Dynamic presentation boosts the Ebbinghaus illusion but reduces the Müller-Lyer and orientation contrast illusions

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Mruczek et al. (2015) showed that a moving version of the Ebbinghaus illusion almost doubles in strength compared to the standard version. In their stimulus, the size of the surrounding inducers was modulated between large and small and the whole stimulus was made to drift during the surround modulation. We first replicated the original dynamic Ebbinghaus illusion and then explored dynamic presentations for other simultaneous contrast and geometric illusions. We found no increase in illusion strength in any that we sampled. Here we report the results for the Müller-Lyer illusion and the orientation contrast illusion. Surprisingly, when these two illusions were presented dynamically, their effects were greatly reduced for the Müller-Lyer illusion and eliminated for the orientation contrast illusion.

Introduction

In the Ebbinghaus illusion, a test disc surrounded by smaller discs appears larger than the same disc surrounded by larger ones (Ebbinghaus, 1902; Titchener, 1905). Mruczek and colleagues showed that when the size of surrounding discs changes while the entire configuration of the Ebbinghaus stimulus moves, the magnitude of the illusion almost doubles (see Movie 1, Dynamic Ebbinghaus illusion; Mruczek, Blair, Strother & Caplovitz, 2015). They suggested that the static version allowed local information to accumulate about the actual size of the central disc and this reduced the illusory size change induced by the surrounding discs. However, when the configuration

was in motion, the accumulation no longer built up locally and therefore the illusion magnitude could increase with fewer restraints. Recently, they reported that the dynamic version of the corridor illusion showed an effect opposite to that of the Ebbinghaus illusion, decreasing in magnitude in the dynamic version (Mruczek, Blair, Cullen & Caplovitz, 2020a). They also investigated whether a dynamic presentation increased the Ponzo illusion but found little effect (Mruczek, Kelly, Sagona, Fanelli & Caplovitz, 2020b). These results suggested that the influence of dynamic presentation differs strongly across these three illusions even though they all involved size contrast.

Here, we further explored the effect of dynamic versions on illusions where size contrast is not involved: simultaneous contrast and Müller-Lyer. To anticipate the results, like Mruczek and colleagues (2020a, 2020b), we find no evidence that other illusions increase in magnitude when set in motion. The Ebbinghaus illusion itself is a type of simultaneous contrast in size so we first tested simultaneous brightness contrast (Heinemann, 1955) and orientation contrast illusions (Westheimer, 1990). Only the results of orientation contrast will be reported here. Despite our expectations that an increase would be seen for these dynamic simultaneous contrast effects, neither illusion showed an increase in the dynamic versions even though we made the parameters of the motions similar to those of the dynamic Ebbinghaus case (Mruczek et al., 2015). We then also tested two geometrical illusions: the Zollner illusion (Zollner, 1860) and the Müller-Lyer illusion (Müller-Lyer, 1889) and, again, we found no
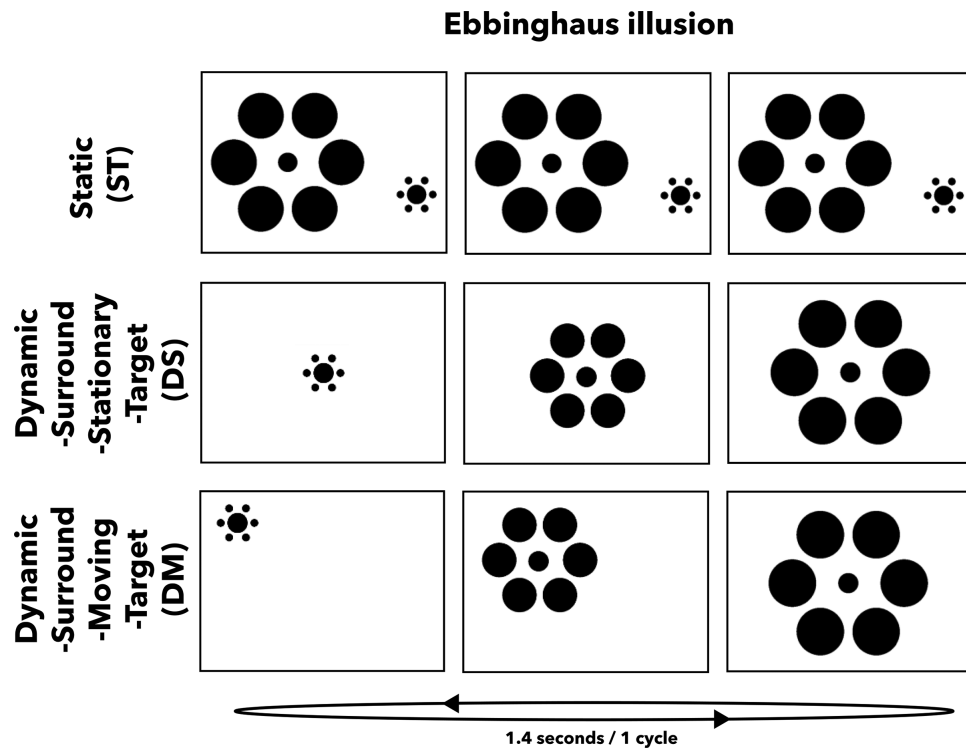
Ebbinghaus illusion

Figure 1. Ebbinghaus illusion.

increase of illusion strength in the dynamic versions of either illusion. Only the Müller-Lyer results will be reported here. What was more surprising was that the illusions not only did not increase but both the orientation contrast and the Müller-Lyer illusions were significantly reduced when set in motion.

Method

Participants

Fifteen participants, including one of the authors, participated (eight males, aged between 19–28 years old). All participants had normal or corrected-to-normal vision and gave written consent. The study was approved by the internal review board of Waseda University.

Stimuli and procedure

Stimuli were presented on a gamma-corrected LCD monitor (1920 × 1080 pixels, 23.5-inch, 100 Hz) with a viewing distance of 57.5 cm, maintained with a chin rest. The green fixation point (0.1 degrees of visual angle in diameter [dva]) was present throughout all trials in the experiment. The procedure was based on

that of Mruczek et al. (2015) and the Ebbinghaus stimulus matched that used by Mruczek et al. (2015). The method of adjustment was used throughout to null the effects of the illusions. Each condition had a matching control condition without the inducers to evaluate any biases (no surrounding discs, Gabors or arrowheads). The *Static condition (ST)* measured the illusion magnitude with the classic stationary configurations.

For the Ebbinghaus illusion (Figure 1, top row), two figures were presented, one on the left and one on the right. The one on the right had a central circle of fixed size (1.8 or 2.0 dva). On half the trials, it was surrounded by six smaller circles (0.7 dva in diameter, 1.5 dva eccentricity from the center of the central circle to the centers of inducer circles) equally spaced around the central circle. On the other half of the trials, it was surrounded by six larger circles (4.25 dva in diameter, 5.0 dva eccentricity from the center of the central circle to the center of inducer circle). On the left side, the figure was similar except that the size of the central circle could be adjusted by the participant and the size of the surrounding circles was the opposite of those around the right central circle (small on the left matched with large on the right and vice versa). The sides of the smaller and larger surrounds were varied randomly. The left target was located on the upper left of the fixation (6 dva to the left and 2 dva above) and the right target on the lower right (6 dva to the right and 1 dva
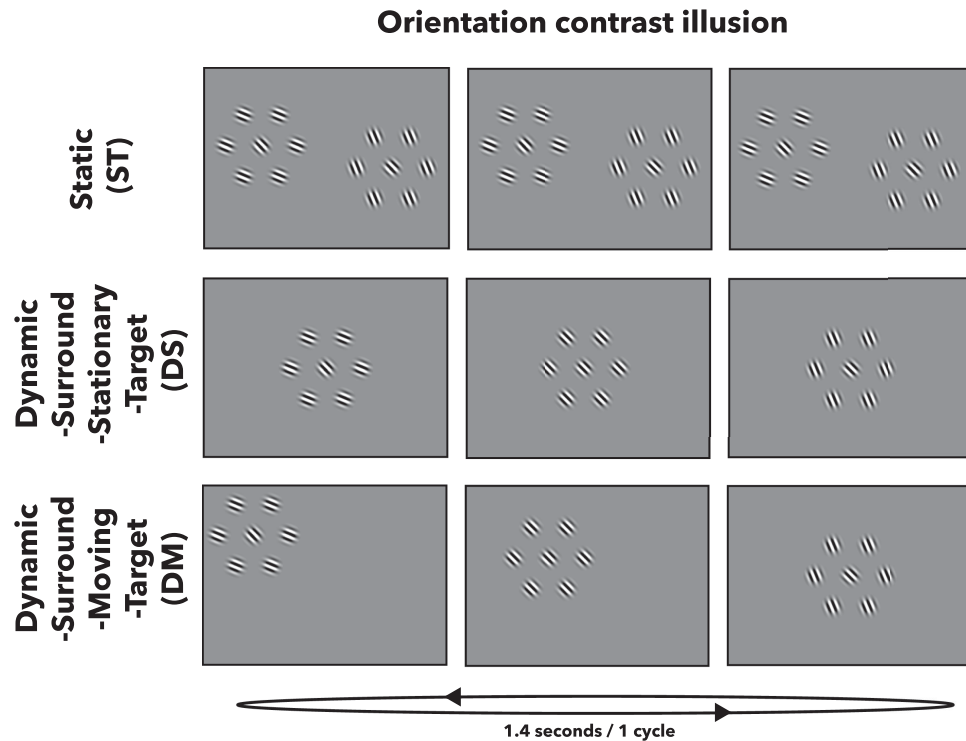
Orientation contrast illusion

Figure 2. Orientation contrast illusion. For visibility, the contrasts shown here are higher than in the experiment.

below). The task was to adjust the size of the central circle on the left side to that perceived on the right side by pressing the F or J keys. Each keypress changed the target diameter by 0.0076 dva (∼0.0084% of the initial target size), and the change was continuous if the participant kept the key pressed down. When the participants were satisfied with their match, they pressed the space key to proceed to the next trial.

For the orientation contrast illusion (Figure 2, top row), the central Gabor patch on the right of fixation was 1.24 dva in diameter with its internal grating (spatial frequency = 1.85 cpd) oriented fixed at 45° or −45°. This target was surrounded by six Gabor patches of the same size, spaced 2.25 dva, center-to-center from the central Gabor, all oriented at 67.5° (or at −67.5° when the central Gabor on the right was at −45°). On the left side was a similar arrangement with a Gabor target surrounded by six Gabor patches oriented at 22.5° (or at −22.5° when the central Gabor on the right was at −45°). The central Gabor on the left had a variable orientation that could be adjusted by the participant. The sides with the 22.5° and 67.5° surrounds were exchanged randomly. The task was to adjust the orientation of the central Gabor on the left side until it matched that on the right side by pressing the F or J keys. Each key press changed the target orientation by 0.20°, and continuous pressing led to a continuous change. The target and inducer locations were identical to those of the Ebbinghaus illusion described above. When the participants were satisfied

with their adjustment, they pressed the space key to proceed to the next trial.

For the Müller-Lyer illusion (Figure 3, top row), a horizontal line ending with inward pointing arrow heads (inducer length: 1.25 dva, inducer angle: 30°) appeared on either the left or right side of the fixation, with the second line on the other side having outward pointing arrow heads (inducer angle: 160°). The central line on the right had a fixed length (2.5 or 2.7 dva), and the line on the left was adjustable. The task was to match the length of the target line on the left side to that on the right side by pressing the keys. One key press changed the target length by ∼0.0076 dva (0.0030 % of the initial target length) and a continuous press led to a continuous change. The locations of the centers of the target lines were identical to those of the Ebbinghaus illusion as above. When the participants were satisfied with their adjustment, they pressed the space key to proceed to the next trial. In the *Dynamic-Surround-Stationary-Target condition (DS)* the illusion magnitude was measured while the inducers change dynamically but the entire configuration did not move.

For the Ebbinghaus illusion, a single target circle (1.8 or 2.0 dva) surrounded by six smaller or larger inducing circles was presented at the center of the display (Figure 1 second row). The surround circles started expanding from smaller to larger or shrinking from larger to smaller, then changing back. The time for each cycle (larger to smaller and back to larger) was
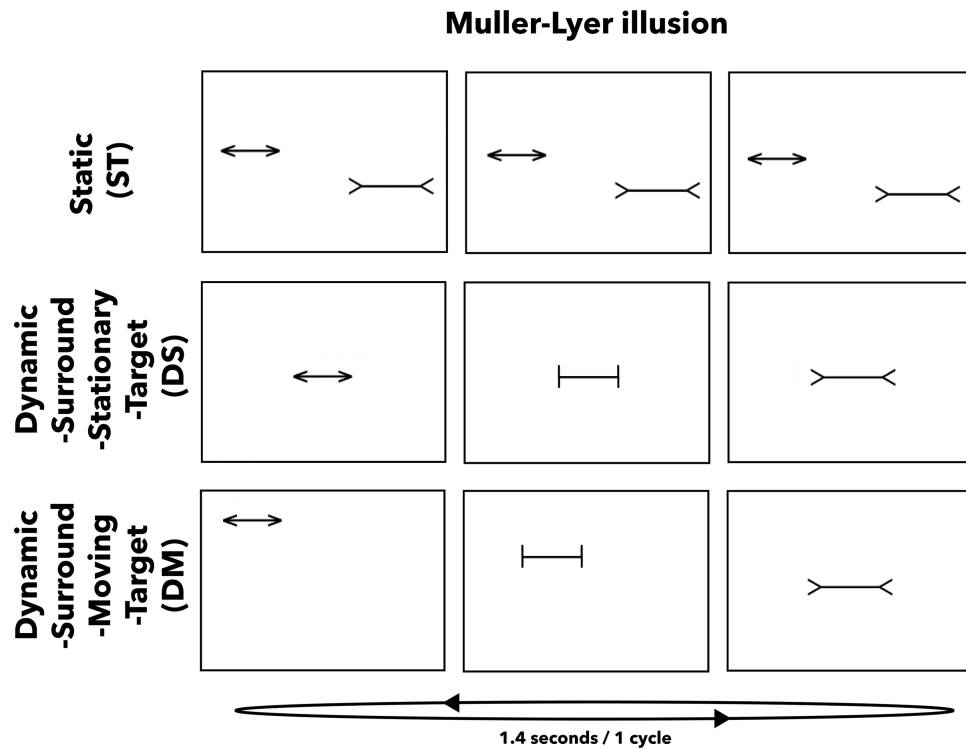
Muller-Lyer illusion

Figure 3. Müller-Lyer illusion.

1.4 seconds and the cycles continued throughout the trial. The participants adjusted the rate at which the central target changed size so that the central target appeared to maintain a constant size over the entire cycle, canceling size changes, if any, induced by the surrounding circles. Pressing the F key increased the rate of size (diameter) increase by 0.20 dva per second per key press on one half of the cycle and the rate of size decrease on the other half of the cycle. Holding down the key led to a continuous change in the rate of size change. Pressing the J key had the opposite effect, increasing the rate of size decrease in the first half-cycle and the rate of size increase in the second half-cycle. Initially, the central target did not change its size (i.e., the initial rate of change = 0). The participant pressed the space key when they were satisfied with their setting and that led to the next trial.

For the orientation contrast illusion, a single target Gabor was presented at the center of the display, initially with an orientation of 45 degree or -45 degree (Figure 2, second row). It was surrounded by six Gabor patches. The orientation of the surrounding Gabors was smoothly changed from 22.5° to 67.5°, then back to 22.5° over a cycle of 1.4 seconds that repeated throughout the trial. The task was to adjust the physical orientation of the central Gabor to cancel any perceived variation in orientation induced by the surrounding Gabors that changed in orientation but maintained a fixed size. With proper adjustment, the central Gabor

should always appear to have a constant orientation. Participants controlled the speed at which the central orientation changed with time by pressing the F key to increase the rate of change, rotating the central Gabor clockwise from 45° in the first half of the cycle and counterclockwise in the second half. Pressing the J key increased the rate of orientation change, rotating the central Gabor counterclockwise in the first half of the cycle and clockwise in the second half. One key press changed the rate of orientation change by 0.20° of rotation per second, and a continuous press led to a continuous change in the changing rate. The rate of orientation change was initially set to 0° per second. Participants pressed the space key when they were satisfied with their setting and that led to the next trial.

For the Müller-Lyer illusion, a single horizontal target line (2.5 or 2.7 dva) with inward or outward inducer lines was presented on the center of the display (Figure 3, second row). The inducer angle started changing from 30° to 160°, then changing back to 30°, with one cycle every 1.4 seconds. The participants adjusted the rate at which the length of the target line changed over time to cancel any induced change of perceived length. The rate of length change was initially set to 0 per second. The task was to adjust the rate of length change of the target line such that it cancelled out and minimized the apparent change. Pressing the F key increased the rate of length increase by 0.20 dva per second per key press on one half of the cycle and the

rate of length decrease on the other half of the cycle. Pressing the J key had the opposite effect, increasing the rate of length decrease in the first half-cycle and the rate of length increase in the second half-cycle. Holding down the key led to a continuous change in the rate of length change. The participant pressed the space key when they were satisfied with their setting and that led to the next trial.

The *Dynamic-Surround-Moving-Target condition (DM)* measured the illusion magnitude when the inducers change dynamically and the entire configuration moved. For the Ebbinghaus illusion, this was a replication of the condition where the illusion magnitude was maximal in Mruczek et al. (2015) (Movie 1). For the orientation contrast and Müller-Lyer illusions, this was the first test of the dynamic presentation procedure (Mruczek et al., 2015) with these illusions. The stimulus configurations and the adjustment tasks were identical to those of Dynamic-Surround-Stationary-Target condition except that the entire stimulus moved back and forth diagonally (3.5 dva distance, 45 degrees angle, and 5 dva per second) once every 1.4 seconds (Figures 1, 2, and 3, third rows) (Movie 2: Orientation contrast illusion, Movie 3: Müller-Lyer illusion).

There are three motion conditions (ST, DS, DM) for each of three illusions. For each illusion, control conditions without the inducers were added. For each combination of three motion conditions and two inducer conditions (present or absent), three trials with two initial target values and two inducer locations, resulting in 72 trials in total. The initial conditions for each trial of the 3 illusions were as follows. For the Ebbinghaus illusion, the small inducer was randomly and equally often on the left for ST conditions; the initial inducer size was randomly small or large for DS and DM conditions with equal frequency. For the DM condition, the stimulus always started its path on the top left. For the Müller-Lyer illusion, the inward inducer lines were on the left or right with equal frequency for the ST condition whereas the initial inducer lines were equally often inward or outward for the DS and DM conditions. The stimulus always started on the top left in the DM condition. For the orientation contrast illusion, the 22.5° inducer orientation was randomly and equally often on the left for the ST condition, and the initial inducer orientation was equally often 22.5° or 67.5° for the DS and DM conditions. The stimulus always began in the top left corner in the DM condition. The three illusions were tested in separate sessions.

Analysis

The nulling adjustments were taken from the mean settings that participants made to null the illusion. For

the ST condition, the perceived size/orientation/length of the central stimulus on the left was matched to that of the central stimulus on the right. The illusion magnitude was the percent size change between the central disks surrounded by large vs small inducers for the Ebbinghaus illusion, the orientation difference (degrees of rotation) of the central Gabors surrounded by the more counterclockwise vs less counterclockwise tilted inducers for the orientation contrast illusion, and the percent length change between central shafts with the outward vs inward arrowheads for the Müller-Lyer illusion. In the DS and DM conditions, the analysis was the same, but rather than the difference between the two static test stimuli, it was based on the difference between the stimulus settings at the two ends of the dynamic change in size, orientation, or length. Then, the direction of the illusion magnitudes was set to positive when the effect was one of contrast (e.g., when the Ebbinghaus target surrounded by large disks appeared smaller so it was adjusted to be bigger to match the other) and negative for the reverse.

To remove any biases, the nulling adjustments for the control conditions without inducers were then subtracted from the values found in the conditions with inducers, individually for each participant and that difference was taken as the illusion magnitude for the analysis of the main findings.

The correlations across participants for the strengths of visual illusions are typically very weak (e.g., Axelrod, Schwarzkopf, Gilaie-Dotan & Rees, 2017, Grzeczkowski, Clarke, Francis, Mast & Herzog, 2017). Here instead of looking at between participant patterns, we are examining the within participant effects.

Results

We first screened for outlier trials, using a conservative criterion that excluded settings that were more than three standard deviations from the mean in each inducer and motion condition for each participant (Van Selst & Jolicoeur, 1994). The proportion of trials excluded was 1.94%, 1.94 %, and 1.67% for the Ebbinghaus, Müller-Lyer, and orientation contrast illusions, respectively.

None of the control conditions showed significant effects, but all three illusions (values with inducers minus values without inducers) were significant in the ST conditions (Figure 4). The dynamic presentation in the DM condition effectively enhanced the Ebbinghaus illusion, as found in Mruczek et al. (2015). However, this was not the case for the other illusions.

An ANOVA showed significant main effects in all the illusion cases [Ebbinghaus illusion: $F(2,44) = 27.09$, $p < 0.001$; orientation contrast illusion: $F(2,44) = 26.88$, $p < 0.001$; Müller-Lyer illusion: $F(2,44) = 52.45$, $p < 0.001$].
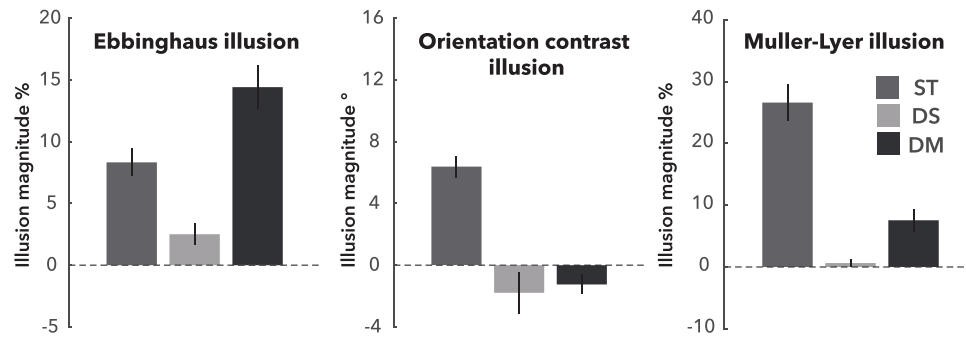
Figure 4. Mean illusion magnitudes for each illusion: The illusion magnitude was calculated as the difference between the null settings for trials with the inducers and without inducers for each participant in each condition. The illusion magnitudes above the horizontal dashed lines represent contrast effects whereas magnitudes below the dashed lines represent assimilation effects.

The differences between the conditions were tested with multiple comparisons using Bonferroni correction. The p values were Bonferroni corrected for an $\alpha = 0.05$. The Ebbinghaus illusion was significant for all the classic ST, the dynamic DS, DM cases [ST: $t(14) = 7.48$, $p < 0.001$, DS: $t(14) = 2.89$, $p = 0.036$, DM: $t(14) = 8.14$, $p < 0.001$]. Moreover, the illusion strength was significantly stronger in the DM condition than the other two [ST vs. DM: $t(14) = -3.25$, $p = 0.017$; DS vs DM: $t(14) = -8.55$, $p < 0.001$], which significantly differed [ST vs. DS: $t(14) = 3.75$, $p = 0.007$], replicating Mruczek et al. (2015). In contrast, for the Müller-Lyer illusion, the illusion strength was significant for the classic ST and the dynamic DM cases [ST: $t(14) = 9.06$, $p < 0.001$; DS: $t(14) = 1.04$, $p = 0.948$; DM: $t(14) = 4.07$, $p = 0.003$] and was significantly stronger for ST than in the two dynamic versions [ST vs. DS: $t(14) = 9.37$, $p < 0.001$; ST vs. DM: $t(14) = 6.08$, $p < 0.001$], which differed significantly from each other [DS vs. DM: $t(14) = -3.87$, $p = 0.005$]. Finally for the orientation contrast as well, the illusion strength was significant only for the classic ST case [ST: $t(14) = 9.16$, $p < 0.001$; DS: $t(14) = -1.32$, $p = 0.627$; DM: $t(14) = -2.00$, $p = 0.195$] and was stronger in ST than in the two dynamic versions [ST vs. DS: $t(14) = 5.19$, $p < 0.001$; ST vs. DM: $t(14) = 7.53$, $p < 0.001$], which did not differ significantly from each other [DS vs. DM: $t(14) = -0.50$, $p = 0.999$]. To summarize the effects of the dynamic procedure from above, the Ebbinghaus illusion was significantly increased, whereas the Müller-Lyer and contrast illusions were significantly reduced, and indeed, the contrast illusion no longer differed from 0.

Discussion

For the Ebbinghaus illusion, the illusion was enhanced when the inducer size was modulated in synchrony with a continuous displacement of the stimulus (Dynamic Ebbinghaus illusion: Mruczek et al., 2015). Motivated by their studies (e.g., Mruczek et al., 2015; Mruczek et al., 2020a; Mruczek et al., 2020b), we tested the effect dynamic presentation on other illusions: first replicating the Ebbinghaus condition, then adding the orientation contrast and Müller-Lyer illusions.

Although the increased strength of the Dynamic Ebbinghaus illusion was replicated, the other illusions we tested—the orientation contrast illusion and the Müller-Lyer illusion—surprisingly either disappeared or decreased with dynamic presentation. In other words, for the orientation contrast illusion and the Müller-Lyer illusion to occur at the original levels, at least with the configurations we tested, the stimuli should be stationary. Why would dynamic presentation boost one illusion but reduce the two others?

Mruczek et al. (2015) originally proposed that the magnitude of the Ebbinghaus illusion was limited in a static presentation as local receptive fields could accumulate information about the veridical size over time, counteracting the induced size effects. In the dynamic case, however, there would be no accumulation as the test has moved onto different sets of local receptors from moment to moment. This explanation clearly no longer holds. Dynamic versions of the corridor illusion (Mruczek et al., 2020a) and the Ponzo illusion actually decrease (Mruczek et al., 2020b), as we also found here for the orientation contrast and Müller-Lyer illusions. We chose the orientation contrast and Müller-Lyer illusions for our tests here because they are not size contrast effects like the original dynamic Ebbinghaus illusion. However, the lack of a size contrast component cannot be an explanation for the loss of these illusions with dynamic presentation because the other two illusions tested by Mruczek and colleagues were also size contrast effects (corridor and Ponzo), and they too decreased in size with dynamic presentation.

Why is the positive effect of dynamic presentation limited to only the Ebbinghaus illusion? We have no explanation yet, but we speculate that the dynamic Ebbinghaus configuration is the only one that produces an impression of a looming and retreating during its animation. This hypothetical depth effect is not present in the dynamic versions of any of the other illusions. Specifically, in the dynamic Ebbinghaus case, as the surrounds increased in size, the whole figure appears to get closer. Since the central disk remains at the same physical size, it should appear smaller due to size-distance scaling—even smaller than it would for the static disk surrounded by the larger ones. Similarly, as the surrounds shrink in size, they appear farther away and the central disk should then appear even larger due to its increased distance. This suggestion requires that the central disk also changes its apparent depth along with the looming and shrinking surround disks. We propose that the central disk and the surrounding disks are bound in their depth changes only when they move laterally together, binding them together through common fate. In contrast, in the DS condition, the surround may again appear to be looming and receding but the central target is stationary. In this case, the target and surround do not share any common motion, breaking any link between the two. The depth effects, if any, from the looming of the surrounding disks would not generalize to the central disk which then should show only the regular illusion, at best. This proposal of a depth component to the Dynamic Ebbinghaus illusion is speculative but may explain why the dynamic presentations provided little or no boost for the simultaneous orientation or Müller-Lyer illusions here, or the corridor and Ponzo illusions (Mruczek et al., 2020a; Mruczek et al., 2020b): these dynamic animations had no looming or depth component. This proposal will need further study.

Whether the looming hypothesis holds up for the Ebbinghaus case, dynamic presentation did have the unexpected effect of eliminating the orientation contrast and decreasing the Müller-Lyer illusions. One possible explanation would be that some illusions require longer periods (i.e., longer time constant) than others to integrate the information from inducing stimuli. For example, the orientation contrast illusion and the Müller-Lyer illusion may need accumulation of information from inducing contexts and the dynamic presentation may hinder it.

Together with Mruczek's studies, our results highlight the diverse effects of motion dynamics on visual illusions. The Ebbinghaus is not the only illusion to increase with dynamic presentation, but the other examples so far all involve motion-induced effects. Specifically, the motion-induced position shift seen for a stationary Gabor with internal drift (De Valois & De Valois, 1991) increases by an order of magnitude when the Gabor is also made to drift—the double-drift, infinite regress, or curveball illusion (Kwon, Tadin, & Knill, 2015; Lisi & Cavanagh, 2015; Shapiro, Lu, Huang, Knight, & Ennis, 2010; Tse & Hsieh, 2006). Similarly, the motion induced in a stationary spot by a moving frame (Duncker, 1929) also increases by an order of magnitude when the spot itself moves orthogonally to the frame (Wallach, Bacon, & Schulman, 1978). However, most other illusions are reduced when presented in motion (the corridor illusion; Mruczek et al., 2020a, the Müller-Lyer illusion here) or even eliminated (as the orientation contrast here). Further investigations are warranted to clarify determining factors of differential effect of dynamic presentation on visual illusions.

Keywords: dynamic presentation, Ebbinghaus illusion, orientation contrast, Müller-Lyer illusion

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Supplementary material

Supplementary Movie S1.   Ebbinghaus illusion in the DM condition: dynamic surround, moving target. This is a replication of the stimulus from Mruczek et al. (2015). In the movie, the central disk has the same size throughout. In the experiment, participants adjusted the rate of change of the central disk's size so that it appeared to have a constant size at all times.

Supplementary Movie S2.   Orientation contrast illusion in the DM condition: dynamic surround, moving target. In the movie, the orientation of the central Gabor remains fixed throughout. In the experiment, participants adjusted the rate of change of the central Gabor's orientation so that it always appeared to have the same orientation.

Supplementary Movie S3.   Müller-Lyer illusion in the DM condition: dynamic surround, moving target. In the movie, the horizontal line has the same length throughout. In the experiment, participants adjusted the rate of change of the horizontal line's length so that it appeared to have a fixed length at all times.