceived temporal interval to 1.58 s for 1422 ms intervals and 1.65 s for 1500 ms intervals. For adjustments of 20% in equal temporal interval conditions, adjustments would be *slightly* more than 5% of the actual temporal interval, and adjustments of 25% would have been 15% more than the actual temporal interval.

Study Two - Direction Study

Background – Direction Study

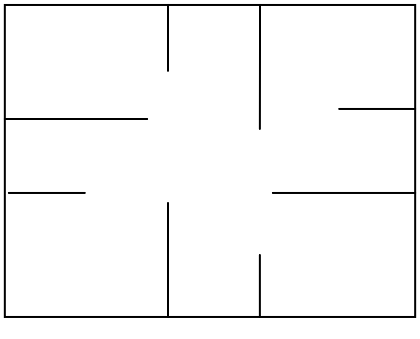
A follow-up study was conducted to examine the possible effects of direction of implied and actual motion on the kappa effect. As mentioned previously, only one previous study has examined the influence of direction on the kappa effect, and this used only implied motion (Cohen et al., 1955). The kappa effect was most evident when stimuli were presented from top-to-bottom, and least evident when presented from bottom-to-top. The authors explain that this effect may have been the result of intuitive knowledge about natural motion of objects. Specifically, they state: “Our familiarity with the acceleration of falling objects and the deceleration of rising objects might lead one to expect apparent acceleration downwards, deceleration upwards, and more linear movement horizontally in our display (p. 371)”. Hubbard’s studies (1990; 1997; 2001;

Hubbard & Bharucha, 1988) in which judged displacements of visual stimuli tend to be strongest when presented from top-to-bottom, support this notion. The strong reverse kappa effect found in Michaluk et al. (in preparation) also supports this notion, but because stimuli were always presented from top-to-bottom, it was necessary to test the effect of direction of motion further. Therefore a follow up study was conducted in which stimuli were presented in four directions: top-to-bottom (TB), bottom-to-top (BT), left-to-right (LR), and right-to left (RL).

Method – Direction Study

In the direction study, the same temporal durations (1500 ms Equal and 1500/1422 ms Unequal) as in the kappa effect study were used; in addition implied and actual motion were also used for each of the four direction conditions (TB, BT, LR, and RL). A no-motion condition was not included in this study because results between no motion and implied motion groups were the same in the kappa effect study. Each participant received one of the four directions and within each direction group, each participant received two trials each of two types of motion: implied and actual. To control for practice effects, one trial of each type of motion was made up of two equal intervals and one was unequal temporal intervals. Refer to Figure 6 for visual stimuli in the direction study.

Figure 6. Visual stimuli in the four direction conditions in the direction study.



Hypotheses and Results – Direction Study

The first hypothesis stated that the kappa effect would be found in apparent motion conditions. As in Experiment One, when the kappa effect is present, temporal estimates in 1500 ms conditions should be at least 5% less than actual intervals, and in 1422 ms conditions, they should be approximately equal to 0. The second hypothesis stated that a reverse kappa effect would be found only in actual motion conditions, resulting in temporal estimates that were greater than actual temporal intervals. The third hypothesis stated that there would be significant differences in temporal interval estimates between top-to-bottom (TB) and bottom-to-top (BT) groups in actual motion conditions, with estimates being longer in TB than in BT conditions.

Results of single sample *t*-tests (see Tables 4 and 5) showed that the kappa effect was not found in any of the four direction groups for first or for second adjustments in either E 1500 ms conditions or U 1422 ms conditions. Therefore, hypothesis one was not supported by these results. It should be noted, however, that for the TB, BT, and LR groups all adjustments in apparent motion conditions were negative, as expected, and were positive only in the RL conditions.

The second hypothesis, that a reverse kappa effect would be found only in actual motion conditions, was only statistically supported for two conditions: for first adjustments in TB (14%) and RL (10%) unequal direction conditions (see Table 4). It is important to mention that variability in temporal estimates for all conditions was high, possibly making it more difficult to find an effect.

Finally, the third hypothesis, that the effects of type of motion (AM, M) would be most evident in TB conditions and least evident in BT conditions was statistically supported only for unequal intervals when actual motion was present for first adjustments *F*(3, 88) = 2.722, *p* = .049, $\acute{\eta}^2$ = .085). A subsequent Tukey's post-hoc analysis revealed that mean first adjustments were significantly higher in the TB (*M* = .17, *SD* = .29) group than in the BT (*M* = .01, *SD* = .17) group as expected. Specifically, estimates were significantly longer in the TB condition than in the BT condition for unequal temporal intervals; thus hypothesis three was partially supported by these results.

Table 4.

Single Sample T-tests for First Adjustment, both Durations in the Direction Study

Motion^a	Dur^b	Group	*N*	*M*	*SD*	*t*	*df*	*p* - level
M	U	TB	25	.16	.29	2.693	24	.013*
AM	U		25	-.03	.11	-1.361	24	.186
M	E		25	.03	.16	0.985	24	.335
AM	E		24	-.03	.12	-1.055	23	.302
M	U	BT	26	.00	.17	0 .047	25	.963
AM	U		26	-.05	.15	-1.619	25	.118
M	E		25	.00	.17	0 .035	24	.972
AM	E		25	-.01	.15	-0.463	24	.647
M	U	RL	19	.11	.14	3.316	18	.004*
AM	U		21	.04	.13	1.399	20	.177
M	E		20	.02	.16	0.650	19	.523
AM	E		21	-.03	.10	-1.313	20	.204
M	U	LR	24	.07	.20	1.614	23	.120
AM	U		24	-.03	.12	-1.427	23	.167
M	E		24	.05	.22	1.064	23	.298
AM	E		24	-.04	.14	-1.281	23	.213

^{a} Motion = AM for apparent motion and M for actual motion. ^{b} E for 1500/1500 ms intervals, and U for 1500/1422 ms intervals. * Statistically significant at *p* = .025.

Although we did not replicate the findings of the kappa effect study in the direction study, these results nonetheless lend support to the conclusion that temporal estimates are influenced differently by apparent and by actual motion. Results of these analyses followed the general expectation that estimates in BT conditions would not be as extreme as those in TB conditions. It seems plausible that direction of presentation of visual stimuli may in fact influence temporal estimates.

As mentioned previously, there was much variability in all temporal estimates, thus, finding an effect, if present, was more difficult. Another potential issue in finding an effect of direction in this study as opposed to the kappa effect study was the method of testing participants in each study. Specifically, in the kappa effect study, participants were tested in groups in a darkened computer lab and were instructed that the experimenter would turn the lights on after there had been plenty of time to complete the task. In the direction study, participants were tested one at a time in a smaller lab, and in many cases, no adjustments were made during the last trial, which suggests that participants may have hurried through trials to finish sooner.

Table 5.

Single Sample T-tests for Second Adjustment, both Durations in the Direction Study

Motion[a]	Dur[b]	Group	*N*	*M*	*SD*	*t*	*df*	*p*-level
M	U	TB	18	.16	.34	1.979	17	.064
AM	U		13	-.03	.09	-1.318	12	.212
M	E		18	.13	.33	1.740	17	.100
AM	E		14	-.03	.09	-1.005	13	.333
M	U	BT	15	.12	.23	1.945	14	.072
AM	U		15	-.06	.16	-1.540	14	.146
M	E		14	.11	.27	1.558	13	.143
AM	E		17	-.04	.17	-1.067	16	.302
M	U	RL	12	.15	.18	3.031	11	.011*
AM	U		14	.04	.15	1.107	13	.288
M	E		14	.05	.23	0.808	13	.434
AM	E		10	-.05	.17	-0.944	9	.370
M	U	LR	19	.05	.24	0.894	18	.383
AM	U		13	-.02	.12	-0.692	12	.502
M	E		20	.09	.32	1.206	19	.243
AM	E		17	-.04	.15	-0.976	16	.344

[a] Motion = AM for apparent motion and M for actual motion. [b] E for 1500/1500 ms intervals, and U for 1500/1422 ms intervals. * Statistically significant at *p* = .025.

Discussion – Direction Study

The general findings in actual motion conditions in Experiment Two lend further support to the notion that RM plays a role in temporal perception as well as in visual perception. Of particular interest is that temporal estimates were longest in TB conditions, intermediate in horizontal conditions, and smallest, at least for first adjustments, in the BT condition. These results are similar to previous findings in Representational Momentum (RM) research (Freyd & Finke, 1984; Hubbard, 1997; 2001; 2002; Hubbard & Bharucha, 1988; Hubbard & Motes, 2002; Verfaillie & d'Ydewalle, 1991), in that judged displacements of visual stimuli tend to be strongest in TB conditions, weakest in BT conditions, and intermediate in horizontal conditions. Furthermore, the findings of the kappa effect and direction studies suggest that RM does play a role in changes in temporal estimates in actual motion conditions in the reverse kappa effect, which will be discussed further below.

Falling objects accelerate according to both RM and Newtonian physics (Kozhevnikov & Hegarty, 2001). In the kappa effect and direction studies, visual stimuli may have appeared to fall when presented from top to bottom. However, the distances that stimuli appeared to fall were different. Stimuli in the short spatial distance would not have appeared to fall as far, and thus would not have accelerated as much as that in the long spatial distance. This may have led to temporal interval estimates that were much longer for the long distance than for the short. It is likely that RM is involved in differences in temporal estimates when direction of stimuli is a factor, as is also the case in judged displacements of visual stimuli, which will now be discussed.

Study Three – Representational Momentum (Current Study)

In representational momentum (RM) studies, the possible role that changes in velocity and duration may play in judged displacements of visual stimuli have not been discussed. This study attempted to bridge the gap between RM, and specifically judged displacements, and temporal estimates of visual stimuli. As mentioned previously, in both the kappa effect and direction studies (Michaluk et al., in preparation), temporal estimates were much longer when stimuli actually moved, and in the direction study, this effect was most pronounced in top-to-bottom conditions. The primary proposed explanation for this finding was that stimuli appeared to fall, at least when spatial distances were longer and thus with greater speed. Because RM studies rely on the notion that people possess an inherent knowledge of the physical laws of motion, it is possible to utilize the perception of temporal intervals to further test this notion, as motion, velocity and duration are related (Abe, 1935; Brown, 1995; Caelli et al., 1978; Cohen et al., 1955; Predebon, 2002; Price-Williams, 1954).

A study by Algom and Cohen-Raz (1987) provides some knowledge as to how motion, velocity, and duration interact in human perception, although it does not address RM. Their paradigm served, in part, as the basis for durations and distances employed in the current study. The primary purpose of Algom and Cohen-Raz's study was to investigate perceptual differences in implied versus actual motion on judgments of velocity. The effects of implied and actual motion on temporal estimates were also examined in the kappa effect and direction studies (Michaluk et al., in preparation), in which implied motion led to estimates that were shorter than actual intervals and actual motion led to estimates longer than actual intervals, at least when direction was not from bottom-to-top. Algom and Cohen-Raz also found differences in judged estimates of velocity of stimuli between implied and actual motion, such that duration influenced actual motion velocity judgments more than did distance; however, for implied motion, distance was more influential than duration in velocity judgments. Specifically, perceived velocity increased more as distance lengthened than it did as duration decreased for implied motion. Furthermore, the reverse was true for actual motion: Perceived velocity increased with decreases in duration more so than with increases in distance. Of primary interest in the present study was that Algom and Cohen-Raz determined that in implied motion conditions, participants employed a rather simplistic rule when judging velocity:

$$\text{Velocity} = \text{Distance} - \text{Duration}$$

while in the actual motion conditions, the rule was as expected:

$$\text{Velocity} = \text{Distance} \div \text{Duration}$$

The second equation will be of use in this study to determine whether temporal interval estimates were influenced:

$$\text{Duration} = \text{Distance} \div \text{Velocity}$$

In Algom and Cohen-Raz (1987), a total of 6 distances and 6 durations were combined in a factorial study (thus, there were a total of 36 distance/duration combinations, although some combinations were redundant). In addition, all 36 distance/duration combinations were presented to each participant as both implied and actual motion. In the current study, 3 of the distances and 3 of the durations utilized by Algom and Cohen-Raz were used in order to extrapolate the expected values for temporal estimates in all conditions. Direction of presentation of stimuli was also manipulated. Participants viewed two equal distances, one after the other, in one of the following 4 direction presentation patterns:

1. standard and test distances both presented from top-to-bottom (TBTB)
2. standard and test distances both presented from bottom-to-top (BTBT)
3. standard distance presented from top-to-bottom, test distance from bottom-to-top (TBBT)
4. standard distance presented from bottom-to-top, test distance from top-to-bottom (BTTB)

Finally, if RM does play a role in temporal estimates, the equation

$$\text{Duration} = \text{Distance} \div \text{Velocity}$$

should *not* accurately predict temporal estimate values when direction of presentation is TBBT or BTTB, because the perceived duration of equal intervals paired with equal distances traveling in opposite directions should not be equal. The duration paired with the TB distance should seem shorter than that paired with the BT distance, because stimuli should appear to fall, and thus accelerate, while that paired with the BT distance should appear to decelerate or move at a constant rate.

Purpose and Hypotheses – RM Study

The purpose of this study was to examine the effects of the combination of four different directions of presentations, three different spatial distances, and three different velocities of visual stimuli on the perception of brief temporal intervals. Each of these is discussed in turn below, as is the interaction of the factors, the hypotheses, and research questions.

First, several studies have shown that direction of presentation of stimuli (Freyd & Finke, 1984; Hubbard, 1990; 1997; 2001; Hubbard & Motes, 2002; Verfaillie & d'Ydewalle, 1991) has predictable effects on estimated vanishing points in representational momentum (RM) tasks. In RM studies, 'direction of motion' displacements of vanishing points are most evident in the TB direction, intermediate in horizontal directions, and least evident, if present at all, in BT directions. In this study, only TB and BT conditions were utilized, because in the direction study, significant differences in temporal estimates occurred only between these two conditions, and only when actual motion was present. It was expected that similar results would occur for temporal estimates of stimuli presented in top-to-bottom (TBBT) and bottom-to-top (BTTB) conditions in the current study, such that when standard and test stimuli were presented first in one direction, then another, the perceived duration of the TB temporal interval would be shorter than that of the BT temporal interval.

If RM plays a role in temporal estimates in a manner similar to that in judged displacements, the presentation of spatial distances in either the same direction or in different directions should have magnified any differences in temporal adjustments due to the perception of stimuli in the BT distance/velocity as rising (decelerating) and in the TB distance/velocity as falling (accelerating) when direction of presentation differed. The purpose of manipulating direction of presentation was therefore twofold: TBTB and BTBT conditions served as control conditions, and it was expected that in these conditions, temporal adjustments would be minimal regardless of length of spatial distance or of velocity, because the standard interval and the test interval durations were identical, and should have been perceived as such if direction of presentation was also identical. In other words, stimuli should have been perceived as accelerating or decelerating for the same length of time when direction of presentation of the standard and test intervals was identical. However, when direction of presentation differed, the BT distance/velocity may have been perceived as longer in duration than equal intervals traveling from TB, because stimuli may have seemed to decelerate as they rose. Furthermore, the distance/velocity paired with the TB interval may have seemed shorter than it was in actuality, because it appeared to fall.

Thus, it was expected that when direction of presentation of standard and test temporal intervals was identical, participant judgments would be minimal, but when direction of presentation of standard and test intervals differed, temporal estimates would have been larger, and the interval paired with the BT distance/velocity would have seemed longer than the interval paired with the TB distance/velocity. Hypothesis one therefore stated that temporal estimates (adjustments) would be minimal in all TBTB and BTBT conditions, regardless of velocity or distance. This was expected because in each trial, the temporal interval of the standard and the test distance/velocity was identical. Hypothesis two stated that in TBBT and BTTB conditions, mean temporal adjustments would be different from 0, regardless of distance [40 mm (1.57 in.), 80 mm (3.15 in.), and 160 mm (6.3 in.)] or velocity [slow (S), medium (M), and fast (F), see Table 6 for velocity conditions for each distance]. Specifically, when participants viewed a TB standard distance/velocity followed by a BT test distance/velocity, they would perceive the BT interval as being longer than the first, and should have therefore adjusted downward to shorten the TB (test) interval. Likewise, the viewing of a BT standard distance/velocity followed by a TB test distance/velocity should have resulted in adjustments upwards to lengthen the TB (test) interval, because the BT standard would have seemed much longer in comparison to the TB test.

Table 6.

Slow, Medium, and Fast Velocity Conditions for each Duration Condition in the Representational Momentum Study

Distance in mm	Velocity	Velocity of stimuli in mm/s
40	S	10
	M	20
	F	40
80	S	20
	M	40
	F	80
160	S	40
	M	80
	F	160

Note. 40 mm distances will be traversed in 4s for the slow velocity (S), 2s for the medium velocity (M), and 1s for the fast velocity (F). These velocities double with each level of distance in order to maintain identical objective durations across levels and velocities.

Second, spatial distance was manipulated in the current study. Three distances (40, 80, and 160 mm) were used. If RM does play a role in temporal estimates, temporal estimates should have been most influenced when distances were long. Stimuli paired with short distances should have appeared to move at a constant rate, while stimuli paired with longer distances should have appeared to move faster, and thus be falling, or conversely, as rising and thus decelerating. The farther an object appears to fall, the more it should appear to accelerate, and the longer an object rises, the more it should appear to decelerate. Therefore, it was expected that for short (40 mm) spatial distances, temporal adjustments should have been minimal for short distance/velocity pairings, regardless of direction of presentation. If adjustments in the short condition were less than in medium (80 mm) and long (160 mm) distance/velocity pairings, a stronger case could be made that temporal adjustments are subject to the effects of perceived deceleration and acceleration, as occurs in RM studies. However, when distances were medium (80 mm) or long (160 mm), temporal estimates should have been minimal in TBTB and BTBT conditions, but not in TBBT and BTTB conditions, when stimuli may have appeared to accelerate or decelerate. Therefore, hypothesis three stated that temporal adjustments would be most influenced in 160 mm conditions, moderately influenced in 80 mm conditions, and least influenced in 40 mm conditions, regardless of velocity. Specifically, adjustments should have reflected a perceived shortening of duration in TB conditions as length of spatial distance increased, while in BT conditions, estimates should have been minimal.

Third and last, velocity of motion was manipulated. Three different durations (1, 2, and 4 s), and therefore 9 velocities (see Table 6), were used for three reasons: to prevent practice effects, to prevent participants from recognizing that velocities (and temporal intervals) were identical for standard and test intervals in all conditions, and to further examine the effects of velocity on temporal estimates. By using slow, medium, and fast velocities, it was believed, based on Algom and Cohen Raz's (1997) study, that temporal estimates would be influenced differently as a result of perceived acceleration or deceleration in M and F conditions versus perceived constant motion in S conditions. Thus, it was believed that by manipulating velocity as well as distance and direction, the effect of RM on temporal estimates would be more apparent if present. Specifically, medium and fast durations paired with 40, 80, and 160 mm distances may have appeared to be accelerating while falling and decelerating while rising, while slow velocities paired with 40, 80, and 160 mm distances may have appeared to move at a constant rate.

Adjustments should have been minimal in S conditions, evident in M conditions, and largest in F conditions. Hypothesis four therefore stated that faster velocities would lead to a perceived shortening of duration in TB conditions and perceived lengthening of duration in BT conditions; conversely, adjustments in slow velocity conditions should have been minimal. Adjustments should have been minimal when direction of presentation of standard and test intervals was the same regardless of velocity, but when direction of presentation differed in M and F conditions, temporal estimates should have been larger, and the interval paired with the BT distance/velocity should have seemed much longer than the interval paired with the TB distance/velocity.

While the use in this study of three different distances and durations may help shed light on the influence of these variables by themselves on temporal perception, it is very likely that the two variables will interact based on previous research (Cohen et al., 1955; Hubbard, 1990; 1997; 2000; 2001; Hubbard & Bharucha, 1988; Hubbard & Motes, 2002; Michaluk et al., in preparation). Thus, part of the purpose of this study was to systematically examine the influence of the nine combinations of distance and velocity on temporal adjustments. In fact, it was hoped that by using 3 distances and 3 velocities, it would be possible to determine whether the effects of distance and velocity were additive, which would not be possible if fewer distances or velocities were employed. It was expected that temporal intervals would be most affected in TB and BT different conditions when distances were longer and velocities faster, and that as distance shortened and velocity slowed, estimates would be minimal, particularly in TBTB and BTBT conditions. Hence, hypothesis five stated that in TBBT and BTTB conditions, temporal estimates would be *most* affected in long distance conditions when velocities were fastest. Specifically, temporal adjustments should have been most influenced in TBBT and BTTB conditions when participants viewed stimuli presented in *both* directions, when distances were longest, and velocities fastest. Conversely, adjustments in TBBT and BTTB conditions should have been least influenced when distances were shortest and velocities slowest. Furthermore, it was expected that because stimuli traveling from TB would appear to fall and thus accelerate and stimuli traveling from BT would appear to decelerate, participants would lengthen TB test intervals and shorten BT test intervals.

Research Question – RM Study

Algom and Cohen-Raz (1987) found that in actual motion conditions, participants employed the rule:

$$\text{Velocity} = \text{Distance} \div \text{Duration}$$

when judging velocity of visual stimuli. In this study, this equation will be converted to:

$$\text{Duration} = \text{Distance} \div \text{Velocity}$$

It is expected that data from this study will *not* fit this equation if RM influences temporal estimates, particularly for TBBT and BTTB conditions, because stimuli should appear to be influenced by gravity. A stronger case could then be made that RM played a role in influencing estimates, assuming that the 5 hypotheses were also supported.

CHAPTER III

METHODOLOGY

Participants – RM Study

A sample size of 139 participants was utilized based on a medium effect size and β = .80 for a Repeated Measures ANOVA with between - subjects factors. Data from three participants were not included in final analyses; one was < 18 years of age, two others were non-compliant. Participants were recruited from the Oklahoma State University Subject Pool after IRB approval was obtained. Ages ranged from 18 – 41 (*M* = 20.58, *SD* = 2.76). African Americans made up 7% of the sample; Asians 5%; Caucasians 80%; Hispanics 2%; and 9 Native Americans 7%. Fifty-nine men and 80 women participated; all had normal or corrected-to-normal vision.

Design – RM Study

This was a 3 within- (distance: 40, 80, and 160 mm) x 3 within- (velocity: S, M, and F), x 4 between- (direction-TBTB, BTBT, TBBT, and BTTB) mixed ANOVA design. The rationale for having direction as a between-subjects variable was threefold: first, to limit number of trials, and thus practice effects, and second, to prevent participants from recognizing that stimuli always moved at the same constant rate, and third, because Kerzel (2002) found that judged displacements were most evident when direction of motion was a between-subjects variable. Velocity was a within-subjects factor, to prevent practice effects and to increase the effects of perceived acceleration and deceleration in faster conditions.

Apparatus and Stimuli – RM Study

Stimuli were created using Microsoft Visual Basic and presented on desktop computers with 43.69 cm (17.13 in.) x 27.31 cm (10.75 in.) LCD monitors. Distances were 40 mm (1.57 in), 80 mm (3.15 in), and 160 mm (6.3 in), and velocities were slow (S), medium (M), and fast (F); refer to Table 6 for velocities for each distance. Stimuli were presented on a black background and marked with a light grey 3.175 mm (1/8 in.) circle. Spatial distances were centered on the screen. Black tri-fold poster boards surrounded computer monitors. A 204.47 cm (80.5 in.) x 153.57 cm (60.5 in.) projection screen was used to demonstrate the practice tasks.

Procedure – RM Study

Participants were run in groups of 2 - 9 per session. In the kappa effect study, participants were run in groups, while in the direction study, they were run one at a time. More participants completed the final trial in the kappa effect study than in the direction study, possibly because participants knew they could not leave until the experimenter excused the group, while in the direction study they were free to leave as soon as they finished the study. Effects obtained in the direction study were not as strong as those in the kappa effect study.

Participants were seated at computers as far apart as possible. Informed consent was obtained. Participants were first trained on the adjustment procedure using a non-temporal task, which was used to prevent practice effects. The experimenter demonstrated the non-temporal task first, telling participants to observe the projection screen until given further instructions. There were two training trials; A large square was presented first in trial one, a small square first in trial two. Squares measured 8.89 cm (3.50 in.) and 6.99 cm (2.75 in.). The experimenter then projected the non-temporal task on the screen. First, two light-grey squares were shown for 1000 ms each, one after the other, with an ISI of 1000 ms. Participants were told to pay attention to the size of each square. Next, the experimenter demonstrated the adjustment of the square size in the non-temporal task by using the mouse to change the size of the second square, so that it was nearly equal in size to the first. The adjustment was made using a scrollbar that changed the percentage of the square upward or downward in size. Following the first adjustment, the experimenter explained to participants that they had three choices after viewing the standard task in all cases. First, if they felt that no adjustment was needed, they could go directly to the next trial. Second, if they felt their adjustment was correct after one adjustment, they could go on to the next trial. Third and last, they could view both squares again (and thus receive feedback), with the size of the second square altered to reflect the previous adjustment, and make one additional adjustment, for a total of two adjustments. After explaining each choice, the experimenter made one more adjustment to the size of the second square in the non-temporal task.

After demonstrating two non-temporal training trials, the experimenter told participants to begin non-temporal training trials when ready by clicking a ‘Click here to begin’ button on screen. Each participant then completed training trials, after which appeared a screen directing them to wait for further instructions.

Following completion of non-temporal training trials, one sample temporal trial was presented. The sample temporal trial utilized a different distance/duration pairing than those in actual trials. Each sample temporal distance measured 15.24 cm (6.00 in.); Duration one (standard interval) was 1018 ms and duration two (test interval) was 4000 ms. Distances were presented horizontally, one after the other, with an ISI of 1000 ms. Only one sample temporal trial was used to prevent practice effects. The experimenter demonstrated the task first, telling participants to note the duration associated with each temporal interval. The experimenter then adjusted the duration of the second temporal interval, telling participants to note that both intervals would be presented again, this time with the second interval changed to reflect the experimenter's adjustment. Experimenter adjustments varied within and between each experimental group so that no two adjustments were the same. The experimenter then made a second adjustment and presented both intervals again. Finally, the group was told to set up their tri-fold poster boards behind their monitors, instructed not to speak during the experiment, and asked if there were any questions. Laboratory lights were then turned off, and participants were instructed to begin the sample temporal trial and 9 experimental trials, one of each combination of distance (40, 80, and 160 mm) and velocity (S, M, and F), when ready.

Participants initiated trials by clicking a 'Click here to begin' button on screen. After completion of one temporal training trial they proceeded to experimental trials by clicking a 'New trial' button on screen. Prior to the onset of experimental trials, a small light-grey square, or fixation point, appeared in the center of the screen and remained onscreen for 500 ms. Participants then viewed the standard spatial distance/temporal interval, which was marked at its onset by visual stimuli [a 3.175 mm (1/8 in.) light-grey circle on a black background] presented from either TB or BT. Visual stimuli marking the distance disappeared following the offset of the interval. Immediately following the standard interval, the second, or test, *identical* spatial distance/temporal interval appeared in the same location as the standard was shown. The test distance/interval was presented in either the *same* or the *opposite* direction as the standard distance/interval, depending on the condition.

Analyses – RM Study

Hypotheses One and Two – RM Study

Hypothesis one stated that temporal estimates would be minimal in all TBTB and BTBT conditions, regardless of velocity or distance. Conversely, hypothesis two stated that mean temporal adjustments in TBBT and BTTB conditions would be different from 0 regardless of (collapsing across) velocity or distance. To test these hypotheses, the average of the first and second adjustments for each of the four direction conditions (TBTB, BTBT, TBBT, and BTTB) were compared to 1.00 (no adjustment) using 1 sample *t*-tests. *T*-tests were one-tailed in TBBT (negative) and BTTB (positive) conditions, with α set at .005. *T*-tests were two-tailed in TBTB and BTBT conditions, with α set at .005.

Hypothesis Three – RM Study

Hypothesis three stated that adjustments would be most influenced in TBBT (condition a3, see Table 7 for complete list of conditions) and BTTB (condition a4) conditions when spatial distances were long (160 mm, factor c3), moderately influenced when distances were medium (80 mm, factor c2), and least influenced when short (40 mm, factor c1), regardless of (collapsing across) velocity. This hypothesis was tested using simple contrasts comparing mean adjustments for short, medium, and long distances in TBBT and BTTB conditions collapsing across (ignoring) velocity, with α set at .05/12 = .0042 (Bonferonni correction). Simple contrasts were run for all data; participants 92 and below, and participants 93 and above. There were four comparisons in each of the three data sets, hence, alpha was divided by twelve.

Hypothesis Four – RM Study

Hypothesis four stated that faster velocities would lead to larger temporal adjustments (in absolute values) in TBBT (condition a3) and BTTB (condition a4) conditions; conversely, adjustments in slow velocity conditions would be minimal. This hypothesis was tested using simple contrasts comparing mean first and second adjustments for slow, medium, and fast velocities in TBBT and BTTB conditions, collapsing across distance, first for all data, then for participants 92 and below, and finally for those 93 and above. To control for alpha inflation, α was again set to .004, using the Bonferroni correction.

Hypothesis Five – RM Study

Hypothesis five stated that in TBBT and BTTB conditions, temporal estimates would be *most* affected in long and medium distance conditions when velocities were faster. Specifically, mean absolute temporal adjustments should have been largest in conditions TBBT (160 mm distance, 160 mm/s velocity, a3b3c3) and BTTB (160 mm distance, 160 mm/s velocity, a4b3c3), second largest in conditions TBBT (80 mm distance, 80 mm/s velocity, a3b3c2) and BTTB (80 mm distance, 80 mm/s velocity, a4b3c2) and smallest in conditions TBBT (40 mm distance, 1mm/s velocity, a1b1c1) and BTTB (40 mm distance, 1mm/s velocity, a2b1c1). Interaction contrasts were used to test mean first and second adjustments for the absolute average of a3b3c3 and a4b3c3 vs. the absolute average of a1b1c1 and a2b1c1. The absolute average of a3b3c2 and a4b3c2 vs.

the absolute average of a1b1c1 and a2b1c1 were also tested, again for all data, participants 92 and below, and participants 93 and above. Because only two comparisons were run, there was no correction for alpha inflation (Keppel & Wickens, 2004), and alpha was set to .05.

Research Question – RM Study

Finally, for each of the 9 distance/velocity pairings, the expected temporal adjustment will be computed from the equation:

$$\text{Duration} = \text{Distance} \div \text{Velocity}$$

and compared to the actual mean first adjustments for each distance/velocity pair.

Additional Analyses – RM Study

Preliminary analyses showed that predicted experimental effects were either small or not present as hypothesized. There are two possible experimental design issues that may account for these results: One, participants had advance knowledge of the study manipulation, and two, that there was not enough power to detect any effects. In the first case, 92 participants were run during the summer 2008 semester when only 3 classes were in session; thus there was a possibility that participants told their classmates that there were no differences between any of the temporal intervals, and if their classmates participated in the study, they would not have to make any adjustments.

To determine whether data from the 92 participants run in the summer differed from the 47 run in Fall 2008, analyses for all hypotheses were tested a total of three times. First, using all 139 participants, next using only data collected in the summer (participants 1-92), and finally, using only data collected in the fall (participants 93-139).

These additional analyses were run for all *t*-tests and for hypotheses three, four, and five. Results for additional analyses are reported below.

The second explanation for the lack of effects was that there was not enough statistical power to detect any effects. This was tested in two ways: First, by running an additional 39 participants to increase the number of participants, and second, by testing hypotheses three through five two times. The first analyses were run as specified, using only TBBT and BTTB groups. Analyses were then run again using all groups. The rationale for running analyses using all groups was to increase the sample size used in each hypothesis.

Finally, if it was obvious to participants that all temporal intervals were equal regardless of group, then the number of non-adjustments should *not* vary by distance/velocity condition. It was expected that the number of non-adjustments should *not* be statistically significantly different for any of the distance/velocity combinations if participants were aware that all temporal intervals were equal because they had prior knowledge of the manipulation. As mentioned earlier, it was most difficult to determine in the long distance/fast velocity condition that intervals were equal. Therefore, the proportion of non-adjustments in the long distance/fast velocity condition for first adjustments were compared to the proportion of the remaining 8 distance/velocity conditions using separate binomial tests for all motion groups combined and again for each separate motion group: TBTB, BTBT, TBBT, and BTTB.

Table 7.

Direction, Velocity, and Distance Conditions in the Representational Momentum Study

			DIRECTION *Factor a* TBTB (al)	
			VELOCITY *Factor b*	
		Slow (b1)	Medium (b2)	Fast (b3)
	Short (c1)	a1b1c1	a1b2c1	a1b3c1
DISTANCE *Factor c*	Medium (c2)	a1b1c2	a1b2c2	a1b3c2
	Long (c3)	a1b1c3	a1b2c3	a1b3c3

			DIRECTION *Factor a* BTBT (a2)	
			VELOCITY *Factor b* Medium (b2)	
	Short (c1)	a2b1c1	a2b2c1	a2b3c1
DISTANCE *Factor c*	Medium (c2)	a2b1c2	a2b2c2	a2b3c2
	Long (c3)	a2b1c3	a2b2c3	a2b3c3

Table 7 Continued.

			DIRECTION *Factor a* TBBT (a3)	
			VELOCITY *Factor b*	
		Slow (b1)	Medium (b2)	Fast (b3)
	Short (c1)	a3b1c1	a3b2c1	a3b3c1
DISTANCE *Factor c*	Medium (c2)	a3b1c2	a3b2c2	a3b3c2
	Long (c3)	a3b1c3	a3b2c3	a3b3c3

			DIRECTION *Factor a* BTTB (a4)	
			VELOCITY *Factor b*	
			Medium (b2)	
	Short (c1)	a4b1c1	a4b2c1	a4b3c1
DISTANCE *Factor c*	Medium (c2)	a4b1c2	a4b2c2	a4b3c2
	Long (c3)	a4b1c3	a4b2c3	a4b3c3

CHAPTER IV

FINDINGS

Hypotheses One and Two, Single Sample T-tests – RM Study

Hypothesis one stated that temporal estimates would be minimal in all TBTB (a1) and BTBT (a2) conditions, regardless of (collapsing across) velocity or distance. Two-tailed single sample *t*-tests showed that the means of first and second adjustments in the TBTB and BTBT group did not significantly differ from 1.00 for all data combined, for participants 92 and below, or for those 93 and above (no adjustment; see Table 8 for means, standard deviations, *t* and *p* values); therefore hypothesis one was supported.

Conversely, hypothesis two stated that the averages of first and second temporal adjustments would be *less* than 1.00 in the TBBT (a3) condition and *greater* than 1.00 in the BTTB (a4) condition, regardless of (collapsing across) velocity or distance. One-tailed single sample *t*-tests revealed that this hypothesis was supported only for the average first adjustment in the TBBT (a3) condition for all data combined and for the first adjustment in the TBBT condition for participants 1-92 below. Results for the TBBT group approached significance for second adjustments for all participants, and for first and second adjustments for participants 93-139 (refer to Table 8 for means, standard deviations, *t* and *p* values). First and second adjustments for the BTTB condition did not differ significantly from 1.00 for any of the 3 data sets. In summary, hypothesis one was partially supported for TBBT conditions, but not for BTTB conditions.

Table 8.

Single Sample T-tests for Averages of First and Second Adjustments for Representational Momentum Study

Group/Adjustment	Participants	*N*	*M*	*SD*	*t*	*df*	*p*-level
TBTB/1	All	35	0.998	0.033	-0.442	34	.662
2		35	0.998	0.026	-0.247	34	.806
BTBT/1	All	32	0.993	0.026	-1.593	31	.121
2		32	1.000	0.031	0.066	31	.948
TBBT/1	All	37	0.981	0.021	-5.604	36	.001*
2		37	0.993	0.021	-2.275	36	.029
BTTB/1	All	35	0.999	0.062	-0.119	34	.906
2		35	1.001	0.038	-0.286	34	.777
TBTB/1	≤ 92	23	0.999	0.039	-0.107	22	.915
2		23	0.996	0.030	-0.618	22	.543
BTBT/1	≤ 92	21	0.998	0.029	-1.871	20	.076
2		21	0.997	0.035	-0.401	20	.693
TBBT/1	≤ 92	23	0.980	0.020	-4.731	22	.001*
2		23	0.998	0.018	-0.673	22	.508
BTTB/1	≤ 92	23	1.006	0.071	0.429	22	.672
2		23	1.004	0.034	0.502	22	.602
TBTB/1	≥ 93	12	0.994	0.019	-1.000	11	.339
2		12	1.004	0.013	1.162	11	.270
BTBT/1	≥ 93	11	1.001	0.018	0.201	10	.845
2		11	1.007	0.016	1.456	10	.176
TBBT/1	≥ 93	14	0.981	0.024	-3.010	13	.010
2		14	0.985	0.021	-2.778	13	.016
BTTB/1	≥ 93	12	0.984	0.037	-1.484	11	.166
2		12	0.999	0.046	-0.111	11	.914

* Statistically significant at $p < .005$.

Additional Single Sample t-tests – RM Study

Collapsing across velocity and distance may have obscured other effects of interest. Therefore, single sample t-tests comparing adjustments in each direction group to 1.00 were done for each separate distance/velocity condition. These analyses were run for all data, for participants 1-92, and for those 93-139. However, to limit the number of tables in this paper, only results from all data combined will be shown as there was more power to detect any effects utilizing the largest sample size. Results of these single sample *t*-tests for all participants combined showed that none of the temporal adjustments from any of the four direction groups for any of the distance/velocity combinations were significantly different from one (all *p*'s > .005, see Tables 9-12). This was also the case for participants 1-92 and for those 93-139.

Table 9.

Single Sample T-tests for all Combinations of Distance and Velocity for First and Second Adjustments for All Participants, TBTB, Representational Momentum Study

Distance/velocity Adjustment	*M*	*SD*	*t*	*p*-level
short/slow 1	1.031	0.075	2.479	.018
2	1.001	0.049	0.209	.836
med/slow 1	1.005	0.075	0.382	.705
2	1.002	0.054	0.219	.828
long/slow 1	0.999	0.072	-0.047	.963
2	1.001	0.053	0.159	.875
short/med 1	0.982	0.081	-1.341	.189
2	0.993	0.091	-0.426	.673
med/med 1	0.993	0.060	-0.706	.485
2	1.003	0.038	0.532	.598
long/med 1	0.999	0.059	-0.086	.932
2	1.001	0.026	0.265	.793
short/fast 1	0.981	0.071	-1.555	.129
2	0.975	0.066	-2.239	.032
med/fast 1	0.981	0.076	-1.517	.139
2	1.009	0.074	0.712	.481
long/fast 1	1.006	0.099	.415	.681
2	1.003	0.063	.293	.771

Note. *N* = 35 and *df* = 34 for all adjustments.

Table 10.

Single Sample T-tests for all Combinations of Distance and Velocity for First and Second Adjustments for All Participants, BTBT, Representational Momentum Study

Distance/velocity Adjustment	*M*	*SD*	*t*	*p*-level
short/slow 1	1.017	0.071	1.396	.173
2	1.013	0.068	1.149	.259
med/slow 1	0.996	0.053	-0.467	.644
2	0.987	0.053	-1.409	.169
long/slow 1	0.983	0.082	-1.192	.242
2	1.014	0.083	0.986	.332
short/med 1	1.002	0.051	0.243	.810
2	1.012	0.047	1.479	.149
med/med 1	0.980	0.051	-2.239	.032
2	0.990	0.057	-0.957	.346
long/med 1	0.987	0.078	-0.954	.347
2	0.980	0.117	-0.953	.348
short/fast 1	0.989	0.068	-0.929	.360
2	1.004	0.071	0.326	.747
med/fast 1	0.978	0.068	-1.180	.080
2	0.994	0.031	-1.027	.313
long/fast 1	1.001	0.074	0.096	.924
2	1.007	0.058	0.668	.509

Note. N = 32 and *df* = 31 for all adjustments.

Table 11.

Single Sample T-tests for all Combinations of Distance and Velocity for First and Second Adjustments for All Participants, TBBT, Representational Momentum Study

Distance/velocity Adjustment	*M*	*SD*	*t*	*p*-level
short/slow 1	0.983	0.058	-1.756	.088
2	0.990	0.053	-1.211	.234
med/slow 1	0.977	0.080	-1.769	.085
2	0.983	0.079	-1.287	.206
long/slow 1	0.993	0.057	-0.745	.461
2	0.977	0.073	-1.913	.064
short/med 1	0.976	0.091	-1.607	.117
2	1.001	0.072	0.091	.928
med/med 1	0.984	0.082	-1.205	.236
2	1.008	0.061	0.750	.458
long/med 1	0.998	0.072	-0.159	.874
2	1.002	0.062	0.214	.832
short/fast 1	0.965	0.076	-2.752	.009
2	0.987	0.076	-1.041	.305
med/fast 1	0.979	0.089	-1.447	.156
2	0.988	0.037	-1.930	.062
long/fast 1	0.970	0.076	-2.393	.022
2	0.997	0.047	-0.350	.728

Note. *N* = 37 and *df* = 36 for all adjustments.

Table 12.

Single Sample T-tests for all Combinations of Distance and Velocity for First and Second Adjustments for, All Participants, BTTB, Representational Momentum Study

Distance/velocity Adjustment	*M*	*SD*	*t*	*p*-level
short/slow 1	1.021	0.108	1.174	.249
2	1.015	0.084	1.050	.301
med/slow 1	0.999	0.118	-0.029	.977
2	1.007	0.091	0.447	.658
long/slow 1	0.985	0.111	-0.840	.407
2	0.982	0.115	-0.941	.353
short/med 1	1.013	0.127	0.600	.533
2	0.999	0.041	-0.769	.447
med/med 1	0.983	0.120	-0.845	.404
2	1.009	0.126	0.403	.690
long/med 1	1.013	0.131	0.613	.544
2	1.014	0.081	1.019	.315
short/fast 1	0.999	0.128	-0.053	.958
2	0.996	0.133	-0.178	.860
med/fast 1	0.996	0.091	-0.241	.811
2	1.007	0.082	0.496	.623
long/fast 1	0.979	0.132	-0.933	.357
2	0.993	0.131	-0.323	.749

Note. *N* = 35 and *df* = 34 for all adjustments.

Hypothesis Three, Simple Contrasts – RM Study

Hypothesis three stated that adjustments would be most influenced in TBBT (a3, see Table 7) and BTTB (a4) conditions when spatial distances were long (160 mm, factor c3), moderately influenced when distances were medium (80 mm, factor c2), and least influenced when short (40 mm, factor c1), regardless of velocity. This hypothesis was tested using planned simple contrasts comparing mean first and second adjustments for short, medium, and long distances in TBBT and BTTB conditions collapsing across (ignoring) velocity, with α set at .05. Alpha was set at .004 using a Bonferroni correction (.05/12) to control the family-wise error-rate. In addition, simple contrasts were run on all data, data for participants 1-92, and for participants 93-139. Finally, these contrasts were run for all four direction groups (TBTB, BTBT, TBBT, and BTTB) combined to gain statistical power.

Results of planned simple contrasts showed no significant differences in first or second temporal adjustments between the averages of short and medium distances, medium and long distances, and short and long distances for any of the three data sets (all *p*s > .004), nor were there any differences when all four groups were included in the analyses. Thus, hypothesis three was not supported by any of the planned contrasts, and there were no differences in average first or second temporal adjustments due to length of spatial distance alone in TBBT (a3) and BTTB (a4) conditions for any of the three data sets.

Hypothesis Four, Simple Contrasts – RM Study

Hypothesis four stated that faster velocities would lead to larger temporal adjustments (in absolute values) in TBBT (condition a3) and BTTB (condition a4) conditions; conversely, adjustments in slow velocity conditions would be minimal. This hypothesis was tested using planned simple contrasts comparing mean first and second adjustments for slow, medium, and fast velocities in TBBT and BTTB conditions, collapsing across distance. The family-wise error-rate was controlled using the Bonferroni correction, and α was set to .05/12 = .0042. Simple contrasts were run on all data, data for participants 1-92, and for participants 93-139.

Results of planned simple contrasts showed no significant differences between first or second adjustments for the averages of slow and medium velocities, medium and fast velocities, and slow and fast velocities (all *p*s > .004). Hypothesis four was not supported by any of the planned comparisons. There were no differences in average first or second temporal adjustments due to velocity alone in TBBT (a3) and BTTB (a4) conditions for any of the three data sets, nor were there any differences when all four groups were included in the analyses.

Hypothesis Five, Interaction Contrasts – RM Study

Hypothesis five stated that in TBBT and BTTB conditions, temporal estimates would be *most* affected in long and medium distance conditions when velocities were faster. Interaction contrasts were used to test mean first and second adjustments for the absolute average of a3b3c3 and a4b3c3 vs. the absolute average of a1b1c1 and a2b1c1; The absolute average of a3b3c2 and a4b3c2 vs. the absolute average of a1b1c1 and a2b1c1 were also tested. Interaction contrasts were run for all data, participants 1-92, and participants 93-139.

Results of interaction contrasts showed that there were no significant differences between absolute averages for first and second adjustments between a3b3c3 and a4b3c3 vs. a1b1c1 and a2b1c1 or between a3b3c2 and a4b3c2 vs. a1b1c1 and a2b1c1 conditions for either the TBBT or the BTTB group for any of the three data sets (all *p*’s > .05). Hypothesis five was not supported and there were no differences in average absolute adjustments as a result of the combination of longer distance combined with fast velocity vs. short distance combined with slow velocity.

However, interaction contrasts were re-run utilizing all groups in the entire data set. Specifically, the absolute averages of first and second adjustments for the short/slow (b1c1) vs. the medium/fast (b3c2) conditions were tested, as were first and second adjustments for the absolute averages of short/slow (b1c1) vs. the long/fast (b3c3) conditions. There were significant differences between the short/slow (b1c1) vs. the medium/fast (b3c2) conditions for first adjustments, $F(1, 138) = 9.22$, $p = .003$. Means and standard deviations for short/slow (b1c1) conditions were 1.013 and .081, while those for the medium/fast (b3c2) conditions were 0.984 and .081, indicating that temporal adjustments were shorter for the medium/fast condition than for the short/slow condition. In addition, there were significant differences between the short/slow (b1c1; $M = 1.103$, $SD = .081$) vs. the long/fast (b3c3; $M = 0.989$, $SD = .096$) conditions for first adjustments, $F(1, 138) = 6.23$, $p = .014$. Temporal adjustments were significantly shorter for the long/fast condition than for the short/slow condition. There were no significant differences for the same comparisons for adjustment two.

Research Question, Fitting the Equation – RM Study

It was expected that data from this study would *not* fit the equation below if RM had in fact influenced temporal estimates, particularly for TBBT and BTTB conditions, because stimuli should appear to be influenced by gravity. A stronger case could then be made that RM played a role in influencing estimates, assuming that the five hypotheses were also supported (see Table 13 for results).

For the purposes of this research, this equation was converted to:

$$\text{Duration} = \text{Distance} \div \text{Velocity}$$

In general, the data fits the equation well. As expected, temporal adjustments were shorter than actual temporal intervals in the TBBT condition. However, the reverse was not true for the BTTB condition. For the TBTB and BTBT conditions, temporal adjustments were relatively accurate as was expected.

Table 13.

Actual and Expected Temporal Adjustment Values for all Four Direction Groups for First Adjustments, Representational Momentum Study

Distance/velocity Adjustment	Expected Value in Seconds	TBTB Actual Values	BTBT Actual Values	TBBT Actual Values	BTTB Actual Values
short/slow	4	4.124	4.068	3.932	4.084
med/slow	4	4.020	3.984	3.908	3.996
long/slow	4	3.996	3.932	3.972	3.940
short/med	2	1.964	2.004	1.952	2.026
med/med	2	1.986	1.960	1.968	1.966
long/med	2	1.998	1.974	1.996	2.026
short/fast	1	0.981	0.989	0.965	0.999
med/fast	1	0.981	0.978	0.979	0.996
long/fast	1	1.006	1.001	0.970	0.979

Non-adjustment Binomial Tests – RM Study

As mentioned previously, it may have been obvious to participants that all temporal intervals were equal regardless of distance/velocity combination. If this occurred, then the number of non-adjustments should not vary by group or by distance/velocity condition. To test this, separate binomial tests were run on first adjustments to determine if the number of adjustments varied by condition or by distance/velocity condition. Only first adjustments were tested both to limit the number of tests run and because it was more likely that non-adjustments would vary only for the first adjustment. Tests were run for all participants, for participants 1-92, and participants 93-139.

For all data combined and collapsing across motion group (TBTB, BTBT, TBBT, and BTTB), the proportion of non-adjustments was determined to be .28 in the long/fast (b3c3) condition. This condition was chosen because there were the fewest number of non-adjustments and because theoretically this would have been the adjustments *least* likely to appear equal. This proportion was then compared one at a time to the proportion of non-adjustments for each of the remaining 8 distance/velocity combinations. Results of 8 binomial tests showed that the proportion of non-adjustments differed between the long/fast (b3c3) condition and the short/slow (b1c1) condition and between the long/fast (b3c3) and the long/medium (b3c2) condition. Specifically, participants made significantly more adjustments, as expected, in the long/fast condition than in conditions above (see Table 14 for number and proportion of non-adjustments and *p*-values).

In addition the number of adjustments and non-adjustments for all participants, collapsing across motion group, were plotted across trials (see Figure 7). If prior knowledge of the manipulation were present, the number of non-adjustments should be higher than the number of adjustments across trials. This was not the case. The number of adjustments was higher than the number of non-adjustments for all trials, refuting the hypothesis that participants had prior knowledge of the study manipulation. Furthermore, the number of both adjustments and non-adjustments remained fairly stable across trials (see Fig. 7). This indicates that participants did not appear to realize early in the experiment that durations were identical and then fail to make adjustments in later trials.

Figure 7.

Number of adjustments and non-adjustments by trial number in Representational Momentum Study.

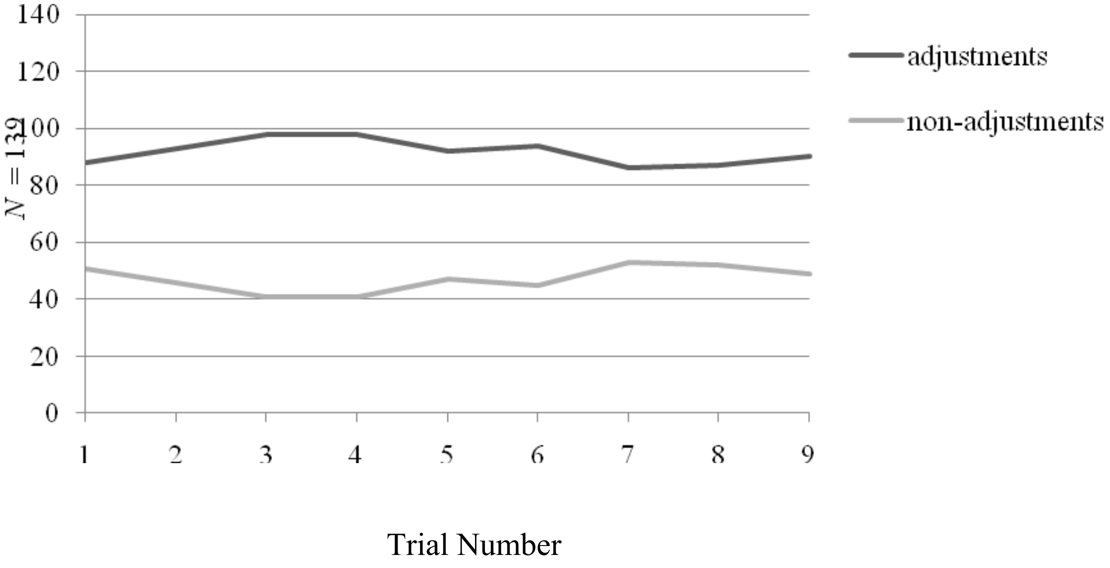


Table 14.

Number of Non-adjustments for all Distance/velocity Combinations for all Participants, Representational Momentum Study

Distance/velocity Adjustment	Number of Non-adjustments/139	Proportion of Non-adjustments	*p*-level
short/slow 1	54	.388	.004*
med/slow 1	47	.338	.078
long/slow 1	47	.338	.078
short/med 1	48	.345	.055
med/med 1	48	.345	.055
long/med 1	49	.353	.037*
short/fast 1	49	.353	.063
med/fast 1	44	.317	.193
long/fast 1	39	.281	__

Note: significant at $p < .05$.

For participants 1-92 (again collapsing across motion group), the proportion of non-adjustments was also .28 in the long/fast (b3c3) condition. Results of 8 binomial tests showed that the proportion of non-adjustments differed between the long/fast (b3c3) condition and the short/slow (b1c1) condition. Participants made significantly more adjustments in the long/fast condition than in the short/slow condition (see Table 15 for number and proportion of non-adjustments and *p*-values).

Table 15.

Number of Non-adjustments for all Distance/velocity Combinations for Participants 1-92, Representational Momentum Study

Distance/velocity Adjustment	Number of Non-adjustments/90	Proportion of Non-adjustments	*p*-level
short/slow 1	36	.40	.009*
med/slow 1	28	.311	.291
long/slow 1	30	.333	.156
short/med 1	30	.333	.156
med/med 1	30	.333	.156
long/med 1	30	.333	.156
short/fast 1	32	.356	.072
med/fast 1	31	.344	.108
long/fast 1	25	.278	__

Note: significant at $p < .05$.

For participants 93-139 (collapsing across motion group), the proportion of non-adjustments was .29 in the long/fast (b3c3) condition. Results of 8 binomial tests showed that for this data set, the proportion of non-adjustments did not differ significantly between the long/fast (b3c3) condition and any of the other conditions (see Table 16 for number and proportion of non-adjustments and *p*-values). Note that $N = 49$ for this data set, which may have contributed to the lack of significant differences in non-adjustments between the long/fast and other distance/velocity conditions as compared to the other two data sets.

Table 16.

Number of Non-adjustments for all Distance/velocity Combinations for Participants 93-139, Representational Momentum Study

Distance/velocity Adjustment	Number of Non-adjustments/49	Proportion of Non-adjustments	*p*-level
short/slow 1	18	.367	.150
med/slow 1	19	.388	.090
long/slow 1	17	.347	.232
short/med 1	18	.367	.150
med/med 1	18	.367	.150
long/med 1	19	.388	.091
short/fast 1	17	.347	.232
med/fast 1	13	.265	.420
long/fast 1	14	.286	__

Finally, binomial tests were run for each separate motion group: TBTB, BTBT, TBBT, and BTTB. Because there were fewer participants in each of the separate conditions, tests were run only for the entire data set. For each of the four sets of binomial tests, the proportion of non-adjustments in the long/fast condition was compared to the proportion of non-adjustments for each of the remaining distance/velocity conditions. For the TBTB group, the proportion of non-adjustments in the long/fast condition was .26. Participants made significantly fewer adjustments in the short/slow and in the medium/medium conditions than they did in the long/fast condition (see Table 17). For the BTBT group, the proportion of non-adjustments in the long/fast condition was .34, and there were significantly more adjustments in the long/fast than in the medium/slow condition (see Table 18). In the TBBT group, the proportion of non-adjustments was .27. Significantly more adjustments were made in the long/fast than in the long/medium condition (see Table 19). In the BTTB condition, the proportion of non-adjustments in the long/fast condition was .26.

Table 17.

Number of Non-adjustments for all Distance/velocity Combinations for TBTB, Representational Momentum Study

Distance/velocity Adjustment	Number of Non-adjustments/35	Proportion of Non-adjustments	*p*-level
short/slow 1	14	.400	$.049^*$
med/slow 1	16	.457	$.009^*$
long/slow 1	12	.343	.176
short/med 1	13	.371	.098
med/med 1	15	.429	$.022^*$
long/med 1	11	.314	.287
short/fast 1	12	.343	.176
med/fast 1	10	.286	.427
long/fast 1	9	.257	__

Note: significant at $p < .05$.

Table 18.

Number of Non-adjustments for all Distance/velocity Combinations for BTBT, Representational Momentum Study

Distance/velocity Adjustment	Number of Non-adjustments/32	Proportion of Non-adjustments	*p*-level
short/slow 1	15	.469	.090
med/slow 1	16	.500	$.045^{*}$
long/slow 1	10	.313	.452
short/med 1	12	.375	.401
med/med 1	15	.469	.090
long/med 1	14	.438	.164
short/fast 1	12	.375	.401
med/fast 1	10	.313	.452
long/fast 1	11	.344	__

Note: significant at $p < .05$.

Table 19.

Number of Non-adjustments for all Distance/velocity Combinations for TBBT, Representational Momentum Study

Distance/velocity Adjustment	Number of Non-adjustments/37	Proportion of Non-adjustments	*p*-level
short/slow 1	11	.297	.414
med/slow 1	7	.189	.179
long/slow 1	13	.351	.175
short/med 1	13	.351	.175
med/med 1	9	.243	.439
long/med 1	16	.432	$.024^{*}$
short/fast 1	14	.378	.099
med/fast 1	11	.297	.414
long/fast 1	10	.270	__

Note: significant at $p < .05$.

Table 20.

Number of Non-adjustments for all Distance/velocity Combinations for BTTB, Representational Momentum Study

Distance/velocity Adjustment	Number of Non-adjustments/35	Proportion of Non-adjustments	*p*-level
short/slow 1	14	.400	.049*
med/slow 1	8	.229	.420
long/slow 1	12	.343	.176
short/med 1	10	.286	.427
med/med 1	9	.257	.573
long/med 1	8	.343	.420
short/fast 1	11	.314	.287
med/fast 1	13	.371	.098
long/fast 1	9	.257	__

Note: significant at $p < .05$.

CHAPTER V

CONCLUSION

Discussion – Representational Momentum Study

The purpose of the current study was to explore the possible influence of representational momentum, or RM, on temporal adjustments of visual stimuli of identical temporal intervals paired with nine different combinations of distance and velocity. The current RM literature typically involves judged displacements of visual stimuli, but these studies often contain differences in direction and temporal factors as well (see Freyd & Finke, 1984; Hubbard, 1990; 1997). Past research on temporal interval perception has shown that the perception of time, space, and motion are related (Abe, 1935; Brown, 1995; Cohen, Hansel & Sylvester, 1953; Michaluk et al., in preparation; Predebon, 2002). This study attempted to bridge the RM literature and the temporal perception literature. Hypotheses stated that visual stimuli should appear to fall and accelerate when moving from top-to-bottom and rise and decelerate when motion was presented from bottom-to-top, resulting in temporal adjustments that differed from actual temporal intervals presented. There were small but significant effects as expected. Notably, the manipulations of direction of presentation, changes in length of spatial distance and changes in velocity of visual stimuli were partly successful. Temporal adjustments differed from actual temporal intervals when direction of presentation differed. It is possible that improvements to the design of the current study may have marked effects on the outcome of future research. Results and interpretations for all analyses and hypotheses are discussed in detail below. Following the discussion of the results are suggestions for improving the experimental design in future studies.

Hypotheses One and Two – RM Study

Hypothesis one stated that temporal estimates of average first and second adjustments would be minimal in all TBTB and BTBT conditions, regardless of velocity or distance; this hypothesis was supported by all analyses and all 3 data sets. Temporal adjustments in TBTB and BTBT conditions were no different from 1.00 (no adjustment) whether all data, only participants 1-92, or only those 93-139 were tested. As described in the results section, first and second temporal adjustments were also broken down for each distance/velocity condition, resulting in a total of 18 separate one-sample *t*-tests for each of the three data sets (all, ≤ 92, and ≥ 93). Again, temporal adjustments in TBTB and BTBT conditions were no different from 1.00 (no adjustment) for all data sets, and hypothesis one was supported.

In the current study, TBTB and BTBT conditions served as control conditions. It was expected that in TBTB and BTBT conditions, temporal adjustments would be minimal regardless of length of spatial distance or of velocity. Standard and test interval durations were identical, and were expected to have been perceived as such when direction of presentation was also identical. The perception that stimuli fell and accelerated in TB intervals and rose and decelerated in BT intervals were predicted to have led to perceived differences in duration only when direction of presentation of stimuli differed, as in TBBT and BTTB conditions. In TBTB and BTBT conditions, temporal adjustments did not differ from the actual temporal intervals.

Hypothesis two stated that average first and second temporal adjustments in TBBT and BTTB conditions would be different from 1.00 (no adjustment) regardless of velocity or distance. Furthermore, adjustments were predicted to have been *less* than 1.00 in TBBT conditions, because the standard (first) interval would have been perceived as shorter than the test (second) interval. Temporal adjustments were predicted to have been *greater* than 1.00 in the BTTB conditions because the standard interval would have been perceived as longer than the test interval. Results partially supported hypothesis two. Specifically, in the TBBT condition, average first adjustments were significantly less than 1.00 as predicted for all data and for participants 1-92; results approached significance for participants 93-139. In addition, for all participants, results of single sample *t*-tests for first and second adjustments for all 9 combinations of distance/velocity showed that while no adjustments were significantly less than 1.00, adjustments for 6 of the 18 distance/velocity combination adjustments approached significance. Furthermore, mean adjustments for 15 of these 18 adjustments were less than one. Note that while not reported here, similar results were found when analyses were run for participants 1-92 and those 93-139. These results are important because they suggest that in this study in the TBBT condition, temporal estimates appeared to be influenced by perceived changes in duration as a result of acceleration and deceleration.

This conclusion that temporal estimates were influenced by perceived changes in acceleration and deceleration did not hold true for the BTTB condition, and results did not support hypothesis two. Specifically, in the BTTB condition, none of the average first or second adjustments were significantly greater than 1.00 for all data, participants 1-92, or participants 93-139. None of the 18 single sample *t*-tests for first and second adjustments for all combinations of distance/velocity approached significance. However, 11 of the 18 mean adjustments were positive as expected.

If RM played a role in temporal estimates in a manner similar to that in judged displacements (Freyd & Finke, 1984; Verfaillie & d'Ydewalle, 1991; Hubbard, 1990; 1997; 2001; Hubbard & Bharucha, 1988; Hubbard & Motes, 2002; Kozhevnikov & Hegarty, 2001), the presentation of spatial distances in different directions should have influenced temporal adjustments due to the perception of stimuli in the BT distance/velocity as rising (decelerating) and in the TB distance/velocity as falling (accelerating). In the present study, temporal estimates were only influenced in the TBBT condition, but not the BTTB condition. Possible explanations for this outcome are discussed next.

A closer examination of the data revealed that effects were most evident in long/fast distance/velocity combinations, and smallest in short/slow combinations. We expected these effects based on results from the kappa effect and direction studies (Michaluk et al., in preparation). Support for differences in for the TBBT condition comes from Hubbard's (1990) experiment examining the effects of direction of motion and perceived gravity on the judged vanishing point of targets. In his study, 'direction of motion' influenced judgments of target vanishing points, and judged displacements occurred in both the 'direction of motion' as well as in 'downward' directions. 'Direction of motion' and 'downward' displacements were largest in the top-to-bottom vertical condition and were least evident in the bottom-to-top vertical condition. Hubbard (1990) suggested that a gravity effect as well as an effect of direction of motion combined to produce displaced judgments.

It is possible that in the current study in the TBBT condition, the effects of direction of motion and gravity effects combined to produce changes in the perceived duration of the standard and test intervals. However, this conclusion does not explain why the same changes in perceived duration did not occur in the BTTB condition. Trends in the data suggest that had only long distances paired with fast velocities been used, stronger effects may have been found in both the TBBT and BTTB groups. Support for this conclusion will be discussed in further detail in the discussion for hypothesis five, which stated that distance/velocity would interact in such a manner that long/fast pairings would result in larger changes in temporal adjustments.

Hypothesis Three – RM Study

Hypothesis three stated that adjustments would be most influenced in TBBT and BTTB conditions when spatial distances were long, moderately influenced when distances were medium, and least influenced when short, regardless of velocity. This hypothesis was based on results of previous studies showing that differences in length of spatial distances affect perceived duration (Abe, 1935; Adkins, 1972; Cohen & Cooper, 1962; Cohen et al., 1953; 1955; Collyer, 1977; Huang & Jones, 1982; Ono, 1966-67; 1976; Ono & Maruyama, 1969-70; Parks, 1967; Price-Williams, 1954; Russo & Dellantonio, 1989; Yoblick & Salvendy, 1970). In these studies, when identical durations were paired with unequal spatial distances, temporal intervals paired with longer distances were judged as longer in duration as well. In addition, results from the kappa effect and direction studies (Michaluk et al., in preparation) suggested that longer distances in the current study would lead to shortening of adjustments in the TBBT condition and lengthening of adjustments in the BTTB condition. Results of hypothesis three analyses showed that this was not the case in the current study, and there were no differences in temporal adjustments due solely to changes in distance traveled by stimuli for any of the three data sets. In addition, analyses were re-run using *all* groups rather than only the TBBT and BTTB groups in an attempt to gain power. However, increasing the sample size did not change the results, and there was still no effect of distance alone on temporal adjustments. It would appear that in this experiment, increases in spatial distance alone did not lead to perceived changes in duration.

There are two possible explanations for these results. The first explanation is that RM does influence temporal interval adjustments, and that longer distances should lead to stronger effects but the design of the current study did not allow for these effects to be detected. Support for this idea comes from the following: First, distance/temporal intervals were based on Algom and Cohen-Raz's (1987) study of implied vs. actual motion. It is possible that in the current study, these distance/temporal interval combinations were not sufficiently extreme to capture any effect of RM. The use of only longer distance/faster velocity conditions may have changed the results, as could the inclusion of unequal distance/unequal velocity pairings, which will be discussed later. Second, it was believed that in the current study, stimuli paired with short distances should have appeared to move at a constant rate, while stimuli paired with longer distances should have appeared to move faster, and thus be falling, or conversely, as rising and thus decelerating. The farther an object appears to fall, the more it should appear to accelerate, and the longer an object rises, the more it should appear to decelerate. It was this perception that stimuli were either rising or falling in the TBBT and BTTB conditions, particularly for longer distances, that would cause participants to rely on heuristics closely related to impetus theory in making temporal adjustments (Kozhevnikov & Hegarty, 2001). It is only possible to test this idea in future studies.

In the direction and kappa effect studies, Michaluk et al. (in preparation) found that temporal adjustments were 20-25% longer on average than the true temporal interval in actual motion conditions. In these studies, the standard distance was always half the length of the test distance, but temporal intervals were approximately equal. Hence, actual motion (as opposed to implied) subjectively *shortened* identical temporal intervals when paired with a longer spatial distance. It was believed that these results occurred due to the perception that stimuli traveled further and thus appeared to fall and accelerate during the test interval, and that these results would generalize to the current study. Results in the current study showed that perceived temporal intervals traveling from top-to-bottom *were* shorter as expected than those traveling from bottom-to-top in the TBBT motion group, but the effects were smaller than in the direction and kappa effect studies. However, there was no perceived change in temporal intervals in the BTTB motion condition. This suggests that changes in velocities and spatial distances used may have resulted in stronger effects for the TBBT motion group and perceived changes in temporal intervals in the BTTB motion group.

Evidence refuting the second explanation, that RM does not influence temporal adjustments regardless of distance/velocity condition, comes from results of binomial tests (for all data combined), which showed that participants were significantly *less* likely to make temporal adjustments in the short/slow condition (54 non-adjustments) and the long/medium condition (49 non-adjustments) than in the long/fast condition (39 non-adjustments). Thus, it was least evident to participants that durations were identical when distance was long and velocity was fast. It is important to mention that results from binomial tests cannot give information about spatial distance alone, only about the combination of distance/velocity. Regardless, the fact that it was most obvious to participants in the short/slow combination that intervals were equal suggests that when distance is short and velocity slow, stimuli do appear to move at a constant rate. Thus, had only long distance/fast velocity conditions been utilized in this study, the outcome may have changed and effects may have been stronger.

Hypothesis Four – RM Study

Hypothesis four stated that faster velocities would lead to larger temporal adjustments (in absolute values) in TBBT and BTTB conditions; conversely, adjustments in slow velocity conditions would be minimal. The reasoning behind this hypothesis followed the findings of Algom and Cohen Raz (1997) that temporal estimates would be influenced differently as a result of perceived acceleration or deceleration in medium and fast velocity conditions versus perceived constant motion in slow conditions. Furthermore, results from Hubbard's 1990 study, mentioned previously, suggested that for TBBT and BTTB conditions, faster velocities in the current study should have led to the perception that stimuli was either rising and decelerating or falling and accelerating. Temporal adjustments would then differ for faster velocities due to the difference of presentation of the standard and test intervals. However, hypothesis four was not supported, and temporal adjustments in the current experiment were not different as a result of changes in velocity of stimuli alone. These results remained constant across the three different data sets. In addition, when all groups were included in the analyses to increase power by increasing sample size, there was still no effect of velocity alone on temporal adjustments.

Again, there are two probable reasons for these results. First, there is no effect of velocity of visual stimuli alone on temporal interval adjustments, and second, velocity of visual stimuli does affect temporal adjustments, but the manipulation of velocity in this study was not strong enough to detect this effect. In fact, it is quite possible that the inclusion of slow and medium velocities greatly reduced effects of faster velocities on perceived duration of temporal intervals. It cannot be determined from the present study whether there was no effect of velocity on perceived duration; only through further research can this be determined. However there is some evidence for the second and more likely explanation, that velocity does effect perceived duration of temporal intervals: Results from the binomial tests (for all data combined) performed on the number of non-adjustments for each distance/velocity condition showed that the fewest number of non-adjustments occurred in the long/fast condition. Therefore, it was least obvious that intervals were equal when distance was long and velocity was fast. The same difficulty applies regarding hypotheses three and four: It is not possible to separate distance/velocity from the binomial results, but the results do suggest that improvements to study design would alter the outcome.

Nevertheless, it is important to mention that Algom and Cohen-Raz (1997) were examining differences in velocity estimates based on type of movement: implied or actual. In the current study, their findings for actual motion conditions were of most interest. In their study, spatial distance and duration were manipulated to determine the effects that changes in both of these variables had on participants' estimates of velocity.

The current study was based on Algom and Cohen-Raz's experiment partly because their study systematically examined the relationship between type of motion, duration, and velocity. Although it did not address RM specifically, it is one of a very few studies that takes into account all three of these variables.

In Algom and Cohen Raz's (1997) study, changes in duration influenced actual motion velocity judgments more than did changes in distance; however, for implied motion, distance was more influential than duration in velocity judgments. Specifically, perceived velocity increased *more* as distance lengthened than it did as duration decreased for implied motion. Furthermore, the reverse was true for actual motion: Perceived velocity increased with decreases in duration more so than with increases in distance. It was believed based on their findings that the use of three velocities and of actual motion in the current study would result in changes in perceived duration of intervals when direction of presentation of stimuli differed. In Hubbard's (1990) study, direction of presentation was the manipulation of interest - not velocity of stimuli. It is likely that stimuli traveled more quickly in his study than in the current study, which would certainly influence the outcome. Perhaps the use of only fast velocities would allow a better test of the theory.

Hypothesis Five – RM Study

Hypothesis five stated that in TBBT and BTTB conditions, temporal estimates would be *most* affected in long and medium distance conditions when velocities were faster. This hypothesis was based on results of previous research on the kappa effect in which temporal estimates (Abe, 1935; Adkins, 1972; Cohen & Cooper, 1962; Cohen et al., 1955; Collyer, 1977; Huang & Jones, 1982; Michaluk et al., in preparation; Ono, 1966-67, 1976; Ono & Maruyama, 1969-70; Parks, 1967; Price-Williams, 1954; Russo & Dellantonio, 1989; Yoblick & Salvendy, 1970) and RM studies (Hubbard, 1990; 1997; 2000; 2001; Hubbard & Bharucha, 1988; Hubbard & Motes, 2002) in which judged displacements were significantly altered by the combination of longer distances and faster velocities. It was expected that temporal adjustments would be most affected in TBBT and BTTB conditions when distances were longer and velocities faster, and that as distance shortened and velocity slowed, estimates would be minimal. Results of planned interaction contrasts showed that hypothesis five was not supported when only TBBT and BTTB groups were included for any of the three data sets. However, when all groups for the entire data set were included in analyses, there were significant differences between short distance/slow velocity and medium distance/fast velocity and between the short distance/slow velocity and long distance/fast velocity conditions. In the current study, longer distance paired with faster velocity led to shorter temporal adjustments. Had distances been longer and velocities faster, results in the current study may have been found when only TBBT and BTTB groups were included in analyses.

Why should longer distance/faster velocity pairings have resulted in shorter temporal adjustments in the current study? As mentioned earlier, Kozhevnikov and Hegarty (2001) stated that people rely on heuristics closely related to impetus theory when circumstances predict different outcomes for Newtonian physics and impetus theories. In RM studies, these heuristics result in displacements in judgments of movement of visual stimuli (Freyd & Finke, 1984; Hubbard, 1990; 1997; 2001; Kozhevnikov & Hegarty, 2001; Riener, Proffitt, & Salthouse, 2005; Verfaillie & d'Ydewalle, 1991). Specifically, visual stimuli in these studies are estimated as disappearing from the screen where one would *expect* them to disappear, based on previous experience and or/intuitive physics. The relationship between time, space, and motion (Abe, 1935; Brown, 1995; Cohen, Hansel & Sylvester, 1953; 1955; Predebon, 2002) highly suggests that in certain circumstances, the same should be true of temporal judgments, and it appears that in the current study, this did in fact occur. Results from this study suggest that participants did rely on heuristics in making judgments, but only when distance was long and velocity fast. When distances were short and velocities slow, stimuli should have appeared to move at a constant rate, thus, no heuristics were necessary when making adjustments. Therefore, further study into the effects of RM on temporal estimates is warranted.

It is worth repeating here that Kozhevnikov and Hegarty (2001) proposed that people may rely on RM, or heuristics, because these heuristics may bestow a survival advantage in the real world. The researchers added that it is advantageous to quickly determine the path a moving object will take, and when conscious deliberation is not possible, people rely on the notion that objects lose their ‘energy’ or impetus. Thus, as would be expected, when conscious deliberation is possible, people with knowledge of physics correctly apply the principals of physics in their judgments of the movement of objects, while people with no formal knowledge of physics may still rely on impetus theory or RM, despite its outdated notions. Results showing that long distance/fast velocity resulted in shorter adjustments and that short distance/long velocity pairs resulted in fairly accurate adjustments suggest that this may be the case. That is, when conscious thought is possible, we can accurately predict the trajectory of a moving object or the temporal interval associated with a distance/velocity. However, when conscious deliberation is not possible, we must rely on heuristics (Kozhevnikov & Hegarty, 2001).

There is another possible interpretation of the results of both RM studies and the current study: that we can attend to a limited number of stimuli if they are present for only a short time. Therefore, if told that we will be required to estimate the vanishing point of moving stimuli, we are most likely not attending to all the relevant information, including distance traveled, velocity of stimuli, and time of onset to time of offset. Rather, we are watching most closely where we expect the stimuli to disappear; thus heuristics are called into play. The kappa effect and direction studies (Michaluk et al., in preparation) as well as the current study provide further evidence for this. In each of these studies, actual motion of stimuli was used. Participants were told to adjust temporal test intervals to match standard intervals, and were likely attempting to pay attention only to time intervals. However, the presence of spatial distance as well as velocity made this task more difficult. This could help explain why results from the kappa effect and direction studies were much stronger than in the current study: There were differences in the spatial distances to attend to as well as differences in velocity. In addition, in the current study, temporal adjustments were most affected when spatial distance was long and velocities fast. More sensory information about each separate stimulus had to be processed in less time. Theories of attention generally support the notion that more stimuli, and that more changes associated with visual stimuli, lead to the perceived lengthening of temporal intervals (Brown, 1995; Predebon, 2002). However, in the studies reviewed here, spatial distance, velocity, and temporal intervals were not separate entities.

Research Question – RM Study

Algom and Cohen-Raz (1987) found that in actual motion conditions in their study, participants employed the rule:

$$\text{Velocity} = \text{Distance} \div \text{Duration}$$

when judging the velocity of visual stimuli. To determine whether participants in the current study utilized a similar rule, the equation was converted to:

$$\text{Duration} = \text{Distance} \div \text{Velocity}$$

If RM did influence temporal adjustments, then mean temporal adjustments should *not* have fit this equation in TBBT and BTTB conditions; in TBTB and BTBT conditions, adjustments should have been fairly accurate. In the current study, participants fairly accurately estimated temporal intervals regardless of distance or velocity in BTTB, TBTB, and BTBT conditions. These results are consistent with expected outcomes only for TBTB and BTBT conditions. As was the case in hypothesis two when temporal estimates were not significantly longer in the BTTB condition as expected, the data did fit the equation for the BTTB condition in general. It is interesting to note that the two most extreme variations in temporal adjustments both occurred in the short distance/slow velocity condition, and that in both cases the actual temporal interval was overestimated. However, the most extreme variation occurred in the TBTB condition, and the second most extreme in the BTTB condition. These results were not expected for the TBTB condition, although they were for the BTTB condition. As occurred for hypothesis two when temporal estimates for the TBBT condition were *less* than the actual temporal intervals, for this equation, temporal estimates were slightly *less* than actual temporal intervals. Temporal adjustments should have been *shorter* than the actual temporal interval in the TBBT condition and *longer* than the actual temporal interval in the BTTB condition, because stimuli should have appeared to have been influenced by gravity. Thus presentation of stimuli in opposite directions would have caused the perceived shortening of the TB interval and lengthening of the BT interval for all conditions. Once again, effects were as expected only in the TBBT condition and were not as expected (in general) in the BTTB condition.

These results suggest that participants did use the equation

$$\text{Duration} = \text{Distance} \div \text{Velocity}$$

when making their temporal adjustments. However, their adjustments were slightly shorter than actual temporal intervals in the TBBT condition.

These results lend support to the notion that RM influences temporal estimates in a manner similar to judged displacements in RM studies. In particular, results from the TBBT condition closely mirror those from Hubbard's 1990 experiment examining the effects of direction of motion and perceived gravity on the judged vanishing point of targets. Judged displacements were most evident for top-to-bottom motion; least evident for bottom-to-top motion. In the current study, evidence that RM influenced temporal adjustments occurred in the TBBT condition. This should have also occurred in the BTTB condition. Again, it is possible that RM is not a factor in determining temporal adjustments, but it is possible that refining the design of the study would significantly influence the outcome. Further evidence to support this is discussed next.

Preliminary analyses for all hypotheses showed that overall effects were present in some cases, but were smaller than anticipated. There are three proposed causes for these results. First, participants had advance knowledge of the study manipulation; second, that more extreme experimental manipulations would have resulted in stronger effects; and third, that RM does not influence temporal adjustments in a manner similar to visual displacements. To determine which of the above explanations was most likely additional analyses were run for all hypotheses, and binomial tests were conducted to determine whether the number of non-adjustments varied in each data set (all participants, participants 1-92, and participants 93-139) as a result of distance/velocity condition.

Binomial Tests – RM Study

Binomial tests were run on the number of non-adjustments for each distance/velocity first adjustment for all data combined, for participants 1-92, and participants 93-139. Results from these analyses were helpful in determining whether participants run in summer 2008 (1-92) may have had prior knowledge that all temporal intervals were equal. Evidence to support this notion comes from analyses showing larger effects and more variability in temporal adjustments for participants tested in fall 2008 compared with those run in summer 2008, when only 3 classes were in session. If the number of non-adjustments did not vary by distance/velocity condition, then we would conclude that in this study, RM did not influence temporal adjustments. If the number of non-adjustments did in fact vary by condition, then we would conclude that RM was a factor in temporal adjustments in the current study.

Binomial tests for all motion groups and all data combined (see Table 14) showed that the number of non-adjustments varied by distance/velocity condition, thus refuting the explanation that participants had advance knowledge of the study manipulation and therefore did not make any adjustments. There were fewer non-adjustments in the long distance/fast velocity condition than in either the long distance/medium velocity or the short distance/slow velocity conditions. For participants 1-92, there were fewer non-adjustments in the long distance/fast velocity condition than in the short distance/ slow velocity condition. There were no significant differences in the number of non-adjustments between the long distance/fast velocity condition and any other distance/velocity condition for participants 93-139. However, in this data set, there were only 49 participants, as opposed to 90 for data set 1-92 and 139 for the entire data set. Thus, it may have been more difficult to find any differences in number of non-adjustments because there were fewer participants. In two of the three data sets, there were significantly fewer non-adjustments when distances were long and velocities fast than when distances were short and velocities slow. This suggests that participants were able to determine that temporal intervals were equal more easily for the short/slow condition than the long/fast condition.

It is also important to mention that all motion groups were included in these analyses. Despite the inclusion of the two control groups (TBTB and BTBT) when temporal intervals should have been perceived as identical, and non-adjustments should therefore not have varied between distance/velocity conditions, there were still significant differences in the number of non-adjustments as a results of distance/velocity condition. Additional binomial analyses for each separate motion group (TBTB, BTBT, TBBT, and BTTB, refer to Tables 17 – 20) showed that regardless of motion condition, there were significant differences in the number of non-adjustments between the long distance/fast velocity condition and at least one other distance/velocity condition. These analyses support the notion that RM did influence temporal adjustments in the current study, as does Figure 7, which compares the number of adjustments and non-adjustments across trials. We would have expected that the number of non-adjustments should be approximately equal to the number of adjustments if participants were aware of the manipulation prior to participating; instead, the number of adjustments was higher across all trials than the number of non-adjustments, despite the inclusion of both control motion groups in the data. Finally, further examination of the data showed that only 8 participants made non-zero first adjustments and then made second adjustments of zero. Prior knowledge of the manipulation would have led to far more second adjustments back to zero.

These results support the conclusion that stimuli should appear to fall and accelerate or rise and decelerate when distances were long and velocities fast as proposed by Michaluk et al. (in preparation) in the kappa effect and direction studies. By the same logic, stimuli should have appeared to move at a constant rate when distance was short and velocity slow. It would appear based on the results of binomial tests that RM did affect perceived temporal intervals in the current study; however, the effects were smaller than those in the direction and kappa effect studies.

Future Research – RM Study

Results of the current study suggest that RM did in fact influence temporal adjustments to some extent in the TBBT condition, but the experimental design perhaps did not allow for this effect to be detected in the BTTB condition. However, results from the current exploratory study suggest the theory that RM influences temporal estimates of visually moving stimuli and as such should be incorporated into the RM literature. Therefore, changes to the design for future studies will be discussed next.

Several factors could lead to marked changes in the outcome of future studies. These include distance/velocity changes, the addition of unequal spatial distances paired with identical temporal intervals (and thus unequal velocities) and of identical spatial distances paired with unequal temporal intervals among trials (again unequal velocities), and the use of larger monitors for presentation of stimuli. Finally, designs should be tested both between and within participants. These suggestions are discussed next. First, it is likely that in the current study, distance/velocity pairings were not sufficiently extreme to capture any effect of RM. This could be remedied in future studies by using only longer distances paired only with fast velocities. For example, rather than a 160 mm/160 mm/s distance/interval pairing, the longest/fastest pairing in the current study, a 228 mm (8.98 in.)/ 228 mm/s distance/interval pair could be used. Participants may have more difficulty attending to all the relevant information in the short time that stimuli are presented, including distance, temporal interval, and velocity of visually moving stimuli. The use of longer spatial distances/faster velocities may force participants to rely on heuristics (Kozhevnikov & Hegarty, 2001) when making temporal adjustments.

Another potentially beneficial alteration to the design of the study would be to use the same four direction groups, but to add unequal distance/velocity trials. The use of all four direction conditions (TBTB, BTBT, TBBT, and BTTB) could extend findings in several areas of temporal/spatial perception literature, including the kappa effect and RM literature. In order to bridge visual judged displacements in RM studies to changes in perceived temporal duration in the temporal literature, varying distance/velocity pairings is necessary. For example, for some trials, distance/velocity would be identical; for others, distances would be identical, but velocities, and thus intervals would differ, and finally, distance for the standard and test would vary, but intervals would be identical. In such a design, participants may be less likely to be able to determine that in some cases distance/velocity were identical, except in the control conditions (TBTB and BTBT). Ideally, the number of trials would be limited because practice effects occur very quickly in these studies. Evidence for possible practice effects comes from fitting the data from the current study to Algom and Cohen-Raz's 1987 study. Participants' adjustments were fairly accurate, suggesting that participants quickly determined that all interval pairs were equal or very nearly equal.

An additional alteration to the current study would involve the use of larger monitors for the presentation of visual stimuli. The logic is to increase the length of distance/velocity pairings as well as to further test Hubbard's (2001) findings of the effects of gravity on judged vanishing points. In his study, participants saw ascending and descending targets disappear at varying heights in a picture plane. Target speed and direction of motion were also varied, and Hubbard found that for targets that disappeared in the top half of the screen, 'direction of motion' displacement was small for fast moving ascending targets, slightly higher for slow-moving descending targets, and higher still for fast-moving targets. However, when targets disappeared in the bottom half of the screen, 'direction of motion' displacement occurred in all conditions, but the effect was strongest in the fast-moving descending target condition. Applying the modifications to the current study to Hubbard's 2001 paradigm may lead to stronger effects.

Conclusion – Representational Momentum Study

The goal of the current exploratory research was to examine the effects of differences in direction of presentation of visual stimuli made up of nine combinations of

identical spatial distance/velocity pairings. It was designed to explore a possible relationship between current studies investigating judged displacement of visual stimuli in Representational Momentum (RM) studies and the temporal perception literature. Results did not support all hypotheses, and effects were small. However, the results suggest that RM does factor into temporal estimates of visual stimuli in much the same way that it occurs in judged displacements, but this experiment was the first of its kind; further research using improved methodology is needed.

REFERENCES

Abe, S. (1935). Experimental study on the co-relation between time and space. *Tohoku Psychologica Folia, 3,* 53-68.

Adkins, C. J. (1972). Verbal estimations of time at four spatial distances. *Perceptual and Motor Skills, 35,* 411-418.

Algom, D., & Cohen-Raz, L. (1997). Sensory and cognitive factors in the processing of visual velocity. *Journal of Experimental Psychology: Human Perception and Performance, 13,* 3-13.

Brown, S. W. (1995). Time, change, and motion: The effects of stimulus movement on temporal perception. *Perception & Psychophysics, 57*, 105-116.

Caelli, T., Hoffman, W., & Lindman, H. (1978). Subjective Lorentz transformations and the perception of motion. *Journal of the Optical Society of America, 68,* 402-411.

Cohen, J., & Cooper, P. (1962). New phenomena in apparent duration, distance, and speed. *Nature, 196,* 1233-1234.

Cohen, J., Hansel, C. E. M., & Sylvester, J. D. (1953). A new phenomenon in time judgment. *Nature, 172,* 901.

Cohen, J., Hansel, C. E. M., & Sylvester, J. D. (1955). Interdependence in judgments of space, time, and movement. *Acta Psychologica, 11,* 360-372.

Collyer, C. E. (1977). Discrimination of spatial and temporal intervals defined by three light flashes: Effects of spacing on temporal judgments and of timing on spatial judgments. *Perception & Psychophysics, 21*(4), 357-364.

Freyd, J. J., & Finke, R. A. (1984). Representational momentum. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 10,* 126-132.

Huang, Y. L., & Jones, B. (1982). On the interdependence of temporal and spatial judgments. *Perception & Psychophysics, 32*, 7-14.

Hubbard, T. L. (1990). Cognitive representation of linear motion: Possible direction and gravity effects in judged displacement. *Memory and Cognition, 18,* 299-309.

Hubbard, T. L. (1997). Target size and displacement along the axis of implied gravitational attraction: Effects of implied weight and evidence of representational gravity. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 23,* 1484-1493.

Hubbard, T. L. (2001). The effect of height in the picture plane on the forward displacement of ascending and descending targets. *Canadian Journal of Experimental Psychology, 55,* 325-329.

Hubbard, T. L., & Bharucha, J. J. (1988). Judged displacement in apparent vertical and horizontal movement. *Perception and Psychophysics, 44,* 211-221.

Hubbard, T. L., & Motes, M. A. (2002). Does Representational momentum reflect a distortion of the length or the endpoint of a trajectory? *Cognition, 82,* 89-99.

Jones, B., & Huang, Y. L. (1982). Space time dependencies in psychological judgment of extent and duration: Algebraic models of the tau and kappa effects. *Psychological Bulletin, 91*, 128-142.

Keppel, G., & Wickens, T. D. (2004). *Design and analysis: A researcher's handbook.* (4th ed.). Upper Saddle River, NJ: Prentice Hall.

Kerzel, D. (2002). A matter of design: No representational momentum without predictability. *Visual Cognition, 9,* 66-80.

Kerzel, D. (2005). Representational momentum beyond internalized physics: Embodied mechanisms of anticipation cause errors in visual short-term memory. *Current Directionsin Psychological Science, 14,* 180-184.

Kozhevnikov, M., & Hegarty, M. (2001). Impetus beliefs as default heuristics: Dissociation between explicit and implicit knowledge about motion. *Psychonomic Bulletin and Review, 8,* 439-453.

Michaluk, L. M., Thomas, D. G., & Page, M. C. (2007). *Effects of motion, representational momentum, and salience of spatial distance on temporal perception in the kappa effect.* Manuscript in preparation.

Ono, A. (1969-70). Interdependence in successive judgments of the duration, distance, and speed of a manual movement. *Tohoku Psychologica Folia, 28*, 29-53.

Ono, A. (1976). A study of the literature on the interrelations between subjective time, distance, and speed. *Tohoku Psychologica Folia, 35*, 1-11.

Ono, A., & Maruyama, K. (1969-70). Interdependence in judgments of the duration, distance, and speed of moving targets and its applied application. *Tohoku Psychologica Folia, 30*, 40-51.

Parks, T. E. (1967). The spatial separation of two light-flashes and their perceivedseparation in time. *The American Journal of Psychology, 81,* 92-98.

Predebon, J. (2002). Stimulus motion and retrospective time judgments. *Acta Psychologica, 109,* 213-225.

Price-Williams, D. R. (1954). The kappa effect. *Nature, 173,* 363-364.

Riener, C. R., Proffitt, D., & Salthouse, T. (2005). A psychometric approach to intuitive physics. *Psychonomic Bulletin and Review, 12,* 740-746.

Russo, G., & Dellantonio, A. (1989). Influence of phenomenal time on perceived space. *Perceptual and Motor Skills, 68,* 971-984.

Verfaillie, K., & d'Ydewalle, G. (1991). Representational momentum and event course anticipation in the perception of implied periodical motions. *Journal of Experimental Psychology, Learning, Memory, and Cognition, 17,* 302-313.

Yoblick, D. A., & Salvendy, G. (1970). Influence of frequency on the estimation of time for auditory, visual, and tactile modalities: The kappa effect. *Journal of Experimental Psychology, 86*, 157-164.

VITA

Lynnette Marie Michaluk

Candidate for the Degree of

Doctor of Philosophy

Dissertation: THE EFFECTS OF DIRECTION OF MOTION, LENGTH OF SPATIAL DISTANCE, AND DIFFERENCES IN VELOCITY ON TEMPORAL INTERVAL ESTIMATES OF VISUAL STIMULI

Major Field: Psychology

Education:
Completed the requirements for the Master of Science or Arts in your major at Oklahoma State University, Stillwater, Oklahoma in May 2005.

Experience:
Teaching:
Developmental Psychology, Oklahoma State University. *August 2006 – May 2007*
Introduction to Speech Communication, Oklahoma State University. *August 2004 – May 2005*
Psychology of Human Problems, Oklahoma State University. *August 2003 – May 2004*
Introductory Psychology, Oklahoma State University. *January 2002 – May 2002*

Professional Memberships:
American Psychological Association
American Psychological Society
Sigma Xi Associate Member
Oklahoma Psychological Society
Southwestern Psychological Association

Name: Lynnette Marie Michaluk Date of Degree: May, 2009

Institution: Oklahoma State University Location: Stillwater, Oklahoma

Title of Study: Title of Study: THE EFFECTS OF DIRECTION OF MOTION, LENGTH OF SPATIAL DISTANCE, AND DIFFERENCES IN VELOCITY ON TEMPORAL INTERVAL ESTIMATES OF VISUAL STIMULI

Pages in Study: 92 Candidate for the Degree of Doctor of Philosophy

Major Field: Psychology

Scope and Method of Study: The vast majority of psychophysical research involving velocity, distance, and duration fails to take into account the effects of each of these dimensions on the perception of the others. In this paper, this issue will be discussed and a study examining this problem presented. Aspects considered in this study included the examination of the combined effects of changes in velocity, length of spatial distance, and direction of motion on estimates of brief temporal intervals paired with visual stimuli. Previous research suggests that the direction of presentation of visual stimuli (i.e. top-to-bottom or bottom-to-top) should alter the perception of intervals so that intervals presented from top-to-bottom are perceived as taking *less* time than equal temporal intervals presented from bottom-to-top (Cohen, Hansel, & Sylvester, 1955; Hubbard, 1990; 1997; Hubbard & Bharucha, 1988; Hubbard & Motes, 2002). In addition, velocity of visual stimuli has also been shown to affect temporal intervals, such that faster velocities are associated with a subjective shortening of duration (Algom & Cohen-Raz, 1987). Finally, differences in length of spatial distances have also been shown to affect perceived duration, and when equal durations are paired with different distances, longer distances are judged as longer in duration as well (Abe, 1935; Adkins, 1972; Cohen & Cooper, 1962; Cohen et al., 1955; Huang & Jones, 1982; Ono, 1966-67; 1976; Ono & Maruyama, 1969-70; Parks, 1967; Price-Williams, 1954; Yoblick & Salvendy, 1970). To date, there is no research examining the influence of these factors in combination on estimates of temporal intervals. Therefore, in this study, each of these variables was systematically manipulated to more closely examine their combined effects on temporal estimates.

Findings and Conclusions: Results indicated that in the current study, temporal intervals were perceived as shorter when presented from top-to-bottom, but were not perceived as longer when presented from bottom-to-top. Furthermore, distance and velocity interacted in such a manner as to lead to a perceived shortening of temporal interval presented from top-to-bottom when distance was long and velocity was fast. Future research in the area is suggested.

ADVISER'S APPROVAL: Dr. David G. Thomas