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Are onscreen cursor movements influenced by the Ebbinghaus illusion? Exploring perception–action interaction in a virtual environment

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Abstract

The Two-Visual-Streams Hypothesis (TVSH) of vision proposes a functional separation between the perception of a visual stimulus and the control of visually guided action toward that stimulus. This study tested whether the separation of perception and action proposed by the TVSH is also demonstrated when executing visually guided cursor movements toward onscreen targets. Participants used a trackpad to click onscreen circular targets embedded within the Ebbinghaus ("Titchener Circles") illusion and were thus perceived as either larger or smaller than their true size. Participants were more accurate when clicking on the perceived larger target compared to the perceived smaller target, indicating their performance was influenced by their perception of target size (Experiment 1). There was no effect of the illusion when visual feedback of the target was removed at the beginning of the trial (Experiment 2) or removed following a 2-second target-viewing period (Experiment 3). Conclusion: The perceptual features of an onscreen stimulus mediate the guidance of cursor movements toward visible targets. Illusion-based perceptions of target size do not affect actions toward disappeared targets, however. These results contribute to the theoretical principles of the TVSH by testing its predictions in a novel onscreen environment.

Keywords

human–computer interaction, cursor accuracy, two-visual-stream hypothesis (TVSH) of vision, size perception, Fitts's law

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Public Significance Statement: Participants' visually guided cursor movements were influenced by the Ebbinghaus illusion. Accuracy was improved when clicking on targets perceived as larger than their true size compared to clicking on targets perceived as smaller; however, there was no effect of the illusion when the target disappeared prior to cursor movement. This study elaborates on the environmental contexts in which the perceptual features of a stimulus influence visually guided interaction and can inform how on-screen stimuli are designed and presented to the user.

Introduction

The two-visual-systems hypothesis (TVSH) of vision proposes a functional distinction between a "vision-for-perception" system, dedicated to processing the perceptual features of a stimulus, and a "vision-for-action" system, dedicated to processing visual information in the support of visually guided action toward that stimulus, such as when reaching toward it and grasping it (Goodale & Milner, 1992). Visual information associated with the processing of the object's "higher order" perceptual features travels from the primary visual cortex (V1) in the occipital lobe to regions of the inferotemporal cortex by way of the ventral (or, "What") stream of processing. This processing contributes to the mental representations of that object, facilitating its conscious perception. According to the TVSH, the computations that serve actions such as reaching toward and grasping an object rely on a set of functionally separate processes within our "vision-for-action" system, associated with the dorsal (or, "How") stream, originating in V1 and terminating in the parietal lobe. Though functionally separate, extensive communication between these two systems is critical for our ability to meaningfully interpret incoming visual information and successfully interact with our environment.

The separation of "perception" and "action" proposed by the TVSH predicts that stimulus presentations that influence a person's conscious perception of a stimulus may not have an equivalent effect on their visually guided action toward that stimulus, as each of these behaviors is allocated to their respective processing streams. For example, one may predict that if a stimulus is misperceived as larger or smaller than its veridical size—as is the case of certain visual illusions such as the Ebbinghaus or "Titchener circles" illusion (Figure 1)—this perceptual adjustment would not be expected to influence participants' movements toward that stimulus. Rather, the calculations performed by the dorsal stream will be fine-tuned to the true size of the stimulus, as this information is critical for effective interaction. Numerous studies demonstrate this result; when presented with an object embedded within a visual illusion, participants who misperceive the object as being smaller or larger than its true size produce anticipatory in-flight grip scaling that is nevertheless appropriately tuned to the true dimensions of the object rather than the perceived size when grasping it, suggesting that the dorsal stream's generation of visually guided action is immune to perceptual influences (Aglioti et al., 1995; Danckert et al., 2002; Haffenden & Goodale, 1998; Marotta et al., 1998; Whitwell et al., 2023; but see Bruno & Franz, 2009; Franz, 2001; Franz & Gegenfurtner, 2008; Pavani et al., 1999 for arguments in favor of a perceptual influence on grasping).

These studies suggest that the dorsal stream relies on closed-loop feedback to perform visually guided action. In contrast, paradigms involving open-loop movements toward target stimuli have produced an increased illusory effect on guided action. In these studies, visual feedback of the target is removed, and participants are required to rely on their perceptual representation of the target's shape and position to perform the task. These perceptual representations, which rely on processing within the ventral stream, appear to be susceptible to illusory influences, such that when the object is embedded within an illusory context, open-loop grasping is affected by the illusion (Carther-Krone et al., 2020; Westwood & Goodale, 2003; Whitwell et al., 2018). This increased susceptibility to illusory influence in the absence of vision has been demonstrated in other types

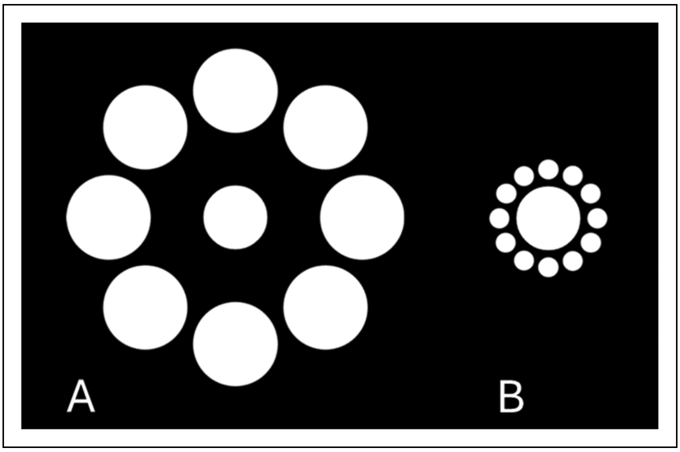


Figure 1. The Ebbinghaus (Titchener circles) illusion. The circles in the middle of each arrangement are veridically the same size, despite appearing as smaller on the left (A) and larger on the right (B). A surrounding annulus of large and distant circles decreases the perceived size of the center circle (A), while a surrounding annulus of small circles in close proximity increases the perceived size (B).

of aiming movements as well, such as tapping (Alphonsa et al., 2016; Meegan et al., 2004) and pointing (Fischer, 2001). These studies suggest that when visual feedback of the target is absent, participants rely on their perceptual representations, i.e., memory, of the disappeared target to guide their movements. As these representations are susceptible to illusory influences, the movements that are produced are also likely to be biased by the illusory context in which the target is presented.

An increasing amount of our behavior involves some form of human–computer interaction (HCI), whether it be controlling the cursor on a computer screen with a mouse or laptop trackpad or using touchscreen devices such as our smartphones and tablet devices. An interesting variation on the classic study of perception–action interactions is to explore how these behaviors are influenced by the onscreen virtual environment in which they occur, in comparison to the traditional reaching and grasping experiments utilizing three-dimensional objects. This question has implications for website design and graphical user interfaces (GUIs), human factors studies of HCI, and other virtual applications involving manual navigation and interaction within a virtual environment.

For example, consider the act of using a laptop trackpad to direct the movement of an onscreen cursor toward a virtual target (e.g., a folder on the desktop). The proximal movements of the finger on the trackpad control the onscreen presentation of the cursor, while the perception of the cursor's onscreen movement provides feedback about its position, the distance and direction it needs to travel to reach its desired position, as well as allowing for corrections if necessary. In many ways, controlling an onscreen cursor resembles other "real-world" actions such as grasping a coffee cup; effector movement is guided by visual feedback of the target's position and relevant features, and this online sensory information is used to update the movement of the hand when necessary to ensure the task is performed accurately. A key difference in this case is the increased perceptual nature of the feedback source relied upon to guide the movement. In natural reach-to-grasp actions, control is represented within an egocentric "body-relative" reference frame, in which the hand is guided directly to the target object. Visual, proprioceptive, and haptic feedback are integrated to support the necessary online corrections that align the spatial and temporal aspects of the movement to the target within the same spatial plane. According to the TVSH, this control of visually guided action is performed directly by the dorsal "vision-for-action" pathway, which is tuned to the immediate physical properties of the object. In contrast, the control of an onscreen cursor, which serves as a virtual representation, or "user representation" (Seinfeld et al., 2020), of the hand in the alternate spatial plane of the display, requires transforming egocentric finger movements on the trackpad into a spatially disparate, "scene-relative" reference frame within the onscreen environment, occurring in a different plane than that of the finger movements. This visuomotor transformation necessitates an increased reliance on perceptual processing within the ventral "vision-for-perception" pathway to accomplish the required spatial realignment between the direct finger movement and indirect movement of the cursor.

The frequency at which we perform this kind of behavior, as well as its similarity to other, more natural visually guided actions, raises the question of whether the predictions made by the TVSH apply to the visually guided control of onscreen cursor movements. In other words, to what degree is the physical act of moving the finger on the trackpad mediated by the perceptual features of the onscreen environment? Due to the highly perceptual nature of the task, we may expect a significant influence of perception on action, such that the cursor movements will be determined by the perceptually relevant information such as the perceived size of a to-be-clicked target, rather than action-relevant information such as the veridical size of that target. Accordingly, we may ask if removing the visual feedback of an onscreen target will increase illusion susceptibility, as has been demonstrated in traditional perception-action studies. Exploring questions that test the predictions of the TVSH in nontraditional circumstances serve to further elucidate the contexts in which these predictions are supported or proven false, and in doing so, contribute to the basic theoretical framework of the TVSH.

To date, there are a limited number of studies exploring how the perception of an onscreen stimulus influences people's cursor movements towards that stimulus. Phillips et al. (2024) recently demonstrated that cursor movements toward graphical images of coffee cups are influenced by the presentation of the images. Specifically, participants' cursor placement differed as a function of the size of the cup, whether it was presented as empty or full, and the directional compatibility of the handle. These stimulus features may be expected to influence physical grasping movements, but perhaps not cursor placement on a two-dimensional display. Additional studies, however, provide evidence suggesting that cursor movements, like real-world movements, are in fact resistant to perceptual features of a stimulus. For example, work by Janczyk et al. (2013) demonstrated that while participants' perceptual judgments of an onscreen target's size were influenced by irrelevant stimulus dimensions such as height and width (i.e., Garner-interference), their cursor movements were unaffected. Currently, more research is necessary to determine if and in which contexts cursor movements are susceptible to the perceptual features of the virtual environment in which they occur.

Langridge and Marotta (2022) performed a related investigation in which participants used finger movements on a laptop trackpad to control an onscreen cursor. Participants were required to use their cursor to click onscreen circular targets embedded within the Ebbinghaus illusion, such that the target was perceived as being smaller or larger than its true size. In that study, participants' perceptual size judgments of the targets were influenced by the illusion; however, their accuracy and speed when clicking on the targets did not differ as a function of perceived size, suggesting that visually guided cursor movements are resistant to perceptual influence. This was the case even when participants were encouraged to prioritize either speed or accuracy when performing the task. The illusory presentation did appear to influence the frequency at which participants "corrected" the direction of their cursor movement as they approached the target. More directional changes were made when clicking on the perceived large presentation (Figure 1B) of the target in comparison to the perceived small presentation (Figure 1A). Langridge and Marotta (2022) argued that this difference may in fact demonstrate a subtle effect of the illusion, such that cursor movements toward a target perceived as larger than its true size may be less accurate, and therefore require more corrections, in comparison to movements directed toward a target perceived as smaller than its true size. Ultimately, the number of directional changes did not appear to influence click-point accuracy or movement time in that study, however. Those results, together with the results of Janczyk et al. (2013), suggest that visually guided cursor movements are mostly unaffected by the perceptual features of the onscreen environment, similar to how real-world grasping movements do not appear to be influenced by the perceptual features of the stimulus being grasped.

It is important to note that participants in the Langridge and Marotta (2022) study participated remotely and performed the task using their personal computers, and these methodological details should be considered when interpreting the results of this study. For example, it is unknown to what degree participants paid attention to the task during participation. Additionally, because participants performed the task on a wide range of devices, screen sizes, and screen resolutions, the visual presentation of the illusory stimuli varied across participants. The intensity of the illusion is known to scale with the size of the stimulus, such that an increase in stimulus presentation is associated with an increase in the magnitude of the illusion (Knol et al., 2015; Massaro & Anderson, 1971). This inconsistency in stimulus size may have meant that some participants were presented with more powerful illusory presentations than others. This decreased experimental control may have weakened the internal validity of these results, warranting an attempt at replication under stricter experimental conditions. As such, the first objective of the current study is to perform an in-laboratory replication of the Langridge and Marotta (2022) study to confirm the previous results under conditions benefitting from higher experimental control (Experiment 1). Our second objective is to test if the Ebbinghaus illusion influences participants' cursor movements when the perceptual nature of the task is increased, by requiring participants to perform the task without visual feedback of the target (Experiments 2 and 3).

Experiment 1

Method

Participants. An a priori power analysis was conducted using G*Power (Version 3.1.9.2) to determine the minimum required sample size for a one-way repeated measures analysis of variance (ANOVA) design with five within-subject experimental conditions. A minimum sample size of 23 participants was determined using the following input parameters: alpha = .05, desired power = .90, and an effect size of $\eta_p^2 = .07$. This particular effect size was chosen as it was the smallest effect size observed for the variables of interest in Experiment 1 of Langridge and Marotta (2022). An initial 32 undergraduate psychology students were recruited through the Psychology Department Undergraduate Participant Pool at the University of Manitoba and participated in exchange for course credit. The data of six participants in total were excluded: Three participants were excluded due to issues during data collection that produced unusable data, two participants were excluded because their average movement times were consistently greater than two standard deviations above the average of the group, and one participant was excluded because their average number of directional changes were consistently greater than two standard deviations above the average of the group. For the remaining 26 participants, the age ranged from 16 to 44 years (M = 23.00 years, SD = 6.35). Fifteen participants reported their sex assigned at birth as female, while the remaining 11 participants reported their sex assigned at birth as male. Participants reported having either normal vision (n = 11) or corrected-to-normal vision, for example, wearing glasses or contact lenses, or having had corrective eye surgery (n = 15). Participants were all right-hand dominant, as determined by a modified version of the Edinburgh Handedness inventory (Oldfield, 1971). Critically, all participants reported using their right hand to control the cursor when using a computer. This research was approved by the University of Manitoba Research Ethics Board, Fort Gary Campus. Informed consent was obtained from each participant.

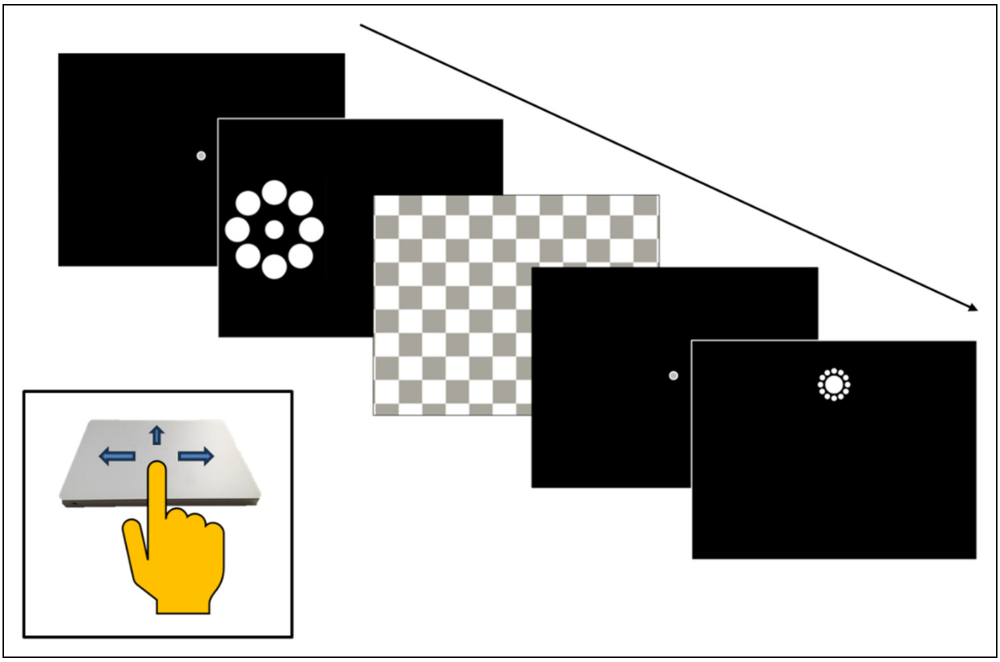
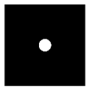
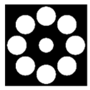
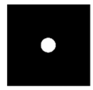


Figure 2. Examples of two experimental trials, separated by a 200 ms mask. The experimental target appeared once participants clicked the start button. Clicking on the experimental target ended the trial.

Materials. Participants were seated at a desk in a height-adjustable chair facing a 27-inch Retina 5K iMAC computer monitor (resolution: 5,120 × 2,880, device-pixel-ratio: 2, and refresh rate: 60 Hz). Participants' chins were stabilized in a chin rest attached to the edge of the table, positioned 40.5 cm away from the screen. At this distance, the entire monitor screen accounted for 91.61° (width) and 62.96° (height) of the participants' viewing angle. A 16.0 cm wide by 11.5 cm deep Apple Magic Trackpad (Apple Inc., Cupertino, CA, USA) was placed on the tabletop at a position aligned with the midsagittal axis of the participant, with its closest edge positioned 23.5 cm from the front edge of the desk. Participants used this trackpad to control the onscreen cursor using either the index finger or the middle finger of their right hand. They were free to use either finger; however, they were required to use the same finger for the duration of the experiment. The experimental interface and onscreen stimuli were constructed using lab.js (Henninger et al., 2021). The onscreen cursor appeared as a "crosshair" to ensure accuracy and avoid any biases encouraged by the traditional directional arrowhead pointer (Phillips et al., 2001, 2003).

Procedure. The experimental procedure is presented in Figure 2. Each trial began with the presentation of a "start button" presented in the center of the screen, and one of the five target stimuli (Table 1) positioned at one of four possible onscreen locations: either 9.5 cm to the left, right, above, or below the screen's center. The specific stimulus and its onscreen position were determined randomly ahead of each trial using blocked sampling without replacement. Participants began each trial by using the cursor to click the start button. Once participants clicked the start button, it disappeared, and participants were required to move their cursor and click on the center of the target stimulus "as quickly and accurately as possible." The circular onscreen target represented the only "clickable area" on the screen. Any click-points outside of the defined region were not registered. Clicking on the target stimulus ended the current trial. The following trial was preceded by a

Table 1. Target stimuli.

Target stimulus	Control small	Perceived small	Control regular	Perceived large	Control large
					
Diameter of center circle (px/cm)	93/2.2	116/2.7	116/2.7	116/2.7	139/3.2

200-ms mask to prevent any afterimage of the previous target. The replacement of the mask with the appearance of the start button and new target stimulus signaled the beginning of the next trial.

Participants completed 20 practice trials, such that each unique stimulus type was presented once at each of the four onscreen positions before beginning the experimental trials. The experimental trials consisted of a primary block of 100 trials (each unique stimulus type presented at each onscreen position 5 times), after which participants were provided with a brief rest, followed by a subsequent block of 100 trials. In total, participants completed 200 experimental trials, such that each unique stimulus type was presented at each onscreen position 10 times. Following the experimental trials, participants were debriefed and received their participation credit. Each session took no longer than 30 min to complete.

Data Analysis. Participants' cursor movements were measured by lab.js and were exported and processed using the Mousetrap package (Wulff et al., 2021) in R (R Core Team, 2020). Performance was collapsed across the four onscreen target positions to produce an average score for each unique type of target stimulus. Each dependent variable was analyzed using a one-way repeated measures ANOVA (stimulus type: control small vs. perceived small vs. control regular vs. perceived large vs. control large).

All statistical analyses were conducted using SPSS (Version 23.0). A Greenhouse-Geisser correction was applied to address any violations of sphericity. Normality assumptions were tested by inspecting the normality of the unstandardized residual values produced by the repeated measures ANOVA. All analyses were conducted using an alpha = .05, partial eta squared (η_p^2) was calculated as a measure of effect size for each analysis, and post-hoc pairwise comparisons were analyzed using Bonferroni-adjusted p-values.

Dependent Variables. Participants' click-point accuracy and movement time were analyzed as indicators of task performance. Fitts' throughput (TP) was also calculated as a composite measure of click-point accuracy and movement time for each target (Fitts & Peterson, 1964; see also MacKenzie, 2015; Soukeroff & MacKenzie, 2004). For this measure, the "effective width" (W_e) of the target was defined using each participant's click-point variability to calculate the effective index of difficulty ID_e for each target. This provided a measure of perceived difficulty for each target type, which was then divided by movement time to calculate TP. Additionally, the number of directional changes was also measured, as Langridge and Marotta (2022) observed consistent differences in the number of times participants changed the direction of their cursor movement toward the experimental targets.

Average Click-Point Accuracy. The Euclidean distance (radial error) between the target's center and the participant's click-point was used to represent performance accuracy. Radial error was used to provide a measure of click-point accuracy that would reflect the average absolute distance between participants' click-points and the center of the target, irrespective of potential movement biases related to the orientation of the participant's hand or the position of the on-screen target. The absolute distance was measured in the logical pixels (px) of the computer screen. Smaller distances between participants' click-point and the center of the target represented higher accuracy.

Average Movement Time. The amount of time (ms) separating the point at which participants clicked the start button to begin the trial and clicked the target stimulus to end the trial.

Fitts' Throughput (TP). Each target's TP value was calculated for each participant using the equation:

$$\mathrm{TP} = \mathrm{ID}_e \,/\, \mathrm{MT}$$

In this calculation, ID_e refers to the index of difficulty associated with each target, and MT represents the participant's average movement time when clicking the target. ID_e is calculated as follows:

$$\mathrm{ID}_e = \log_2 ([D \,/\, W_e] + 1)$$

where distance to the target (D) is divided by the effective width of the target (W_e), which is calculated as 4.133 multiplied by the standard deviation of the participant's click-point accuracy when clicking the particular target.

Average Number of Directional Changes. Participants' cursor movements were time-normalized into 101 equally sized time steps (0%–100% total movement time) using the mt_time_normalize function in the mousetrap package in R. This normalization ensured that each trajectory contained a consistent number of data points to be analyzed, allowing cursor trajectories of varying durations to be compared as a standardized proportion of the overall movement. The on-screen position (measured in pixels) of the cursor at each of these points was used to measure the number of times the cursor changed direction in either the horizontal or vertical direction during the trial: A directional change was recorded if the direction of the cursor movement at the current proportional step was measured as the reverse of the direction at the previous point.

Results

Excluded Data. The circular onscreen target represented the only "clickable area" on the screen. Any click-points outside of the defined region were not registered. However, this clickable area was defined in lab.js using square boundaries, which made it possible for click-points to occur "outside" of the circular target while remaining within the corners of the square clickable region. This occurred in a total of 35 trials (accounting for 0.67% of all experimental trials), all of which were excluded from analysis.

Click-Point Accuracy. The main effect was significant, $F(2.27, 56.76) = 26.14$, $p < .001$, $\eta_p^2 = .51$ (Figure 3). Pairwise comparisons indicated that participants were significantly more accurate when clicking the control small target compared to all the other targets (all ps $< .001$). In addition, participants were significantly more accurate when clicking the control regular target and the perceived large target in comparison to the control large target ($p = .003$ and $p < .001$, respectively). Of direct relevance to the current hypothesis, participants were significantly more accurate when clicking the perceived large target compared to the perceived small target ($p = .014$).

Movement Time. The main effect was significant, $F(4, 100) = 10.02$, $p < .001$, $\eta_p^2 = .29$ (Figure 4). Pairwise comparisons indicated that participants were significantly slower when clicking the control small target compared to the control regular target ($p = .014$) and compared to the control large target ($p < .001$). Participants were also slower when clicking the perceived large target compared to the control large target ($p < .001$). There were no other significant comparisons (all ps $> .05$).

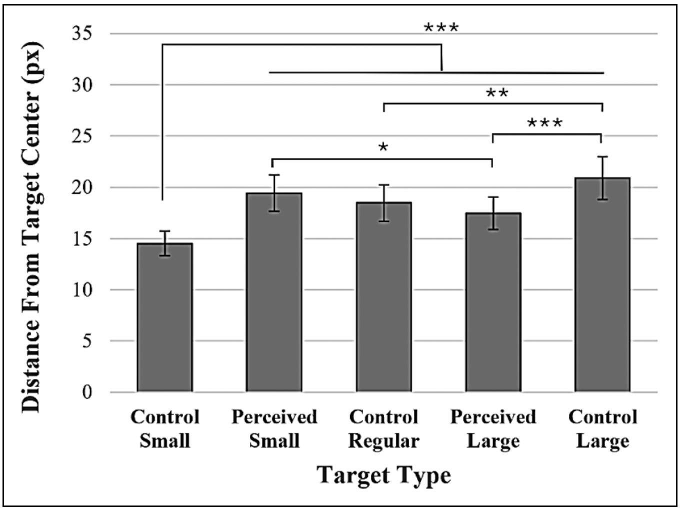


Figure 3. Average distance from click-point position to target center. Smaller values indicate higher accuracy. Error bars represent the standard error of the mean (SE). * $p < .05$, ** $p < .01$, *** $p < .001$.

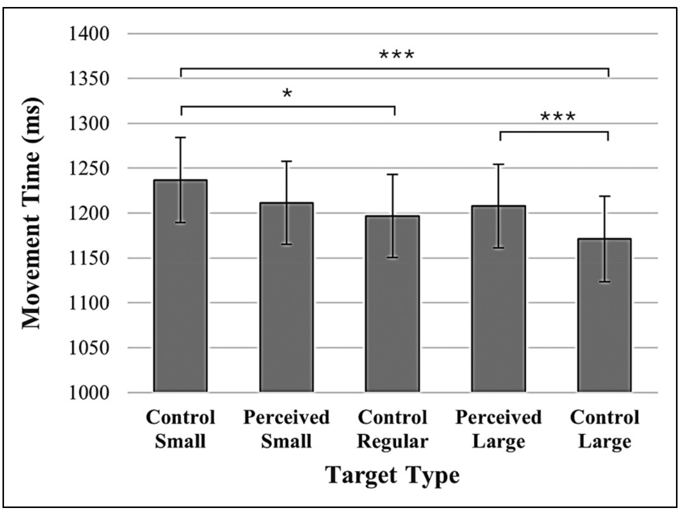


Figure 4. Average movement time (ms). Error bars represent the standard error of the mean (SE). * $p < .05$, *** $p < .001$.

Fitts' Throughput. The main effect of target was not significant, $F(4, 100) = 2.11, p = .086, \eta_p^2 = .08$. Average ID_e and TP scores are presented in Table 2.

Number of Directional Changes. Trajectory plots of one participant selected from each experiment are displayed for context in Figure 5. The main effect was significant, $F(4, 100) = 3.82$, $p = .006$, $\eta_p^2 = .13$. Pairwise comparisons indicated that participants demonstrated a significantly higher number of directional changes when clicking the control small target

Table 2. Target effective index of difficulty and throughput value.

	Control small	Perceived small	Control regular	Perceived large	Control large
Effective index of difficulty (ID_e)	3.76 (0.50)	3.53 (0.66)	3.55 (0.64)	3.55 (0.62)	3.43 (0.70)
Throughput (TP)	3.14 (0.61)	2.99 (0.61)	3.04 (0.57)	3.00 (0.53)	2.99 (0.60)

Note. Standard deviations are provided in parentheses.

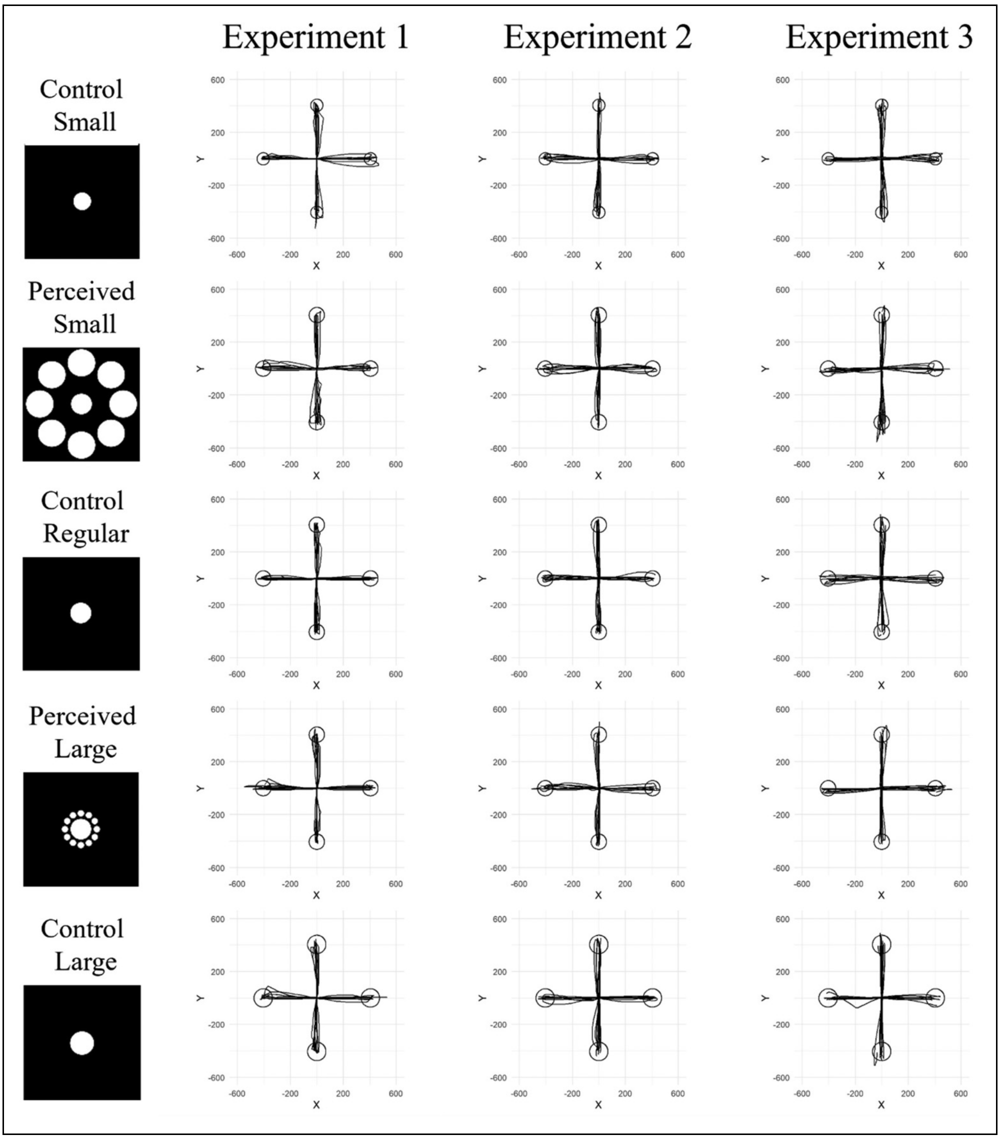


Figure 5. Trajectory plots of one participant selected from each experiment. Axes represent distance from the start button (center of the screen) in pixels. The target boundaries (without annulus) are included, despite participants not having visual feedback of the targets in Experiments 2 and 3.

($M = 2.51$, $SE = 0.14$) in comparison to the control large target ($M = 2.29$, $SE = 0.13$; $p = .011$). There were no other differences in the frequency of directional changes involving the other targets (perceived small: $M = 2.38$, $SE = 0.13$; control regular: $M = 2.36$, $SE = 0.15$; perceived large: $M = 2.39$, $SE = 0.14$; all ps > .05).

Experiment 1 Discussion

The aim of this experiment was to perform an in-lab replication of Langridge and Marotta's (2022) study, in which the illusory context did not demonstrate an influence on participants' click-point accuracy or movement time, suggesting that cursor movements are resistant to perceptual illusions. In contrast to those original results, this study demonstrated an effect of the illusion on click-point accuracy. There are several important differences between the previous study and the current investigation that may have contributed to the contradictory results. First, the presentation of the target stimuli was held constant across all participants in the current study, whereas participants in the original study performed the task remotely, using their own devices. The increased variability among participants limits the validity of the original experiment, as well as the statistical power of the analysis (Norton & Strube, 2001). Second, the screen on which the target stimuli were presented in the current study was considerably larger than the laptop screens used in the previous study. The magnitude of the Ebbinghaus illusion is known to scale with the size of presentation (Knol et al., 2015; Massaro & Anderson, 1971), meaning that participants in this study likely experienced a more powerful presentation of the illusion than those of the previous study. Together, the increased experimental control and larger stimulus presentation in the current investigation may have contributed to the significant illusion effect that was not seen previously. These differences highlight the importance of considering how the specific presentation of the illusion may influence the magnitude of the effect and, therefore, influence the observed effects on behavior (e.g., Knol et al., 2015).

Our current results show that participants were more accurate when clicking the perceived large target compared to the perceived small target. This result at first seems counterintuitive, as one may expect participants to be more accurate when clicking a target perceived as smaller than its actual size, and therefore requiring more precision compared to a target perceived as larger. However, these findings agree with a number of other studies that have also demonstrated improved motor performance when interacting with targets perceived as larger than their true size (Chauvel et al., 2015; Marchant et al., 2019; Witt et al., 2012; Wood et al., 2013). It is worth noting that these studies used golf ball putting to explore the effect of the illusion, an action which is fundamentally different from that of controlling an onscreen cursor. Still, an effect of the illusion on performance is apparent. Movements toward targets perceived as larger than their true size are typically performed faster as well (Handlovsky et al., 2004; van Donkelaar, 1999), although there were no significant differences in movement time between the perceived large and perceived small targets in this study.

It is possible that participants incorporated each of the illusory targets' surrounding annuli in their representation of each target's size. In this case, the perceived large target would in fact be considered the smaller of the two targets, and the associated increase in accuracy would align with the predictions made by Fitts' law. This object-based, Gestalt grouping perspective may explain the observed performance advantage in the perceived-large configuration of the Ebbinghaus illusion shown in this experiment and others.

Alternatively, misperceiving the perceived large target as larger than its true size may have reduced the perceived difficulty of the task, making it seem as though this was an "easier" target to click. According to Fitts's law (Fitts, 1954), the index of difficulty of a task decreases as the size of the target increases, such that larger targets are perceived as easier to intercept. Thus, one may reason that the increased accuracy observed when clicking the perceived large target in this study is a result of participants perceiving it as an easier target due to its illusory larger size, despite requiring the same degree of precision as the perceived small target. Conversely, participants' perception of the perceived small target may have increased the perceived difficulty of the task, leading to a decrease in performance. This reasoning aligns well with theories highlighting self-efficacy as a predictor of motor performance (Chauvel et al., 2015; Wulf et al., 2012; Wulf & Lewthwaite, 2016). If we are to presume that an increase in perceived size is associated with a decrease in task difficulty, then logically the control large target should be perceived as the "easiest" target to click on. As predicted by Fitts's law, participants were generally faster when clicking the control large target; however, click-point accuracy was worse in comparison to all targets, except for the perceived small target. The decreased accuracy associated with the control large target is likely explained by its larger clickable area; participants were simply provided more space to click inaccurately compared to the other targets. In other words, both the perceived large and control large targets may have been perceived as "easier," however, the perceived large target did in fact demand a higher degree of precision than did the control large target, due to its comparatively smaller "clickable" area. This may explain why participants were significantly slower when clicking the perceived large target in comparison to the control large target as well, as Fitts's law would predict longer movement times to be associated with a smaller target.

More directional changes were observed when clicking the control small target compared to the control large target, confirming that the number of directional changes is associated with the veridical size of the target and the degree of precision required. In the previous investigation, Langridge and Marotta proposed that cursor trajectories directed toward targets perceived as larger than their true size may involve more directional changes if the planning stage of the movement is influenced by the illusion (e.g., a planning-control model of goal-directed movement, Glover, 2004; Glover & Dixon, 2002). This was not the case in the current investigation; however, as the illusion did not affect the number of directional changes in this experiment.

In summary, Experiment 1 demonstrated that participants' click-point accuracy was influenced by the illusory context. Participants were more accurate when clicking targets perceived to be larger than their true size in comparison to when clicking targets perceived to be smaller than their true size. These results suggest that onscreen cursor movements are mediated by perceptual processing and that this type of action is distinct from goal-directed movements directed toward physical stimuli, which have been shown to be resistant to such perceptual influences.

Having demonstrated a perceptual influence on the visually guided control of an onscreen cursor in Experiment 1, we predicted an increased effect of the illusion in situations that require participants to rely entirely on their perceptual representations of the onscreen stimuli. To test this hypothesis, a second experiment was conducted, in which participants were required to click on targets that were once again embedded within the Ebbinghaus illusion. In this experiment, however, the target disappeared at the beginning of the trial, and participants were required to use their perceptual representations, that is, their memory of the target's size and position, to accurately click its location.

Experiment 2

Method

Participants. To maintain consistency and ensure appropriate comparison between the results and effect sizes observed in the current experiment to those of Experiment 1, we recruited a sample size comparable to that in Experiment 1. Accordingly, an initial 29 undergraduate psychology students were recruited through the Psychology Department Undergraduate Participant Pool at the

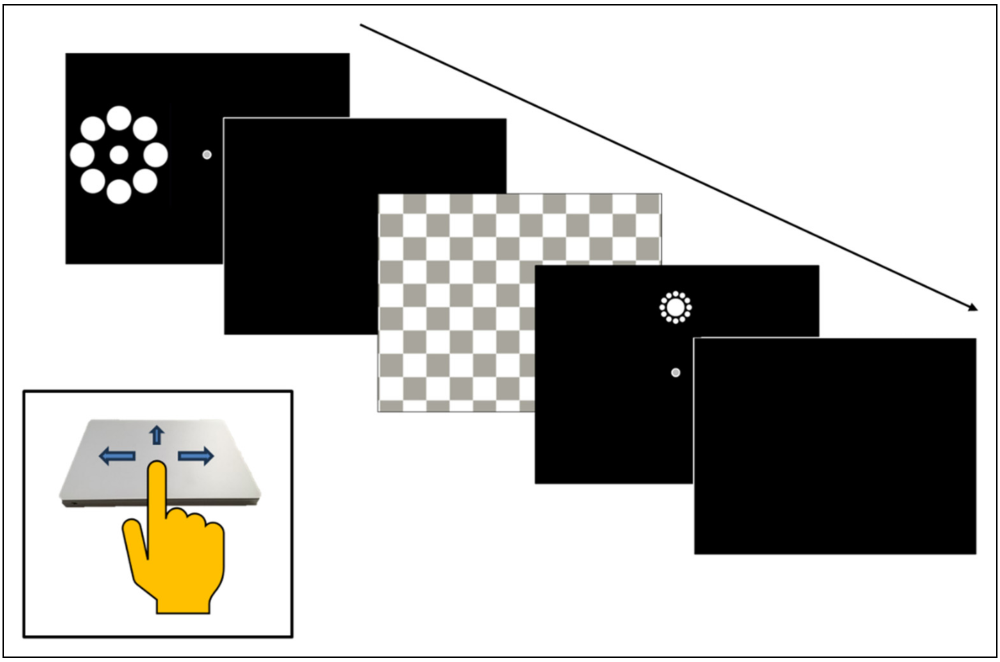


Figure 6. Examples of two experimental trials, separated by a 200 ms mask. The experimental target disappeared once participants clicked the start button. Clicking on the target's previous location ended the trial.

University of Manitoba and participated in exchange for course credit. To ensure adequate power was once again achieved with this sample size, an a priori power analysis was conducted again using G*Power (Version 3.1.9.2) to determine the minimum required sample size for a one-way repeated measures ANOVA design with five experimental conditions. Considering the increased robustness of the effect sizes observed in the first experiment relative to those reported by Langridge and Marotta (2022), the desired effect size was increased to $\eta_p^2 = .10$. A minimum sample size of 16 participants was determined using the following input parameters: effect size $\eta_p^2 = .10$, alpha = .05, and desired power = .90.

One participant was removed for having an average number of directional changes that was consistently greater than two standard deviations above the average of the group. The age range of the remaining 28 participants was between 17 and 46 years ($M = 22.41$ years, $SD = 7.08$). Twenty-three participants reported their sex assigned at birth as female, and five participants reported their sex assigned at birth as male. Fourteen participants reported having normal vision, and 14 participants reported having corrected-to-normal vision. Participants were all right-hand dominant, and all participants reported using their right hand to control the cursor when using a computer. This research was approved by the University of Manitoba Research Ethics Board, Fort Gary Campus. Informed consent was obtained from each participant.

Materials, Procedure, and Data Analysis. The experimental procedure is presented in Figure 6. The materials and procedure were identical to Experiment 1, with the following exceptions. Each trial began with the presentation of the central start button and a target stimulus presented at one of the four onscreen locations. Clicking the start button caused both the start button and the target stimulus to disappear, and participants were required to click the center of the disappeared target as quickly and accurately as possible without visual feedback of the target. The number of practice and experimental trials participants completed remained the same as in Experiment 1 (total of 200 experimental trials; each unique stimulus type presented at each onscreen position 10 times). Once again, each session took no longer than 30 min to complete. The experimental conditions and analyses of the dependent variables remained the same as in Experiment 1.

Results

Excluded Data. Participants' click-points fell outside of the target boundaries while remaining within the square clickable region in 49 trials (accounting for 0.86% of all trials). These trials were excluded. As a result of a coding error, a small portion of the top and bottom of the control large target were not included in the defined clickable region, which meant that participants could have accurately clicked the target in these locations without these click-points being registered. All trajectory and click-point data were inspected, and any trials in which this was believed to have occurred were excluded, accounting for an additional 34 trials (0.61% of all trials). A total of 83 (accounting for 1.48% of all trials) were excluded.

Target Exposure Duration. The average amount of time each experimental target was visible is presented in Table 3. These durations represent the amount of time taken by participants to click the start button, at which point the target disappeared and the experimental trial began.

Click-Point Accuracy. The main effect was significant, $F(2.95, 79.79) = 17.16$, $p < .001$, $\eta_p^2 = .39$ (Figure 7). Pairwise comparisons indicated that, as was the case in Experiment 1, participants were significantly more accurate when clicking the control small target compared to all the other targets (all ps < .001). Participants were also significantly more accurate when clicking the perceived large target in comparison to the control large target ($p = .039$). There were no additional significant comparisons (all ps > .05).

Movement Time. The main effect was significant, $F(1.25, 33.81) = 6.37$, $p = .012$, $\eta_p^2 = .19$ (Figure 8). Participants were significantly slower when clicking on the control small compared to the control large target ($p = .047$); however, there were no other significant pairwise comparisons involving any of the other targets (all ps > .05).

Fitts' Throughput. The main effect of target was not significant, $F(4, 108) = 0.463$, $p = .763$, $\eta_p^2 =$ .02. Average ID_e and TP scores are presented in Table 4.

Number of Directional Changes. The main effect was significant, $F(4, 108) = 7.46$, $p < .001$, $\eta_p^2 =$ 0.22 (Figure 9). Pairwise comparisons indicated that participants made significantly more directional changes when clicking on the control small target compared to the perceived small target ($p = .006$), the control regular target ($p = .031$), and the control large target ($p < .001$), but not the perceived large target ($p = .152$). There were no other significant comparisons (all ps > .05).

Experiment 2 Discussion

The goal of Experiment 2 was to explore how the Ebbinghaus illusion influenced cursor movements and click-point accuracy without visual feedback of the target. The TVSH proposes that within the ventral stream, perceptually relevant information about a stimulus, such as its perceived size, is stored as a component of its perceptual representation, and the results of Experiment 1 suggested these perceptual

Table 3. Average duration of target exposure.

	Control small target	Perceived small target	Control regular target	Perceived large target	Control large target	Total
Duration (ms)	1258.10 (427.70)	1268.82 (450.52)	1296.37 (535.23)	1286.66 (495.63)	1268.81 (478.43)	1275.75 (472.44)

Note. Standard deviations are presented in parentheses.

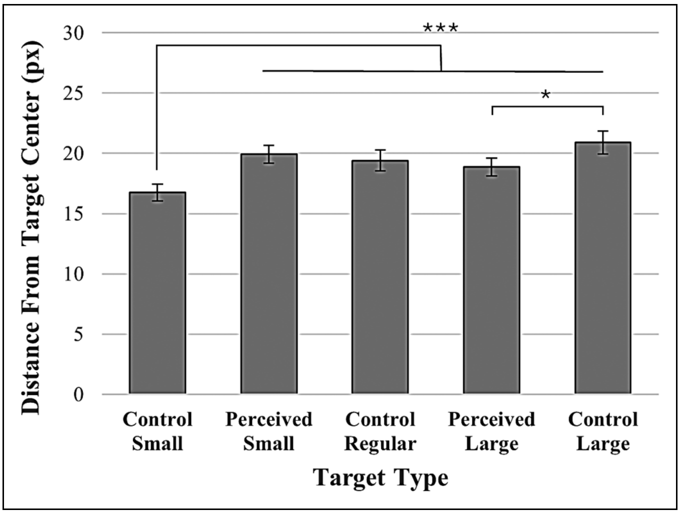


Figure 7. Average distance from click-point position to target center. Smaller values indicate higher accuracy. Error bars represent the standard error of the mean (SE). * $p < .05$, *** $p < .001$.

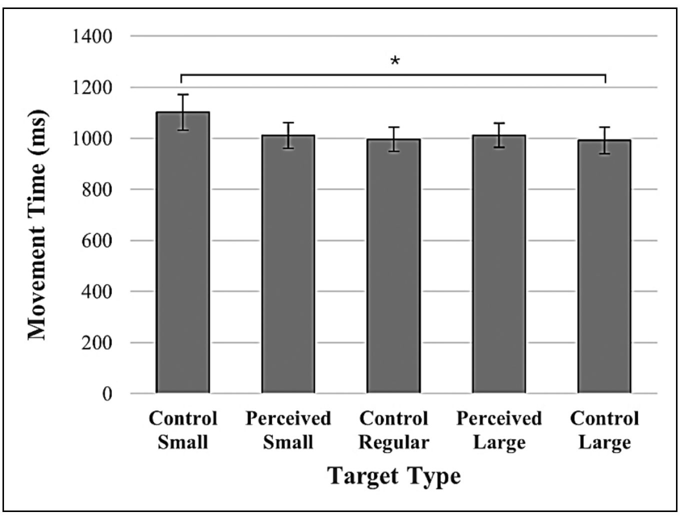


Figure 8. Average movement time (ms). Error bars represent the standard error of the mean (SE). * $p < .05$.

Table 4. Target effective index of difficulty and throughput value.

	Control small	Perceived small	Control regular	Perceived large	Control large
Effective index of difficulty (ID_e)	3.52 (0.24)	3.29 (0.27)	3.29 (0.27)	3.34 (0.29)	3.20 (0.31)
Throughput (TP)	3.50 (1.01)	3.47 (0.94)	3.51 (0.89)	3.50 (0.89)	3.43 (0.87)

Note. Standard deviations are provided in parentheses.

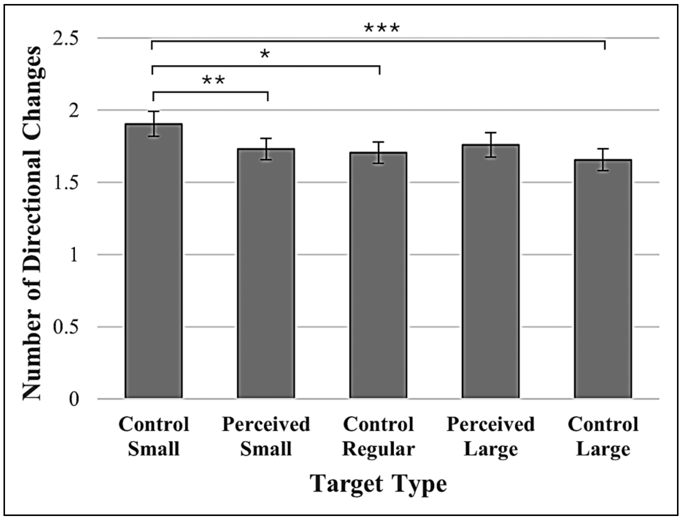


Figure 9. Average number of directional changes. Error bars represent the standard error of the mean (SE). * $p < .05$, ** $p < .01$, *** $p < .001$.

representations mediated participants' cursor movements. Accordingly, it was reasoned that altering participants' perception of target size using the Ebbinghaus illusion prior to the disappearance of the target would similarly affect their performance in this study as well. The results did not support this prediction, however. Participants' click-point accuracy, movement duration, and number of directional changes did not significantly differ between the perceived small and perceived large targets, suggesting that the illusion did not affect participants' control of the onscreen cursor.

As observed in Experiment 1, participants were more accurate when clicking the perceived large target in comparison to the control large target. The perceived small and control regular targets, despite being the same veridical size as the perceived large target, did not significantly differ from the control large target; however, and this perhaps once again suggests a subtle increase in accuracy when clicking on a target perceived to be larger than its true size. Cursor trajectories directed toward the perceived large target also demonstrated a comparable number of directional changes to those directed toward the control small target, which was veridically smaller than the other targets and, therefore, demanded the highest degree of accuracy, whereas all other target types demonstrated fewer corrective movements. As argued previously by Langridge and Marotta (2022), more corrections may be needed as the movement unfolds and the cursor approaches a target originally perceived to be larger than its true size. Ultimately, however, the absence of any significant comparisons between the perceived large and perceived small targets in this experiment suggest the direction of the illusory context did not convincingly affect participants' performance of the task, as was observed in Experiment 1. Considering that participants were expected to demonstrate an exaggerated effect of the illusion when forced to rely on their perceptual representation of the target, how can we explain the absence of an illusory effect in this experiment? We propose three possible explanations.

Explanation 1: The presentation of the illusion, while visible, did not affect participants' perception of target size, and therefore their perceptual representations were tuned to the veridical size of the onscreen target. We believe this explanation to be unlikely, considering the Ebbinghaus illusion has been shown to have a strong and reliable effect on perceptions of target size, both of visible targets as well as on perceptual representations stored in memory (Ben-Shalom & Ganel, 2012). Further, the targets used in this study have been shown to produce a demonstrable change in perceived size in a previous investigation (Langridge & Marotta, 2022). Nevertheless, it is possible that the specific presentation of the illusory stimuli in this experiment did not achieve the desired effect, meaning participants' perceptual representations of target size were not influenced, and accordingly, their cursor movements were also unaffected.

Explanation 2: The illusion affected perceived target size, and these illusory size perceptions were incorporated in participants' perceptual representations, but the magnitude of these perceived size differences were not substantial enough to affect task performance without visual feedback of the target. Following the disappearance of the target and in the absence of a visible stimulus, the initially perceived effects of the illusion simply may not have been large enough to generate any measurable differences in performance between the perceived small and perceived large targets.

Explanation 3: Perceptions of target size were influenced by the illusion. However, as a result of the demands of the particular task, participants did not pay sufficient attention to the illusory presentation of the target when visible, and therefore, perceptions of target size did not contribute to their perceptual representation of the disappeared target. The size-contrast effect of the Ebbinghaus illusion is thought to arise from the spatial relationship between the center circle and the surrounding annulus, making the perceived organization and binding of its features an important determinant of its magnitude. The quality of attention allocated to a target stimulus is known to influence the perceptual organization of that stimulus (i.e., feature-integration theory; Treisman & Gelade, 1980), and therefore the allocation of visual attention toward the illusory stimulus may also determine the magnitude of its effect. In this experiment, participants were required to click a start button positioned in the center of the screen to make the target stimulus disappear at the beginning of each trial. Participants were aware that the target would disappear when they clicked the start button, and consequently, they may have allocated more attention to the relative position of the target than to its perceived size, as information about the target's position would determine the subsequent direction of cursor movement. Additionally, if attention was directed toward the start button in the center of the screen, participants' processing of the illusory target's perceived size would have occurred in their periphery. The position of an illusory figure within a person's visual field is known to influence the efficacy of the illusion's effect, such that the processing of illusory stimuli in the periphery requires increased attentional control (Bakar et al., 2008). Considering the well-documented limits to both selective attention and the amount of information that can be stored in visual working memory (see Baddeley, 2003; Cowan et al., 2024, for review), the reallocation of attention away from the target and toward the start button may have diminished the effect of the illusion. Consequently, any manipulations of perceived target size while the target was visible may not have been incorporated in the perceptual representation of the target once visual feedback was removed. To test this explanation, a third experiment was conducted. Once again, participants were required to rely on their perceptual representations of a disappeared target when guiding their cursor movements. When participants clicked the start button in this experiment, however, the on-screen target appeared for two seconds before disappearing, allowing participants to direct their full attention to the visible target prior to its disappearance. It was predicted that by increasing the attention participants allocated to the illusory stimulus while visible, the changes in perceived target size would be more effectively incorporated into their perceptual representation of the target after it disappeared, and thus demonstrate a stronger influence on their performance.

Experiment 3

Method

Participants. Having determined adequate a priori power estimates using the sample sizes in Experiments 1 and 2, a comparable sample size to that of these experiments were recruited to ensure

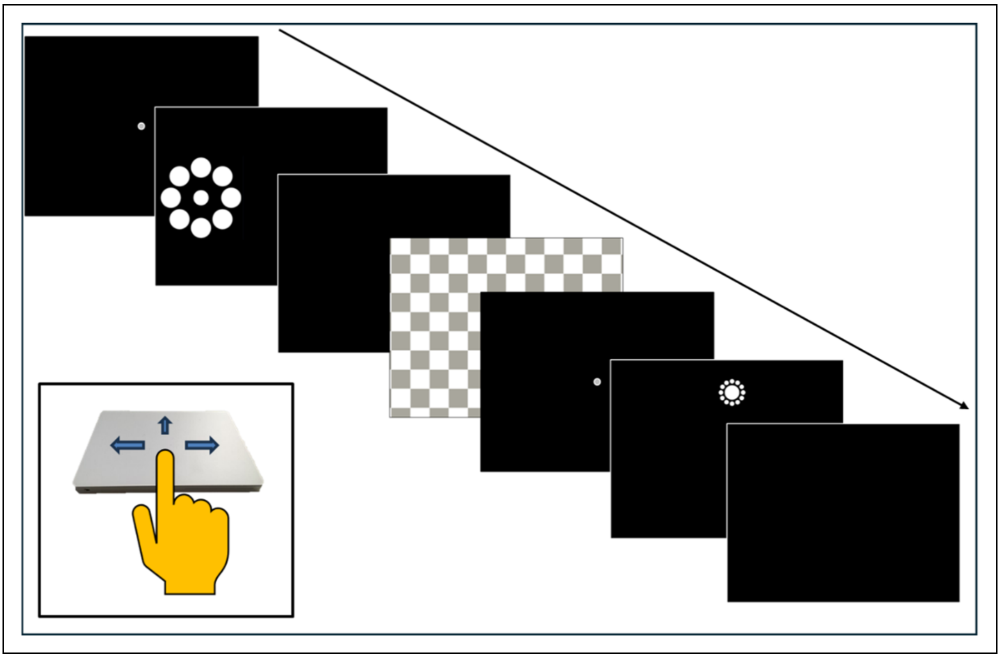


Figure 10. Examples of two experimental trials, separated by a 200 ms mask. When participants clicked the start button, it disappeared, and the experimental target appeared and remained visible for 2 s. After 2 s, the target disappeared, and participants were required to click its previous location, ending the trial.

appropriate comparative interpretation of results and effect size. Thirty-two undergraduate psychology students were recruited through the Psychology Department Undergraduate Participant Pool at the University of Manitoba and participated in exchange for course credit. The data of four participants was removed due to their consistent movement of the cursor during the two-second window prior to the target disappearance, despite instructions not to move their cursor. One participant was removed for having average movement times that were consistently greater than two standard deviations above the average of the group, and another participant was removed for having an average number of directional changes that was consistently greater than two standard deviations above the average of the group. The age range of the remaining 26 participants was between 17 and 27 years ($M = 20.69$ years, $SD = 2.83$). Eighteen participants reported their sex assigned at birth as female, and eight participants reported their sex assigned at birth as male. Sixteen participants reported having normal vision, and 10 participants reported having corrected-to-normal vision. Participants were all right-hand dominant, and all participants reported using their right hand to control the cursor when using a computer. This research was approved by the University of Manitoba Research Ethics Board, Fort Gary Campus. Informed consent was obtained from each participant.

Materials, Procedure, and Data Analysis. The experimental procedure is presented in Figure 10. The materials and procedures replicated those of Experiment 2, with the following exceptions. The start button was presented alone at the beginning of each trial. Once the participant clicked the start button, it disappeared and was replaced with a target stimulus presented at one of the four on-screen positions. Participants were instructed not to move their cursor from the start position in the center of the screen until the target stimulus disappeared. After a viewing period of 2 s, the target disappeared, at which point participants were allowed to move their cursor toward its remembered position and click its center as quickly and accurately as possible. In this experiment, the movement time variable was defined as the amount of time between the disappearance of the target and the time the participant clicked the disappeared target. The number of practice and experimental trials participants completed remained the same as in the previous experiments (a total of 200 experimental trials; each unique stimulus type presented at each onscreen position 10 times). After completing the two blocks of experimental trials, participants performed a perceptual comparison task to confirm if the illusory stimuli were, in fact, affecting their perceptual judgments of target size. This task has been described previously (Langridge & Marotta, 2022) and involves a forced-choice decision made between two of the target stimuli presented side-by-side. Participants simply clicked on the target they perceived to be larger. Each unique target type was compared with each of the other target types twice: once while presented on the left side of the screen, and once while presented on the right side of the screen. Each session took no longer than 30 min to complete. Otherwise, the experimental conditions and analyses of the dependent variables remained the same as in Experiment 2.

Results

Perceptual Comparisons. Participants' perceptual comparison scores indicated the illusion successfully influenced participants' judgments of perceived target size (Table 5).

Excluded Data. Participants' click-points fell outside of the target boundaries while remaining within the square clickable region in 29 trials (accounting for 0.56% of all trials) and were excluded. Despite instructions to avoid moving the cursor prior to the target's disappearance, participants prematurely moved the cursor toward the target while it was still visible in 229 trials (accounting for 4.40% of all experimental trials). These trials were excluded from analysis. A total of 258 (accounting for 4.96% of all trials) were excluded.

Click-Point Accuracy. The main effect was significant, $F(2.47,\ 61.85) = 12.31$, $p < .001$, $\eta_p^2 = .33$. Pairwise comparisons indicated that participants were more accurate when clicking the control small target ($M = 16.63$ px from target center, $SE = 0.90$) in comparison to all other target types (perceived small: $M = 19.76$ px, $SE = 1.18$, $p = .005$; control regular: $M = 19.32$ px, $SE = 1.01$, $p < .001$; perceived large: $M = 18.85$ px, $SE = 1.11$, $p = .019$; control large: $M = 20.67$ px, $SE = 1.02$, $p < .001$). Participants were also more accurate when clicking the perceived large target in comparison to the control large target ($p = .038$). There were no additional significant differences (all ps > .05).

Movement Time. The main effect was significant, $F(2.45,\ 61.14) = 4.19$, $p = .014$, $\eta_p^2 = .14$. Participants were significantly slower when clicking the control small target ($M = 1294.21$ ms, $SE = 60.20$) in comparison to the control large target ($M = 1231.01$ ms, $SE = 60.59$; $p = .001$). Participants were also significantly slower when clicking the control regular target ($M = 1265.13$ ms, $SE = 61.19$) in comparison to the control large target ($p = .047$). There were no significant comparisons involving the perceived small ($M = 1308.91$ ms, $SE = 64.41$) or perceived large ($M = 1281.63$ ms, $SE = 65.79$) targets (all ps > .05).

Fitts' Throughput. The main effect of target was significant, $F(4,\ 100) = 5.250$, $p = < .001$, $\eta_p^2 = .17$. Average ID_e and TP scores are presented in Table 6. TP scores were significantly higher when clicking the control small target compared to the perceived small ($p = .009$), control regular ($p = .03$), perceived large ($p = .04$), and control large ($p = .03$) targets. There were no significant comparisons between the TP scores of the illusory targets (all ps > .05).

Table 5. Perceptual comparisons.

		Right side of the screen				
		Control small	Perceived small	Control regular	Perceived large	Control large
Left side of the screen	Control small	–	100%	100%	100%	100%
	Perceived small	100%	–	**69.23%**	**88.46%**	76.92%
	Control regular	100%	**88.46%**	–	**100%**	100%
	Perceived large	100%	**80.77%**	**80.77%**	–	85.71
	Control large	88.46%	88.46%	100%	73.08%	–

Note. Scores represent the percent of comparisons that demonstrated the expected size ordering (smallest to largest): control small < perceived small < control regular < perceived large < control large. Bolded scores represent the comparisons between targets of the same veridical size.

Table 6. Target effective index of difficulty and throughput value.

	Control small	Perceived small	Control regular	Perceived large	Control large
Effective index of difficulty (ID_e)	3.66 (0.45)	3.38 (0.34)	3.39 (0.43)	3.41 (0.38)	3.23 (0.34)
Throughput (TP)	3.00 (0.81)	2.76 (0.79)	2.85 (0.79)	2.86 (0.81)	2.80 (0.76)

Note. Standard deviations are provided in parentheses.

Number of Directional Changes. The main effect was significant, $F(4, 100) = 4.44$, $p = .002$), $\eta_p^2 = .15$. Participants generated a significantly lower number of directional changes when clicking the control large target ($M = 1.80$, SE = 0.11) in comparison to the control small ($M = 1.99$, $SE = 0.10$, $p = .003$), perceived small ($M = 1.97$, $SE = 0.11$; $p = .018$), and control regular ($M = 1.96$, $SE = 0.10$; $p = .046$) targets, but not the perceived large target ($M = 1.89$, $SE = 0.13$, $p = .990$), for which the number of directional changes generated did not significantly differ from any of the other targets (all ps > .05).

Experiment 3 Discussion

The results of this experiment confirmed those of Experiment 2: there were no differences in participants' click-point accuracy, movement duration, FT, or the number of directional changes when comparing the perceived small, perceived large, or control regular targets, suggesting the illusory presentation did not have an influence on participants' performance of the task. This was the case even though participants were given a two-second period to view the target prior to its disappearance, confirming that the results of Experiment 2 cannot be explained by a diversion of attention away from the target prior to their cursor movement. Rather, these results suggest that the illusory presentation did not affect participants' cursor movements toward the disappeared targets.

General Discussion

Across three experiments, this study tested the influence of the Ebbinghaus illusion on visually guided cursor movements toward onscreen targets perceived as smaller or larger than their veridical size. The results of the current study demonstrated an effect of the illusion when visual feedback of the target was available (Experiment 1), but movements were unaffected when visual feedback of the target was removed (Experiments 2 and 3). This finding is the reverse of what would be predicted based on studies of action in the "real-world," for which movements toward visual stimuli are not influenced by illusory features of the target (Aglioti et al., 1995; Whitwell et al., 2023), whereas actions in the absence of visual feedback are more likely to be affected by the illusion, presumably due to an infiltration of the illusion on the perceptual representations used to guide the action in the absence of visual feedback (Carther-Krone et al., 2020; Westwood & Goodale, 2003).

Langridge and Marotta (2022) previously reported an increased number of directional changes when clicking targets misperceived as larger than their true size compared to targets misperceived as smaller. It was proposed that this result may be explained within the context of Glover and Dixon's planning-control model (Glover & Dixon, 2002; Glover, 2004). The planning-control model proposes a planning system which is susceptible to illusory influences, and a control system that produces the necessary "realtime" corrections needed to facilitate an accurate movement. As originally suggested by Langridge and Marotta, more directional changes—that is, corrections facilitated by the control system—may have been required when clicking a target that was misperceived to be larger than it's true size by the planning system. Glover and Dixon's planning control model echoes the TVSH in that it also predicts accuracy to be unaffected by the illusion when clicking visible targets (Experiment 1), as the available visual feedback is used by the control system to accurately click the target and to correct any illusory misperceptions present in the planning stage. Their model also predicts an increased influence of the illusion when visual feedback of the target is not available to the control system (Experiments 2 and 3). Neither of these predictions were supported in the current study, suggesting that neither the TVSH nor the planning-control model can fully account for the current findings in their conventional interpretations.

The results of the present study, though not directly supporting the traditional predictions of the TVSH, may be explained by considering the increased perceptual nature of the task used in this study. The TVSH predicts that illusions such as the Ebbinghaus illusion influence our perceptual representations of viewed stimuli, and movements utilizing these stimulus representations are susceptible to the influence of the illusion, whereas movements which do not recruit these simulations will be unaffected. Therefore, the presence of an illusory effect on a movement can be used as an indication of the perceptual system's mediation of that movement. The translation of physical finger movements on the trackpad into onscreen cursor movements toward virtual targets likely involves the recruitment of the ventral stream to process the perceptual features of the onscreen cursor and target stimuli. When reaching toward and grasping physical objects, the dorsal stream of visual processing can direct these movements without recruiting such perceptual representations within the ventral stream, which explains why these movements are not affected by illusions in the same way.

This argument can explain why participants' cursor movements are influenced by the seemingly irrelevant features of an onscreen image, such as the virtual images of coffee cups used by Phillips et al. (2024). Their participants' interaction with the images likely involved activation of their representational knowledge of a coffee cup (i.e., its "spillability"; Phillips et al., 2024), leading to an influence on their action. Langridge and Marotta proposed that one's perceptual knowledge of a stimulus can influence their actions toward virtual images of that stimulus, which can explain why precision grasps toward symmetrical onscreen stimuli appear to follow similar rules as grasps toward physical objects (Langridge & Marotta, 2021).

In the absence of visual feedback (Experiments 2 and 3), however, participants needed to rely entirely on their perceptual representation of the target post's disappearance. What can explain the absence of the illusory effect? It is possible that the perceptual change in target size caused by the illusion and stored within participants' perceptual representations was simply not of a strong enough magnitude to affect participants' accuracy, movement time, or cursor trajectory without visual feedback of the target present. In other words, while the illusion may have had some influence on participants' perceptions of target size, these perceived differences only affected participants' cursor movements when they were reinforced by the visible presentation of the target. Without the illusory features of the target visible, however, any illusory influence on task performance appears to have been diminished. Interestingly, despite finding no difference in accuracy between the illusory targets in Experiments 2 and 3, participants were consistently more accurate when clicking the perceived large target than they were when clicking the control large target in all three experiments. The reliability of this finding suggests a subtle influence of the illusion, which increased click-point accuracy when clicking on the perceived large target. This increase in accuracy appears to have been statistically significant when compared to the control large target, which generally generated the worst accuracy overall. We may therefore infer a slight benefit to the accuracy of cursor movements toward targets perceived as larger than their true size, while recognizing that this benefit was not large enough to generate differences in accuracy between the same-sized targets used in this study.

In summary, the act of using a cursor to interact with an onscreen stimulus appears to be fundamentally distinct from actions involving interaction with a physical object, such as reaching, grasping, and pointing movements. Cursor movements are mediated by the perceptual features of that stimulus, whereas physical movements are not. These findings have direct relevance to the design of GUIs and other applications in which a cursor is used to interact with onscreen stimuli, as the size and grouping of such stimuli are programmable by design and can be used to influence the user's perceptual representations. This knowledge can be leveraged for various purposes, such as increasing the clarity and readability of onscreen text, enhancing engagement, and optimizing the layout of presented stimuli to effectively direct users' attention. Based on the results of this study, for example, one may choose to present a preferred button or selection as surrounded by smaller visual elements and, in doing so, induce a size-contrast illusion similar to the perceived large target in this study. This illusory influence will not only influence users' perceptions of button size, but, as we have shown in the present study, will also facilitate participants' interaction with that onscreen element.

Testing the TVSH's predictions using nontraditional actions, such as onscreen cursor movement, provides an important complement to the traditional reaching and grasping studies that led to its foundation. The results of this study contribute significantly to our understanding of perception–action interaction and further refine the theoretical basis of the TVSH by expanding its application to interaction with onscreen targets. Future studies utilizing additional forms of action within a variety of contexts will further contribute to our theoretical understanding of the TVSH's role in visual perception and action.

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Ethical Considerations

This research was approved by the University of Manitoba Research Ethics Board, Fort Gary Campus [Approval No.: HS21645 (P2018:023)].

Consent to Participate

Written informed consent was obtained from each participant.

Consent for Publication

Not applicable.

Author Contribution(s)

Ryan W. Langridge: Conceptualization; Data curation; Formal analysis; Investigation; Methodology; Project administration; Writing – original draft.

Jonathan J. Marotta: Formal analysis; Methodology; Project administration; Resources; Supervision; Writing – review & editing.

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