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Representational momentum:
Effects of symbolic meaning on perception of movement

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ABSTRACT

Regarding the perception of movement, there has been much work exploring the perceptual distortions occurring when we encounter moving objects. One such phenomenon is 'representational momentum', in which one's memory of the last location of a moving object is displaced further along its trajectory. Like many other perceptual phenomena, there has been evidence that representational momentum is influenced by the object's symbolic meaning. An object's symbolic meaning encapsulates its defining and distinctive properties, such as size, weight, semantic meanings, and the typical ways in which it interacts with the environment. In particular, in a study by Reed and Vinson, it has been shown that our pre-existing knowledge of an object's typical direction and speed of movement can affect the magnitude of representational momentum generated. Objects with larger typical real-world speed (for example, a rocket) generated a larger representational momentum effect than objects with no typical real-world speed (for example, a church). In this thesis, I attempted to replicate the results found in Reed and Vinson 1996's study by using the same set of stimuli on 24 participants. The target traveled along a continuous and upward trajectory before disappearing. It would then reappear in varying locations of displacement, and the participants were instructed to compare the relative points of disappearance with points of reappearance. Contrary to Reed and Vinson's findings, my analyses found no effect of representational momentum for either stimuli. However, an effect of symbolic meaning was observed, as the stimulus with larger typical speed (the rocket) yielded less forward displacement along the moving trajectory than the stimulus with no typical speed (the church). These results support the idea that symbolic meaning has an impact on movement perception, while providing contrasting evidence on the direction in which this impact is manifested with Reed and Vinson's observations. The disparity in results compared to Reed and Vinson's 1996 study also suggests a number of potentially key influential factors in investigating the effects of symbolic meaning on perception of movement, including the stimuli's parameters and the participants' perceptual illusions.

1. INTRODUCTION

You see two people standing at a corner of a seemingly squared room. They look normal, of somewhat similar height. Until one of them started walking towards the other corner of the room. And now one of them is a giant, the other looks of modest height. Did one of them grow, or did the other shrink?

You see two perfect cubes, made of the same material (like wood, because we are environmentally friendly), with the same color (like blue, because I like blue). One of them is obviously smaller. You pick them up, and the small one definitely feels heavier in your hand than the big one.

But in both cases, despite the conviction with which you see before your eyes and feel in your hand, no human grows or shrinks, it is just the room is skewed and not actually square, and no cube is actually heavier than the other. “What a strange world we live in” (Lewis Carroll, *Alice in Wonderland*). Said Alice, and probably say you. But one could argue that the world is not a strange place, it is the discordance between the image we have of the world and the reality that is strange.

Though we like to think that what we see is what we know, it is hardly the case, as the act of perceiving, like all behavioral acts, has limitations. We are prone to errors and illusions, regardless of how certain we are of what we see. The study of perception concerns two layers of questioning, the first being how elements of the external world are represented in our mind, while the second posing the age-old epistemological question of how accurately our perception represents reality. Attempts to address these matters, at the risk of oversimplification, fall into a spectrum, with one end maintaining human perception is made of nothing more but the senses, while the other opening up to the possibilities of influences other than external and environmental. Current works in cognitive psychology favor the latter, where perception is seen as a process, not an instant occurrence, and is influenced by many factors belonging to internal mental processes, and hence, to a varying degree, by past perceptual experiences.

Years-worth of perceptual experiences is accumulated in a complex system of information organization in our mind, so that we can access whatever we need to make our daily perceptual decisions as quickly as possible. Has the person grown? Is the smaller box heavier? Is the car going to collide with me if I cross the road now? Each object and event is assigned a symbolic meaning, which informs us of what they are, how they should look like, how they behave, and how they interact with us, as well as with the environment. Though the mechanism is still unclear, abundant evidence has shown that symbolic meaning influences perception, sometimes to the degree that our conclusions misalign with the actual reality.

In the study of movement perception, a phenomenon termed *representational momentum* has been documented as a “mental analogue to the momentum of a moving physical object” (Freyd and Finke, 1984). It is depicted as a form of memory distortion of a moving object along its trajectory of motion. Representational momentum, like many perceptual phenomena, is also influenced by an object's symbolic meaning, as demonstrated in a notable study by Reed and Vinson (1996). The authors observed that participants’ representational momentum changed as an effect of the type of stimuli presented, with images representing objects with faster typical speed generating larger representational momentum.

The study featured in this thesis replicates the experiment paradigm in Reed and Vinson’s study to investigate the influence of an object's symbolic meaning of speed on representational momentum, providing supporting evidence for the role of symbolic meaning in perception, particularly the perception of movement and speed. However, an opposite effect of what was observed in Reed and Vinson’s study was found. The disparity in observed results could contribute to supporting the role of internalized and possibly naive physics constraints in perception. The results also provide supporting evidence for the phenomenon of *expected-speed violation illusion,* opening up possibilities for further investigation into this intriguing illusion.

The next section will be dedicated to an elaboration on the study of perception itself, and how the role of past experiences and symbolic meaning in the process of perception was recognized. Subsequently, an overview of the concept of representational momentum and its influencing factors will be addressed. A description of the study is given. Finally, the last section will touch on how pre-existing knowledge of physics constraints could be of importance in accounting for the study’s results. Additionally, I will give an overview of *expected-speed violation illusion,* and how the observed phenomenon in this study relates to the illusion.

1.1. Perception

The word “perception” has a Latin root - “perceptio” - which essentially means “receiving” or “collecting.” It is tempting to think of perception as simple as such, as only consisting of the act of *receiving* information from the external world. We perceive everything the way they are because it is truly the way they are. This seems to be a given assumption, as Thomas Reid summarized: “By all the laws of all nations, in the most solemn judicial trials, wherein men’s fortunes and lives are at stake, the sentence passes according to the testimony of eye or ear, witnesses of good credit.” But the long history of the study of perception suggests that perceiving is not always a passive, unidirectional process. Why, then, is perception something we ponder over, if we have already perceived everything the way they truly are?

Protagoras (ca. 480-411 B.C.) said “just as each thing appears to me, so too it is for me, and just as it appears to you, so too again for you.” If the wind feels warm to me, to me it is warm; and if the wind feels cold to another, to them it is cold (Theaetetus, 152a). This marked the start of the Sensism doctrine, where one’s knowledge of the environment is believed to rely entirely upon one’s sensation, and distortions between perception and reality reflects the limitations of the mind. John Locke expanded the view, maintaining that perceptual experience was the source of cognition. The mind is simply a *tabula rasa - blank paper*, waiting to be written on by sensory experience. Though there have been many contradictory arguments to this viewpoint throughout history, in the 20th century, it was partly reincarnated by James J. Gibson’s theory of direct perception (Gibson, 1950; 1979). Essentially, all the information we collect through our senses is enough to form our conscious percept. For instance, considering the visual perception of a particular object, though the optical images in the eye can change due to the observer’s changing point of view, there remains certain consistent stimulation elicited by the object that informs the observer of its properties in reality, such as its shape, size, reflectiveness, distance, and affordance (the action possibilities the observer can take to interact with the object). According to Gibson, such information is directly available to the observer in the external environment, and is not the result of high-level cognitive processing (Gibson, 1950; 1979).

However, Gibson’s theory of direct perception and its predecessors are unable to explain the plethora of visual illusions, one notable example is the Ames room. In 1946-1947, Adelbert Ames Jr. constructed a room that an observer could view with one eye through a peephole. To the observer, the room was an ordinary rectangular cuboid, yet somehow when two adults each stood in one corner of the room, they appeared to have vastly different size: one being a giant, the other a dwarf. It turned out that the shape of the room was actually an irregular hexahedron, designed so that one corner of the room is farther away from the observer than the other, creating the optical illusion (Ittelson, 1952). This illusion demonstrated the limitation and inadequacy of sensory processes in constructing a reality-compliant concept, and how our personal beliefs of how the environmental elements should behave affect our judgment.

The role of the intellect or reasoning in perception was acknowledged by Plato (ca. 428-348 B.C.), who believed that as sensory inputs were inconsistent and inaccurate, the intellect's role was to amend such inaccuracies, and to provide us with a correct representation of the external environment. In medieval times, St. Thomas Aquinas (1225-1274) presented the concept of *sensus communis*, which includes the individual past experience, forming a center of common sense that actively modulates all sensory inputs. But it was Hermann von Helmholtz that provided an elaborated mechanism for the involvement of previous experience in perception. In his influential work of *Treatise on Physiological Optics,* he proposed the concept of *unconscious inference,* stating that a percept was formed using both information derived by the senses, and, as this information is inadequate, the individual's past experience (Boring, 1942). Richard Gregory's constructivist theory of perception echoes this view, further emphasizing the importance of experience in the interpretation of sensory data, which he considered to be essential, much more than sensory image. In this sense, perception is an active process, involving not only the gathering of sensory information, but most critically, the inferences and interpretations we make based on our previous knowledge and experience (Gregory, 1990).

1.2. The influence of symbolic meaning on perception

Every stimulus we perceive is stored within a complex system of semantic memory, where we would use them, in combination with existing knowledge, to construct mental representations of objects and phenomena we interact with. By doing so, we attribute to each object a symbolic meaning, which defines to us how the object behaves in the real world, both as a standalone and in relation to its surroundings and other objects. As discussed above, perception is a simultaneously unconscious and active process, where past experiences and current contexts constantly interact with one another, and influence how we make interpretations and inferences from sensory input. Since symbolic meaning is essentially the culmination of past sensory experiences between us humans and the environment, it is only reasonable to assume that symbolic meaning plays an influential role in perceptual judgments.

There have been many lines of evidence in support of the interrelationship between object's characteristics and perception. Regarding neuroelectrical activities, it was found that retrieval of perceptual information correlates with increased activation in brain regions that encode sensory experiences associated with the referenced objects. These results suggest that the process of making perceptual judgments relies on brain regions that mediate initial stages of sensory processing (Goldberg et al., 2006). In school age children, time perception is shown to be affected by symbolic meaning of velocity. In time reproduction tasks featuring two stimuli indicating different speed (the car represented fastness, the truck represented slowness), the car was significantly under-reproduced in comparison to the truck (Mioni, 2014). Temporal perception has also been investigated in relation to nontemporal dimensions. When observers are faced with different types of nontemporal magnitude information, they tend to judge the duration of stimuli with larger magnitudes to be longer. This observation suggests that perception of properties of target objects (in this case, the magnitudes, or the amount, of the stimuli) can exert a cross-dimensional influence on our perceptual judgments (Xuan et al., 2007).

Another example of the effect of symbolic meaning on perception is weight perception. Weight assessment has never been reliable, as described in multiple phenomena of weight illusion, where weight assessment is influenced by visible properties of the object. However, weight perception is affected by more than just the size (Koseleff, 1957), shape (Dresslar, 1894), material (Wolfe, 1898), and color (De Camp, 1917) of the object. In a unique study by Dijker (2008) and a followup study by Saccone and Chouinard (2019), Ken-like dolls and Barbie-like dolls were used to investigate how our pre-existing cultural biases affect weight perception of the dolls. As hypothesized, despite sharing the same weight, Ken-like dolls were perceived to be heavier than Barbie-like dolls. In another study, experienced golfers (who expect a weight difference between ball types) tended to judge practice golf balls to be heavier than real golf balls, despite them sharing the same weight; while non-golfers (who expect no weight difference between ball types) tended to judge both types of golf balls to be of equal weight. Within group analyses also showed that those who expected the most difference in weight between the two types of balls reported the strongest illusion effect after actually lifting (Ellis and Lederman, 1998). These findings suggest that pre-existing yet unacknowledged factors like biases and experience with perceived objects can permeate our most basic perceptual processing, namely, weight perception.

Vision is currently the most well-researched of all sensory modalities, and the effect of symbolic meaning on visual perception has been extensively studied. The interaction between visual and conceptual information is believed to be active at multiple levels in the object recognition process, hence influencing the acquisition of perceptual knowledge. In a set of experiments focused on observing ERP components associated with meaning access and low-level visual perception in response to visually ambiguous stimuli, P1 amplitude was found to be bigger when participants interacted with objects associated with minimal prior knowledge. This finding suggested that prior in-depth knowledge of the object is involved in shaping perception by influencing early visual processes, regardless of whether or not this knowledge is directly relevant to the task at hand (Rahman and Sommer, 2009). Evidence supported the notion that primary stages of perception could be influenced by higher-order, nonvisual conceptual representations. In a study where participants were conditioned to semantically associate novel objects with nonvisual elements, it was found that acquired semantic knowledge about the novel object reduced viewpoint dependence. As participants assigned a meaning to the object, they recognized it easier regardless of the point of view from which the object was displayed (Collins and Curby, 2013). Categorical knowledge of an object affects its discriminability, with objects that are perceived as belonging to the same category being more difficult to discriminate (Livingston, Andrews, & Harnad, 1998). This relation is also demonstrated in facial recognition, with categorical perception being a potential modulator of the distinguishability of category-relevant facial features after perceptual learning. From the early stages of visual perception, the influence of learned knowledge of an object’s properties and semantic information has exerted substantial influence on our eventual perceptual judgments (Collins and Olson, 2014).

As the world around us rarely remains static, movement and speed perception are the pillars of our visual abilities. Strong interactions have been observed between visual modules concerning motion perception and areas involved in high-level object recognition, suggesting a synergic relationship between the two factors (Ramachandran et al., 1998). According to Shepard and Cooper (Shepard and Cooper, 1982), since the perceptual system constructs mental representation of constraints of objects’ movement that are coherent with real-world laws of motion and geometry, mental imagery should feature the same constraints as it is formed based on similar mechanisms. These constraints of real-world motion are applicable without regards to the situation in which the object is displayed, and are internalized as humans evolve in order to cope with incomplete visual representations due to occluded visual information. Consistent with Shepard’s idea, it has been demonstrated that semantic knowledge or internalized, intuitive physics constraints and mechanisms influence participants’ judgments in perceptual and cognitive tasks, particularly ones regarding motion perception (Vicovaro, 2012; Vicovaro et al., 2019).

An important and relevant aspect of movement and speed perception is temporal perception. It has been shown that symbolic meaning of objects, especially regarding speed and motion tendency, has an impact on temporal processing of stimuli (Mioni, 2015). In a series of experiments using the Ternus display, it was demonstrated that prior semantic knowledge of a frog movement tendency created a bias in the perception of element and group motion of stimuli representing frogs (Hsu et al., 2015). The effect of an object's symbolic meaning on time-to-contact has also been investigated. Vagnoni and colleagues studied the effect of semantic content on time-to-collision judgment by manipulating the threat value of a looming visual stimulus, and discovered that when faced with threatening stimuli (snakes and spiders), observers tended to underestimate its time-to-collision compared to non-threatening stimuli (Vagnoni et al., 2012). Regarding the object’s particular symbolic meaning of speed, Makin (2009) conducted a study showing that an object's typical velocity influenced motion extrapolation. In his experiment, participants were presented with a red target and a green target, which they then assigned a symbolic meaning to, with red target being slow and green target being fast. When performing a time-to-contact task, observers judged the green target as moving faster even when both targets moved at the same speed (Makin et al., 2009). Effects between the object's symbolic meaning of speed and time-to-contact estimates have also been observed in experiments using ecological stimuli, such as motorbike and bicycle (Battaglini and Mioni, 2019*)*.

1.3. Representational momentum

The term *representational momentum* was first used by Freyd and Finke (1984), as "a mental analogue to the momentum of a moving physical object." (Freyd and Finke, 1984). As an object moves with a consistent speed along a trajectory, it will gain momentum. Momentum is derived directly from the Latin root "momentum", meaning "movement, motion, alteration, change." In physics, it describes the impetus gained by a moving object, which is essentially how hard it is for the object to change its trajectory or come to a stop. When we attend to a moving object, we form a mental representation of it, including its characterizing features, and as it moves, our mental representation also moves. Similar to how an object has its physical momentum, our mental representation has representational momentum. Even when the object physically stops, our mental representation continues to shift along the direction of movement of the object, making us remember the stopping point further along the trajectory. This tendency is representational momentum.

Representational momentum is a type of memory distortion (Freyd, 1983; Freyd & Finke, 1984). When viewing a static image with implied motion, a person would memorize the image as it is moving along the implied trajectory, hence forming an incorrect mental representation about the final location of the object. In particular, after viewing static photographs with implied irreversible motion, subjects found it harder to reject distractors when they were photographs shot later chronologically than when they were photographs shot earlier chronologically (Freyd, 1983). This point is reinforced in another experiment by Freyd and Finke in 1984. Subjects were presented with a static rectangle at three orientations, and were instructed to memorize the last position of the rectangle in the sequence. They were then presented with a fourth orientation, and asked to indicate whether it was different from the third. When the fourth orientation was shifted in the same direction of rotation as the third, subjects had much more difficulty detecting the shift. These results suggest that people's memory of objects' location in a sequence of movements can be distorted by their perception of motion direction (Freyd and Finke, 1984).

While the stimuli used in Freyd and Finke's works utilized implied motion to induce representational momentum, similar forward displacement in memory of an object's location was also demonstrated using targets with continuous motion (Hubbard and Bharucha, 1988). After moving horizontally or vertically in a continuous, unidirectional motion, the target disappeared, and the observers were instructed to indicate the point of disappearance using a cursor on the screen. It was observed that observers had a tendency to place the cursor slightly ahead (along the axis of motion) of the actual point of disappearance, exhibiting a forward displacement of memory of the moving target's final location consistent with the concept of representational momentum.

Akin to representational momentum, which depicts a displacement in the direction of motion, comparable representational forces have also been observed. Hubbard (1995a, 1995b) noticed that forward displacement effect decreased when the target object was displayed as moving in constant contact with, or under an implied compressing force from a solid surface. He believed that this decrease in displacement was reflective of an increase in implied friction, a phenomenon he referred to as *representational friction.* The concept was consistent with Bertamini's (1993) observation, and has since received supporting evidence (Hubbard, 1998b; Kerzel, 2002b). Another connatural, perpetual, and universal force that undoubtedly has an influence on human life and general perception is gravity. Implied gravity, therefore, has also been considered to generate a similar displacement effect when observers are faced with a moving object. *Representational gravity* depicts a tendency to perceive moving objects as displaced downward along the axis of gravitational attraction. The phenomenon has been observed in both horizontal and vertical motion (Hubbard, 2020). This concept will be discussed more thoroughly in later sections.

Consistent with Shepard's hypothesis, as referred to previously, it is found that the magnitude of representational momentum generated has been shown to be affected by multiple aspects of the target's characteristics. Correlations between representational and physical momentum of the target object have been demonstrated. Freyd and Johnson (1987) conducted an experiment using a sequence of images with implied rotating motion, and within 30 ms after the last image was presented, participants' memory shifts were analyzed. The magnitude of the memory shift was found to be proportional to the implied velocity of the stimuli (Freyd and Johnson, 1987). There is also a consistent effect of the direction of motion on perceived displacement. Horizontal motion results in larger forward displacement than vertical motion, and descending motion results in larger forward displacement than ascending motion (Hubbard, 1990). Nagai et al. (2002) reported that objects that appeared to be receding generated larger displacement than approaching ones. Regarding the target's velocity, faster display velocity corresponds to larger forward displacement along the trajectory of movement (Freyd and Finke, 1985; Hubbard, 1990; Munger and Minchew, 2002). The effect of target's implied mass and size is also relevant, with larger size and larger implied mass leading to more tendency of downward displacement for vertically moving targets (Hubbard, 2005). This effect will be discussed in detail.

2. EXPERIMENT

2.1. Hypothesis

As the above findings have indicated, representational momentum is influenced by existing knowledge of an object's properties. One notable study that investigated this influence was Reed and Vinson’s 1996 study, in which they hypothesized that objects with different typical, real-world motions should produce different representational momentum effects. Four experiments were conducted to demonstrate this influence. In Experiment 1, two groups of participants were presented with a similar, ambiguous stimulus with an upwardly pointed head while receiving different instructions as to what the stimulus represented. The group that was told the stimulus represented a rocket (which has fast typical, real-world speed) showed greater representational momentum effect than the group that was told the stimulus represented a steeple (which has no typical, real-world speed). The effect was most noticeable when the stimulus moved in a direction congruent to the pointed head, which was upward. Experiment 4 was to replicate the general findings of Experiment 1, featuring a within-participant paradigm, and stimuli more resembling the real-world images of a rocket and a church. The rocket and the church had similar size: width = 1,3 cm; height = 2,3 cm. A group of participants were presented with the image of either a rocket or a church, which moved in one of the four directions: upward, downward, leftward, or rightward. It was found that the rocket induced a significantly larger representational momentum effect in comparison to the church, especially in the upward motion condition. The authors therefore concluded that when objects move in similar directions, especially ones that are congruent to their typical real-world motion, at a similar speed, the object with greater typical real-world speed would induce a greater representational momentum effect (Reed and Vinson, 1996).

The experiment featured in this thesis is aimed at replicating the result found in Reed and Vinson’s 1996 study “Conceptual Effects in Representational Momentum”, in particular that of Experiment 4. Similar stimuli were used - an image of a rocket to represent an object with fast typical real-world speed, and an image of a church to represent an object with no typical real-world speed. Regardless, a few changes were made in the experimental paradigm. First, the size of the stimuli used is larger than the ones used in Reed and Vinson’s study. Second, the stimuli were displayed with continuous motion, not in separate frames that indicated an implied motion. Third, only upward motion was investigated, instead of multidirectional motions as in the original experiment, for no significant difference between the two stimuli had been found for the implied downward motion (Reed & Vinson, 1996).

According to Reed and Vinson, because of the pre-existing knowledge that a rocket has an inherently larger speed than a church, when both objects are seen moving along the same trajectory with the same speed, the magnitude of representational momentum in the rocket condition is larger than the church. It is expected that a similar effect would be observed in my experiment. Similarly, I hypothesized that it is the pre-existing symbolic meaning of each object’s real-world motion that produces the difference in the perception of representational momentum.

2.2. Methods

Participants

24 participants took part in the experiment: 17 females and 7 males aged between 19 and 34 (mean age = 23,8). Participants were recruited using a variety of methods: online notices via social media, in-person requests made to friends and acquaintances, email requests sent to known addresses due to previous communication. All participants had normal, or corrected-to-normal vision. Gender was not an influencing factor considering the purpose of this experiment.

Participants were fully aware of the purpose of the experiment, and had given their informed consent in accordance with the Declaration of Helsinki. The informed consent form, approved by the Ethics Committee for Psychological Research (area 17), protocol n.4781, was read and signed in person by all participants prior to the beginning of the experiment

Stimuli

The stimuli were generated using MATLAB and the Psychophysics Toolbox (Brainard & Vision, 1997; Pelli & Vision, 1997), and were displayed on a 19-inch LCD Asus monitor with a refresh rate of 60 Hz. The screen's resolution was 1920 x 1080 pixels. The maximum luminance was 90 cd/m^2 for white background, and the minimum luminance was 1 cd/m^2. Participants were seated in a dark room, with the viewing distance from the display screen being approximately 57 cm.

The moving targets used were 2D, simplified images representing a church and a rocket (Figure 1). The images shared the same size: width = 4,4 cm, height = 7,4 cm.

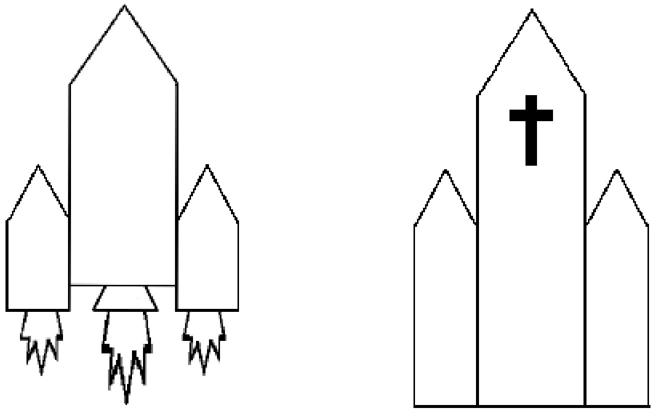
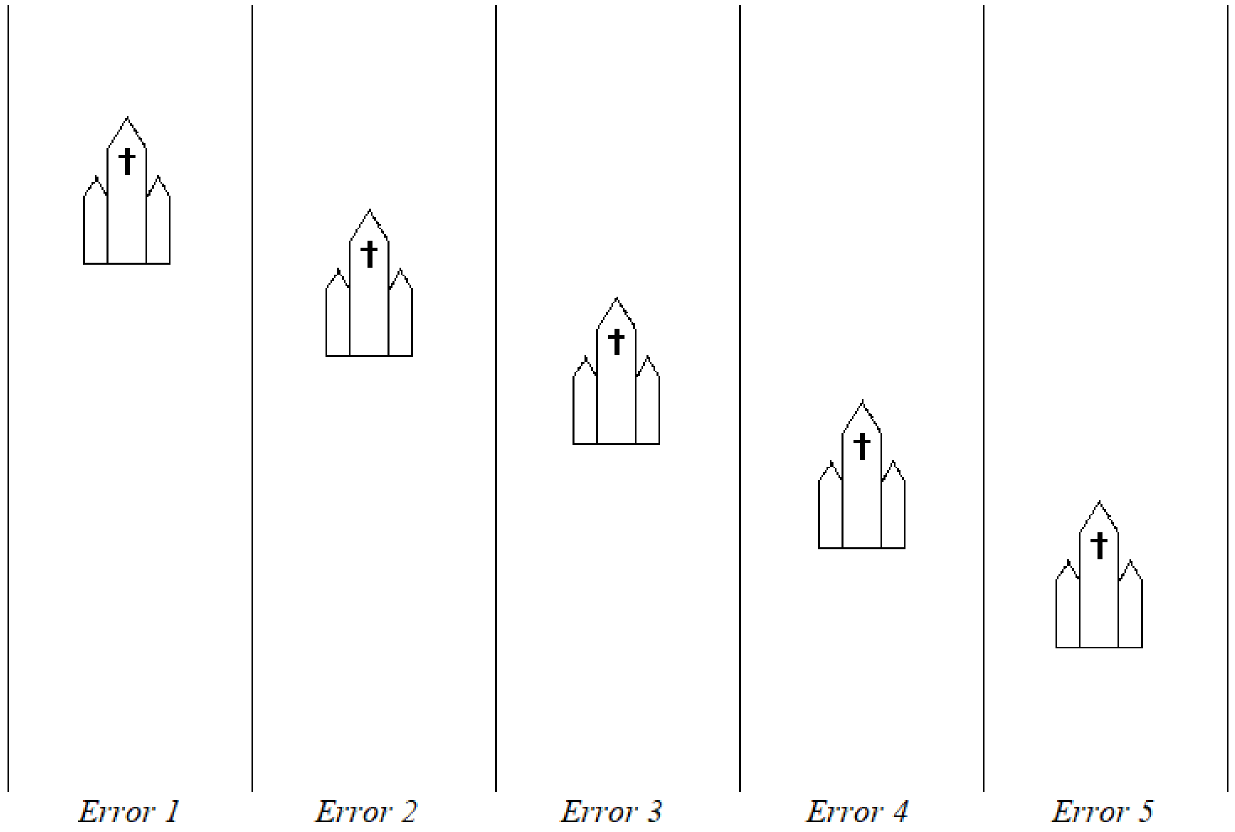


Figure 1. *Stimuli used in this study. They are 2D, simplified images of a rocket and a church (respectively). The images have similar size: width = 4,4 cm; height = 7,4 cm.*

At each trial, one of the two images appeared on the screen, and traveled in a continuous, vertical, upward motion, at the speed of 22,5 cm/s. After traveling for a certain distance, the image disappeared, then reappeared at one of the 5 points of errors in relation to the point of disappearance. The reappearance errors are numbered from 1 to 5, and are +0,74 cm, +0,37 cm, 0 cm, -0,37 cm, -0,74 cm respectively (Figure 2). '-' signifies that the reappeared position is below the point of disappearance along the upward vertical trajectory, while '+' signifies that the reappeared position is above the point of disappearance. Error 3 ('0') signifies that the reappeared position is the same as the point of disappearance.

Procedure

Each participant performed 250 trials. For each trial, they were instructed to observe the image as it moved vertically upward on the screen. The image could either be a rocket or a church. The image would disappear after traveling a distance, then reappeared again in one of the 5 errors. Participants performed a forced-choice task where they had to determine whether the reappeared image was more above or more below compared to the point of disappearance. They would indicate their choices using respective keys on the keyboard that represented "above" or "below" answers. No error feedback was given. A typical session lasted approximately 30 minutes.



Error 1	Error 2	Error 3	Error 4	Error 5
+0,74 cm	+0,37 cm	0 cm	-0,37 cm	-0,74 cm

Figure 2. *Stimulus' Errors, depicting potential points of reappearance. Error 3 (0 cm) coincides with stimulus' point of disappearance. Error 1 and 2 signify that the reappeared image is above the point of disappearance, at 0,74 cm and 0,37 cm respectively comparing to the point of disappearance. Error 4 and 5 signify that the reappeared image is below the point of disappearance, at 0,37 cm and 0,74 cm respectively comparing to the point of disappearance.*

2.3. Results

Mean proportion of “below” responses was calculated for each stimulus and each point of error. A summary is displayed below in Table 1. Accuracy was measured by the percentage of “below” response for Error 1 (-0,74 cm) and Error 5 (+0,74 cm). Participants with a less than 50% “below” response for Error 1 and more than 50% “below” response for Error 5 were eliminated from the final analyses to guarantee that any effects observed did not result from accidents or pure guessing. One participant was eliminated.

Mean proportion of “below” responses of Error 1 and Error 5 was calculated to determine whether participants were actively trying to answer as accurately as possible. The mean proportion of “below” response for Error 1 was 31% for the church, and 32% for the rocket, indicating that participants had more “above” (the accurate) responses. The mean proportion of “below” response for Error 5 was 70% for the church, and 67% for the rocket, indicating that participants had more “below” (the accurate) responses. These results show that participants were actively trying to maintain accuracy.

Mean proportion of “below” responses of Error 3 (0 cm) was analyzed to determine whether the representational momentum effect was present. Because Error 3 means there was no difference between the point of reappearance and disappearance, if representational momentum effect was present for both stimuli, there would be a forward displacement in the memory of the point of disappearance, and the observer would perceive the reappeared image as below the point of disappearance. This means that more “below” than “above” responses needed to be produced to be able to conclude that representational momentum effect was present. Contrary to my expectation, for both church and rocket stimuli, the mean proportion of “below” responses were lower than 50% (49,2% and 42,4%, respectively). These results suggest that with this experimental paradigm, representational momentum effect was not present for both stimuli.

	Church_1	**Church_2**	**Church_3**	**Church_4**	**Church_5**
Mean	0,313	0,367	0,492	0,546	0,704
ds	0,147	0,133	0,14	0,142	0,149

1.1. Church

	Rocket_1	**Rocket_2**	**Rocket_3**	**Rocket_4**	**Rocket_5**
Mean	0,323	0,351	0,424	0,565	0,674
ds	0,156	0,152	0,138	0,149	0,13

1.2. Rocket

Table 1. *Mean proportions of "below" responses in each Error condition for church stimuli (1.1) and rocket stimuli (1.2).*

An Object Type (rocket, church) x Errors (1, 2, 3, 4, 5) Analysis of Variance (ANOVA) was performed. The analysis yielded a significant effect: $F(4, 88) = 2.538$, $p < 0.05$, partial eta squared = 0.103. These results suggest a notable interaction between the object type and the error. Post-hoc Bonferroni corrected t-test returned $t = 2.69$, $p < 0.01$, Cohen's $d = 0.487$. Figure 3 shows a disparity in the mean proportion of "below" responses between rocket and church stimuli in Error 3, which is absent in the remaining 4 errors. In Error 3, the mean proportion of "below" responses for the rocket (42,4%) is lower than the mean proportion of "below" responses for the church (49,2%) These results revealed that in Error 3, participants gave more "below" responses when the stimulus was a church in comparison to when it was a rocket.

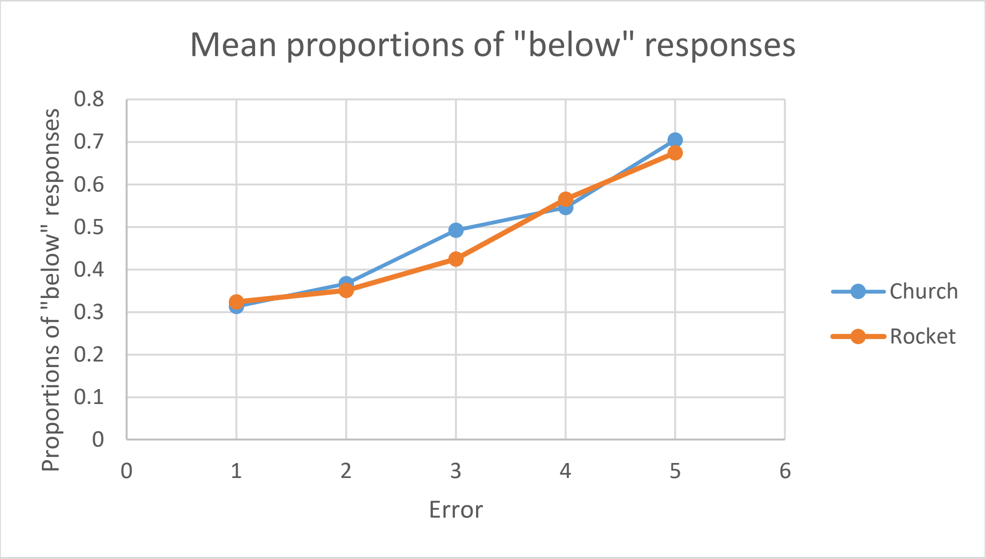


Figure 3. *The graph shows the mean proportions of "below" responses for both stimuli church and rocket. In Error 3, where the image reappeared at the same location where it had disappeared, the mean proportion of "below" responses for rocket is lower than that of the church condition. In Error 3, participants tended to perceive the reappeared image of the church to be more below the point of disappearance than that of the rocket.*

Overall, no representational momentum effect was found. At the same time, participants showed less displacement in memory of the location of the rocket than that of the church. These findings are inconsistent with Reed and Vinson's original study.

3. DISCUSSION

There are two notable points drawn from the results. First, no effect of representation momentum was observed for both stimuli, in contrast to the strong effect present in Reed and Vinson's 1996 study. The major difference in stimulus size is theorized to account for this disparity in the observed effect. Larger stimulus size may have led to targets being perceived as heavier, thus under a stronger influence of an implied gravitational force. Relating to the concept of *transposition principle*, larger stimulus size could correspond with a slower perceived target velocity, which may have led to less representational momentum effect. Second, an effect between object type and perceived displacement was found for Error 3, showing that when both stimuli (rocket and church) reappeared in the same position, the rocket condition showed an underestimation tendency. This, again, contradicts the effect observed in Reed and Vinson's study, where the object's typical speed was positively correlated with its perceived displacement. To account for the observed phenomenon, the concept of *expected-speed violation illusion* was discussed.

3.1. Difference in stimulus size

Though there has been conflicting evidence as to whether or not target size affects representational momentum in general, arguments are in favor of the existence of this effect in conditions where motion is displayed along the axis of implied gravitational attraction (Hubbard, 1997; 2005). In the 1997 study, Hubbard investigated the effects of target size and implied mass on displacement. It was found that for vertically moving targets, target size had an effect on displacement, but only along the axis of motion. He argued that this effect was due to the fact that the object was moving along the axis aligned with gravitational attraction, therefore the perception of its movement was subjected to a concept termed *representational gravity.* This idea will be explored in more detail. Additionally, similar effects were observed by Kozhevnikov and Hegarty (2001), in an experiment where participants were presented with ascending targets varying in size across trials. They found that larger ascending targets generated no representational momentum effect, while smaller targets did. Hubbard summarized this pattern in his 2005 review: "effects of target size are exhibited only along the axis aligned with implied gravitational attraction." In particular, when objects are presented as moving vertically upward, mental representation of larger objects will be situated lower than that of smaller objects.

Upon solely visual inspection, larger objects are perceived as being heavier (Koseleff, 1957). The experience of heaviness is induced by the weight of the object, or more accurately, as Koseleff stated, “the naive realistic attitude that the experienced heaviness is identical with the physical weight.” An object’s momentum is directly proportional to its mass, as it is defined by the product of its velocity and mass. As stated previously, mental representations are heavily influenced by subjective experience of real-life physical constraints, therefore, it is reasonable to believe that representational momentum of an object is affected by its implied velocity and mass. Given the evidence, displacement is only affected by target size if it is displayed along the gravitational axis. This pattern suggests that displacement is influenced by implied weight rather than implied mass of the object. Weight of an object is a measure of gravitational force exerted on that object, while mass is defined by the amount of matter contained in the object. Regardless, mass and object are proportional, and as we all experience gravitational attraction similarly on Earth, weight and mass are interchangeable concepts in our daily lives. In his 1997 study of the effects of implied weight on memory displacement of targets, Hubbard proposed that the involvement of weight in the perception of displacement meant that our representational system employed our subjective experience of physical principles. In the experiment described in this thesis, the stimuli used are significantly larger in size than the ones used in Reed and Vinson’s 1996 study. It is reasonable to assume that not only did observers perceive this experiment’s stimuli to be larger, they also perceive them to have larger weight. The difference in perceived weight could therefore be of relevance in explaining the difference in the perceived displacement.

Hubbard (1990, 1995b, 1997) proposed the concept of representational gravity to describe the effect of implied gravity on the perception of moving objects. The idea that the perception of an object’s movement is affected by the forces, or implied forces, exerted on it is not foreign in the study of perceptual displacement in general and representational momentum in particular, and gravitational forces has been investigated as one of such forces. A tendency of the memory of moving object’s to be displaced along the direction of the Earth’s gravitational pull has been demonstrated in many studies. For rotating stimuli, it has been discovered that larger forward displacement was generated when the stimulus rotated downward rather than upward (Munger et al., 1999; Munger and Minchew, 2002; Munger and Owens, 2004). For horizontal motion, objects have been found to be displaced along a parabola towards the implied gravitational pull (Hubbard and Bharucha, 1988; Hubbard, 1990; Kerzel et al, 2001). However, the effect of implied gravity on the perception of an object's movement is demonstrated most markedly in paradigms using vertical motion (Hubbard and Bharucha, 1988; Kozhevnikov and Hegarty, 2001; Nagai et al., 2002; Hubbard, 2020), showing a trend of larger forward memory shift in the direction of gravity. Hubbard and Bharucha (1988; Hubbard, 1990, 1997) found that forward displacement was larger when the target descends than when it ascends. Hubbard (2001) also reported that targets with longer descending distance and shorter ascending distance generated a larger forward displacement effect than targets with shorter descending distance and longer ascending distance (Hubbard, 2001). He attributed this phenomenon to the fact that as physics principles dictate, gravity accelerates descending objects and decelerates ascending objects (Hubbard, 2005).

Given that weight is the measure of gravitational force, objects with larger weight means the gravitational force on it is larger. If we abide by the line of thinking that our mental representation is congruent with our subjective experience of real-life physical constraints, a mental representation of an object with larger implied weight will experience larger implied gravitational force. Hubbard (1995b) suggested an interaction of representational gravity with representational momentum in vertically moving objects, conceptualizing it as a relationship of summation. In descending motion, the representational gravity and representational momentum sum, thus creating large forward displacement. In ascending motion, however, representational gravity and representational momentum are two opposite representational forces, they cancel each other out. Considering the relationship of summation between two forces, as the targets ascend, meaning the representational momentum operates in the opposite direction to the representational gravity, the larger implied gravitational force would lead to smaller forward displacement effect.

Another account for the possible effect of stimulus size on the perceived displacement requires the application of *transposition principle* in visual motion (Brown, 1931). According to this principle, the perceived speed of a moving object varies according to its size and the size of the spatial framework within which it moves. Given that other physical parameters are equal, the bigger the size of the moving object and its framework, the slower its perceived speed. This phenomenon has been demonstrated in many subsequent studies on motion and speed perception (Epstein and Cody, 1980; Sokolov et al., 1997). Since the targets used in the experiment featured in this thesis have significantly larger size than the ones featured in Reed and Vinson's study, it is possible that the participants perceived them to have slower speed.

The effect of target velocity on representational momentum has been featured in previous studies (Freyd and Finke, 1985; Finke, Freyd, and Shyi, 1986; Hubbard, 1990; Munger and Minchew, 2002). Freyd and Finke (1985) investigated the velocity effect for representational momentum using rectangular stimuli presented in implied rotating motion with varying implied speed. They found that the magnitude of the memory shift is a function of the target's implied speed, with faster implied speed corresponding to larger forward displacement. Similar effect was observed for horizontal and vertical motion (Hubbard, 1990). It has also been reported that the magnitude of representational momentum effect increased when targets accelerated, and decreased when targets decelerated (Finke, Freyd, and Shyi, 1986). However, this effect is only maintained in certain conditions. It is diminished when implied friction is present, when the motion of the target is generated upon contact with another object, when the target moves at high speed, and when it is impossible to track. Regardless, since the aforementioned conditions are not present in this thesis' experiment, this effect is maintained. If the observers perceived our targets to have slower speed, and the effect of speed on representational momentum holds true, the magnitude of perceived displacement for our experiment is much smaller than the one observed in Reed and Vinson's study.

3.2. Expected-speed violation illusion

Expected-speed violation illusion is a phenomenon termed by Battaglini and colleagues in their 2021 study “Probing the effect of the expected-speed violation illusion,” which investigated the influence of the symbolic meaning of speed on the perception of speed itself. In other words, the study provided insights into how our prior knowledge and experience of an object’s real-world typical speed affect our perception of its speed. Two lines of hypothesis were formulated, the first concerning the Bayesian account of perception, the second drawing from an *anti-Bayesian* bias (Brayanov and Smith, 2010) analogous to the phenomenon of size-weight illusion (Buckingham et al., 2014).

Bayesian approach to perception considers the human mind to be “a Bayesian prediction machine” (Battaglini et al., 2021), where perception is inferred from sensory evidence gathered from prior perceptual experiences the same way as a probabilistic conclusion is reached. Regarding aspects of speed perception, previous research has shown that acquired expectations about the world can have an effect on speed encoding (Stocker and Simoncelli, 2006) and time perception (Mioni et al., 2014; 2018). According to the Bayesian account, our accumulated knowledge and expectations of speed influence our perception of speed itself. Therefore, considering this study, a Bayesian observer should expect the archetypical slow vehicle to move at the speed exceeding that of the archetypical fast vehicle, in order to perceive both vehicles to have equal speed.

The second hypothesis was formulated on the basis of expectation violation, analogous to the concept of size-weight illusion. When participants are asked to lift two objects of identical shape, identical material, and have identical weight, they usually perceive the visually smaller one as heavier (Buckingham et al., 2014). The illusion is called an *anti-Bayesian* bias (Brayanov and Smith, 2010), for it does not fit with the Bayesian model of perception, in which the perception should be the product of the accumulated expectation, not the opposite. Translating this phenomenon to speed perception, when presented with two vehicles moving at the same physical speed, observers would perceive the archetypical slow vehicle to be faster than the archetypical fast vehicle. This would reflect a violation of the prior expectation of the objects’ speed.

6 experiments were conducted, using varying sets of stimuli, each containing two images representing objects with archetypically fast speed (e.g. a motorbike) and with archetypically slow speed (e.g. a bicycle). Participants’ point of subjective equality was measured in a two-interval

forced choice speed judgment task. As a result, a consistent bias was observed in participants' speed perception, where the archetypically fast vehicle was perceived as traveling slower when presented with the archetypically slow vehicle traveling at the same physical speed. The authors considered this illusion to have arisen when structural expectation was broken, similarly to what was discussed in the second hypothesis.

Regarding the experiment in this thesis, an effect between object type (rocket and church) and perceived displacement was found, suggesting that their symbolic meaning of speed had an effect on the underestimation tendency observed in the rocket. This result is congruent with the phenomenon arising from expected-speed violation illusion, and by extension, demonstrating the similar breach of expectations in size-weight illusion. An attempt to explain size-weight illusion in a Bayesian framework showed that the perceived effect might be due to the inferred density of the object, which reflected its mass rather than its weight (Peters et al., 2016). It can be argued that a similar explanation may exist for the phenomenon in this thesis, meaning that the underestimation tendency seen in the rocket might not be due solely to its symbolic meaning of speed. However, both stimuli were minimal representations of their real-world model, with near-identical shape and identical size. Therefore, whatever the unaccounted for factor may be, it is not apparent.

A similar reverse effect was found in a prediction motion task, where stimuli codified as having slower speed corresponded with shorter time-to-contact estimation when they moved at speed larger than approximately 10 deg/s (Battaglini and Mioni, 2019). In this thesis, the stimuli were displayed at the speed of 22.5cm/s (which is 22.5 deg/s), thus it is possible that the phenomenon observed here resembles that of Battaglini and Mioni’s study. The authors also found an effect of symbolic meaning of speed. They believed that a cognitive elaboration must be made in order for the object’s symbolic meaning to influence judgment regarding its time-to-contact. However, this process was time consuming, therefore, it could not be utilized with lack of time (when stimuli moved at high speed). Instead, an erroneous perceptual judgment occurred. When object with expected slow speed moved fast, observers’ expectations of its speed were violated, leading to them overestimating its time-to-contact compared to the object with expected fast speed. In our experiment, observers’ memory of the expected fast object (the rocket) was shifted downward along the trajectory of movement, meaning that it was underestimated compared to the expected slow object (the church). This erroneous perceptual judgment could reflect a compensation mechanism, utilized when elaborated cognitive processes could not be made to make up for the anticipated potential mistakes in judgments. However, to my knowledge, the existence of such mechanism is subject to further investigation.

3.3. Continuous motion display

In this experiment paradigm, stimuli were displayed as moving continuously, instead of in sequences of static images as in Reed and Vinson's study. Though representational momentum has been observed using both continuous and implied motion paradigms, there is evidence that the nature of the motion might influence the degree of displacement. Poljansek (2002) found that the type of motion affected the perception of displacement differently when the target accelerated or decelerated. In his 2003 study, Kerzel presented participants with a target moving along a circular trajectory. The interstimulus intervals were varied (ISIs), with shorter ISIs creating an effect of more continuous motion. He reported that shorter ISIs correlated with smaller forward displacement effect, meaning that the perceived displacement was smaller as the object's motion became more continuous. Regardless, evidence is insufficient to account for the disparity in results between Reed and Vinson's study and the one described in this thesis. Faust (1990) found an opposite effect than the ones described using horizontally moving targets, which showed that forward displacement was larger when the target was displayed with continuous motion. Additionally, there is also data showing that implied motion and continuous motion generate equal displacement effect (Munger & Owens, 2004). Hubbard concluded in his 2005 review that the type of motion did not have a discernible effect on the perception of displacement. Therefore, the difference in the nature of displayed motion cannot be concluded as accounting for the absence of representational momentum effect in this study.

4. CONCLUSION

This study aimed to replicate the results found in Reed and Vinson's 1996 study "Conceptual Effects on Representational Momentum," which discovered that pre-existing knowledge of an object's typical speed affects the magnitude of representational momentum. Using similar stimuli as Reed and Vinson's Experiment 4, with a rocket representing an object with fast real-world typical speed, and a church representing an object with no real-world typical speed, I expected to observe representational momentum in both experimental conditions. Consistent with the findings in the original study, the rocket should generate larger displacement effect than the church, and this disparity should be due to observers' difference knowledge of each object's symbolic meaning of speed. However, the results observed in this study contrasted the original expectation.

First, no representational momentum effect was observed for either stimulus. I attributed this absence to the increased stimulus size in my experiment in comparison to the ones used in Reed and Vinson's study, in particular, to how stimulus size affects the perceived gravitational pull in vertical upward motion, and how stimulus size affects the general perceived speed of motion. It has been proposed that mental representation of moving objects is under the influence of implied forces similar to the one that drives representational momentum, one of such forces being implied gravity, which gives rise to the phenomenon of representational gravity. This phenomenon is most markedly seen in vertically moving objects, which is along the typical trajectory of real-world gravitational pull. As weight is the direct measurement of the strength of gravitational pull on an object, and an object size is indicative of its weight, representational gravity has been shown to be influenced by object size. In particular, in ascending motion, objects with larger size generate less forward displacement effect in the direction of movement due to the influence of an implied gravitational force exerting on the object in the opposite direction. Therefore, the increased stimulus size in my experiment may have led to targets being perceived as being under larger gravitational pull, hence the reduced displacement effect. Additionally, stimulus size has been shown to affect speed perception, with visually larger objects being judged to move slower, according to the transpositional principle in visual motion. Given that slower perceived speed has been observed to generate less displacement effect in representational momentum research, it is fair to conclude that the absence of representational momentum effect in my study can be due to increased stimulus size.

Second, the rocket (representing objects with fast real-world typical speed) generated less displacement effect than the church (representing objects with no real-world typical speed). This observation is in direct contradiction with Reed and Vinson's work, which found that faster real-world typical speed led to larger representational momentum effect. However, an effect of oject type was still observed in my study, which means that participants' semantic knowledge of the object displayed still influenced their perception of its movement. In an attempt to account for this effect, I drew on the concept of expected-speed violation illusion (Battaglini et al., 2021), particularly on how the observer's expectation of an object's typical speed may lead to a perceptual judgment that violates that initial expectation. A similar effect was observed in a time-to-contact estimation paradigm, which the authors proposed to be the result of an erroneous perceptual judgment overriding the time-consuming cognitive elaboration normally taking place to connect object's symbolic meaning to its real-life movement (Battaglini and Mioni, 2019).

The study featured in this thesis provides additional evidence for the influence of object's symbolic meaning on the perception of its movement in particular, and of pre-existing semantic knowledge on perception in general. It also supports the existence of the expected-speed violation illusion phenomenon, and of the variety of directions in which symbolic meaning can influence perception. Additionally, the effect of observer's experience and expectation of real-world physics on the construction of mental representations of movement is reflected through the potential impact of implied gravitational force. Nevertheless, an experimental design identical to that used in Reed and Vinson's 1996 study should be conducted to re-evaluate the observations found in my study. The effect of stimulus size and gravitational force remains to be further investigated, perhaps in a within-participants paradigm. Expected-speed violation illusion and similar observations as in my study suggest that there possibly exists a perceptual compensation mechanism in high-velocity display conditions, where connections between the object's symbolic meaning and movement have yet been made. This phenomenon in general and its underlying mechanism in particular should be an intriguing topic of future studies.

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