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Title: Attractive contours of the Ebbinghaus illusion.

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Summary: There is debate as to whether or not the Ebbinghaus illusion is driven by high-level cognitive size contrast mechanisms as opposed to low-level biphasic contour interactions. In this study, we examine the variability in effects that are shared between this illusion and a different illusion that cannot be explained logically by a size contrast account. This comparison revealed that nearly one quarter of the variability for one illusion is shared with the other – demonstrating how a size-contrast account cannot be the sole explanation for the Ebbinghaus illusion.

Introduction

What processes occur along the progression from retinal input to an illusory perceptual experience of the Ebbinghaus illusion? The display causing the illusion consists of an inner circle surrounded by a ring of contextual circles that are physically either larger or smaller than the inner circle. The surrounding contextual elements leads the viewer to perceive the inner circle to appear smaller or larger than it actually is (Fig. 1a). Some researchers invoke a size-contrast explanation, arguing that a cognitive comparison of the physical size of the inner and surrounding circles leads to a perceptual accentuation of their differences (Massaro & Anderson, 1971; Coren & Miller, 1974; De Fockert, Davidoff, Fagot, Parron, & Goldstein, 2007; Gold, 2014). Others favour a lower-level explanation, such as the biphasic contour interaction theory (Weintraub & Schneck, 1986; Roberts, Harris, & Yates, 2005; but see Rose & Bressan, 2002). This theory proposes that contours proximal to the inner circle perceptually attract the edges of the circle while contours further away, past a certain distance, perceptually repel the edges of the circle. The latter fits better with the known properties of activation as measured with functional magnetic resonance imaging (fMRI) and the known characteristics of lateral inhibition of neurons in early visual pathways (Schwarzkopf, Song, & Rees, 2011; Song, Schwarzkopf, & Rees, 2011).

In a recent study published in *Perceptual & Motor Skills*, Jaeger and Klahs (2015) created different versions of the Ebbinghaus illusion by gradually adding tiny circles along the edges of where the contextual circles of the traditional Ebbinghaus figure would normally lay (Fig. 2a-d). During testing, the participants were provided with four cards, each corresponding to a different version of the Ebbinghaus illusion (Fig. 2a-d), as well as a fifth card consisting of only the inner circle to serve as the control. The participants were tasked to rank order the cards, starting with the one that appeared to have the smallest inner circle and ending with the one that appeared to have the largest inner circle.

Jaeger and Klahs (2015) reasoned that the size-contrast and biphasic contour interaction theories each predict a different set of results from their experiment. According to size-contrast theory, the inner circle should appear larger as a function of the number of tiny circles added – in a manner similar to how an average-sized person would appear smaller when surrounded by a greater number of professional basketball players over six feet (or 2 metres) tall (Massaro & Anderson, 1971). In contrast, a biphasic contour interaction account would predict that the apparent size of the central circles would be primarily dependant on contour proximity. Here, tiny circles near the central circle should produce an overestimation whereas their addition at increasing distances along the perimeter of where larger contextual circles would typically lie should result in an underestimation due to increased contour repulsion.

In opposition to size contrast theory, Jaeger and Klahs (2015) did not find any progressive increase in apparent inner circle size from the addition of the tiny circles. Instead, after a certain point, adding more tiny circles decreased as opposed to increase the apparent size of the inner circle. Specifically, the cards containing 1 or 5 tiny circles per each surrounding contextual circle were ranked as significantly higher than those containing 9 or 13 circles per each surrounding circle. The explanation provided by Jaeger and Klahs (2015) was that the addition of a greater number of contextual elements caused greater perceptual repulsion of the edges of the inner circle – favouring the biphasic contour interaction over the size-contrast theory.

Reading Jaeger and Klahs (2015) led us to consider other ways in which one could test the biphasic contour interaction theory. One simple way would be to examine the effects of a different illusion which can be more parsimoniously explained by the biphasic contour interaction theory and see whether or not variability in susceptibility to this illusion is shared with variability in susceptibly to the Ebbinghaus illusion in the same cohort of participants. Such an illusion would be the Delboeuf illusion (Fig. 1b). In this case, an annulus as opposed to a ring of circles surrounds the inner circle. The inner circle appears larger when the surrounding annulus is close to it and smaller when the surrounding annulus is farther away from it. Note how a size contrast explanation cannot really account for this effect. Why? In both cases, the contextual annuli are larger than the inner circle yet we perceive the former as being larger than it actually is and we perceive the latter as being smaller than it actually is (Coren, 1999).

Method

Using the Method of Adjustment, 39 right-handed volunteers (mean age: 22.6 years, age range: 18 to 56 years) matched the size of an inner circle (the comparison stimulus) to the one (the standard stimulus) in the opposing configuration of the Ebbinghaus or Delboeuf illusion. This was done under the following four conditions: 1) matching A1 to A2 in the Ebbinghaus illusion (Fig. 1a), 2) matching A2 to A1 in the Ebbinghaus illusion (Fig. 1a), 3) matching B1 to B2 in the Delboeuf illusion (Fig. 1b), and 4) matching B2 to B1 in the Delboeuf illusion (Fig. 1b). This experiment was created in Flash (Adobe Systems, San Jose, CA).

The participants made their adjustments by pressing “Decrease” and “Increase” buttons on the computer screen. When they felt they matched the comparison to the standard stimulus, they then pressed a “Done” button also on the computer screen. Participants were given as much time as they needed to complete each trial. The participant’s final adjustment was measured as the diameter in pixels. The displays were presented on a computer monitor with an aspect ratio of 16:9. For each participant, the order of the trials was generated randomly. The standard stimulus was always 40 pixels in diameter (corresponding to a visual angle of 2.6°) while the comparison stimulus was initially presented either 30 or 50 pixels in diameter. Four trials, each corresponding to one of the four different starting combinations, were presented per illusion for a total of 8 trials. Normalised indices of susceptibility to each illusion were calculated as [(Perceived Size in Configuration 2 – Perceived Size in Configuration 1) / (Perceived Size in Configuration 1 + Perceived Size in Configuration 2); configuration 2 denoting the condition one would expect to see greater judgements in perceived size] in the same way as one of us has done in a previous publication (Chouinard, Noulty, Sperandio, & Landry 2013).

Results

One-sample t-tests revealed that participants were susceptible to both the Delboeuf [$t(38) = 10.96$, $p < .0001$, $M = .080$, $SD = .046$, Cohen’s $d = 1.75$] and the Ebbinghaus [$t(38) = 14.31$, $p < .0001$, $M = .104$, $SD = .046$, Cohen’s $d = 2.29$] illusions (Fig. 3a). A paired sample t-test revealed that the participants were more susceptible to the Ebbinghaus relative to the Delboeuf illusion [$t(38) = 3.30$, $p = .002$, Cohen’s $d = 0.54$] (Fig. 3a). More importantly, for the purposes of this investigation, we wanted to determine the degree to which susceptibility to each of these illusions correlated with each other, demonstrating shared variability in the effects induced by the two illusions. As shown in Fig. 3b, a Pearson correlation revealed that the two were correlated ($r(37) = .493$, $p < .001$) with 24.3% of the variability in one explaining the variability in the other ($R^2 = .243$). In other words, nearly a quarter of the underlying cognitive processes could be construed as being shared between the two illusions.

Discussion

Based on our findings along with converging evidence, we propose that the Ebbinghaus illusion is dependent upon low level visual processes, likely related to biphasic contour interactions, which operate independently of high level mechanisms related to size contrast processing. If one considers the difficulties of size-contrast theory to explain the Delboeuf illusion and that susceptibility to both the Delboeuf and Ebbinghaus illusions share nearly a quarter of the variance explaining the other then a size-contrast account cannot be the sole explanation for the Ebbinghaus illusion. Furthermore, there are many reasons as to why size contrast cannot sufficiently explain the Ebbinghaus illusion.

Logically, size contrast must involve high level mechanisms given it requires one to first recognise various elements in a visual scene as being distinct before a comparison can be made. Further underscoring size contrast as a cognitive process is the known influence of semantics. For example, effects are reduced when comparing an average-sized adult standing beside an average-sized tree relative to when this same adult is standing beside an unusual tall tree such as either the Coast Redwood in California or the Mountain Ash in Tasmania. On the other hand, similar kinds of semantic manipulations in the Ebbinghaus illusion (e.g. comparing the effects of small blueberries and large oranges as inner and contextual circles with standard configurations) has no effect on susceptibility when the physical features of the stimuli are well-controlled (Rose and Bressen, 2002). Given that semantics can accentuate size contrast but has little to no influence on the Ebbinghaus illusion, it then follows that size contrast may not play an important role in explaining the illusion.

On the other hand, biphasic contour interaction theory could be explained by low level mechanisms. Studies that have used interocular techniques to present the inner circle of the Ebbinghaus display in one eye and its surrounding contextual circles to the other eye have shown that the susceptibility to this illusion is hampered significantly compared to when these elements are presented to both eyes (Song et al, 2011). These results suggest strongly that the Ebbinghaus is driven primarily by low level as opposed to high level mechanisms given that the retina and the lateral geniculate nucleus are the only brain structures that process visual information from only one eye (Hubel and Wiesel, 1962; 1968). Neurons in early cortical visual areas also process information from eye but their numbers decrease greatly as visual information is processed beyond the lateral geniculate nucleus (Hubel and Wiesel, 1962; 1968). Conversely, other illusions, such as the Ponzo illusion, have been shown to be as strong when the target stimuli and the contextual elements are presented separately to each eye as compared to when they are presented on both retina (Song et al, 2011). Thus, some illusions depend more on high level mechanisms than others. The Ebbinghaus illusion being one that is dependent on low level mechanisms.

In closing, it appears that the Ebbinghaus illusion is driven by low level mechanisms, which is more in line with the biphasic contour interaction theory than it is with the size contrast theory. The precise nature of these low level mechanisms requires further investigation. This study does not confirm that the biphasic contour interaction theory is correct but rather provides evidence undermining a size-contrast explanation.

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Figures

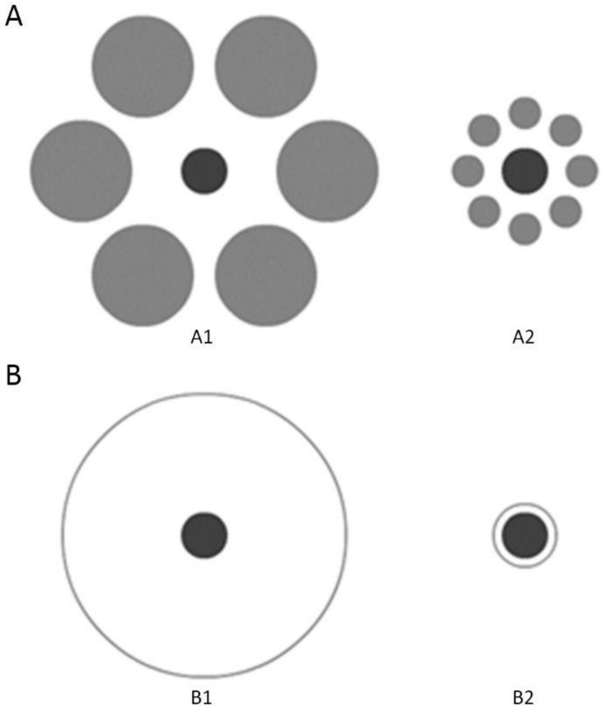

Fig. 1. Ebbinghaus and Delboeuf illusions. Panel A shows the Ebbinghaus illusion and Panel B shows the Delboeuf illusion. In both cases, the apparent size of the inner circle on the left appears smaller than the one on the right – although both inner circles have the same physical size.

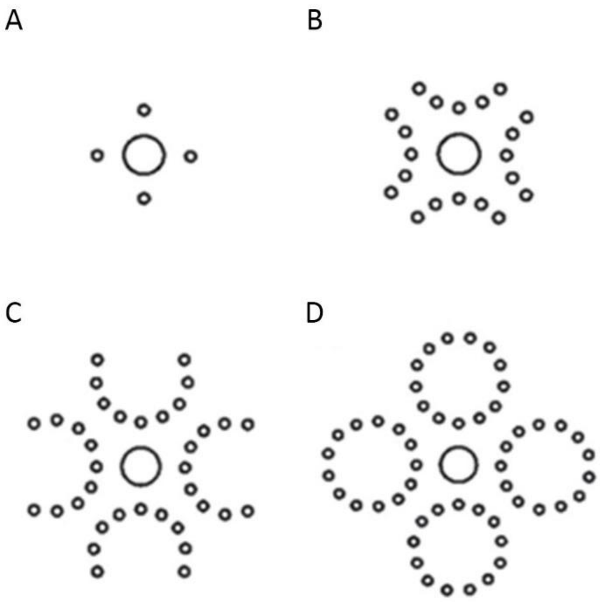

Fig. 2. The stimulus set used by Jaeger and Klahs (2015). Panels A-D show the cards that Jaeger and Klahs (2015) presented to their participants. The cards had 1, 5, 9, or 13 tiny circles located progressively along the perimeter of where the large contextual circles of the more traditional Ebbinghaus figure would lay.

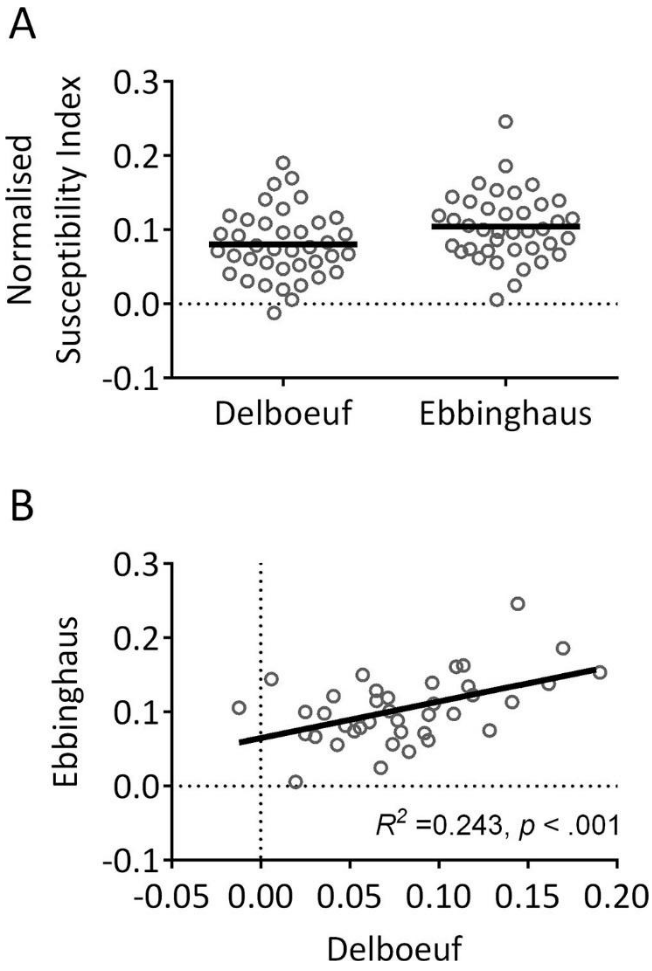

Fig. 3. The results. Panel A denotes each individual (grey circles) and group average (black lines) susceptibility scores for the Delboeuf and Ebbinghaus illusions. Both illusions showed a significant effect (both $p < .001$) and there was a significantly greater effect for the Ebbinghaus compared to the Delboeuf illusion ($p = .002$). Panel B illustrates the correlation between the Delboeuf and Ebbinghaus illusions ($R^2 = 0.243$, $p < .001$).