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Congruent familiar size relationships decrease size contrast illusion

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A thesis submitted in partial fulfillment of the requirements for the Master of Science degree in Psychology

CONGRUENT FAMILIAR SIZE RELATIONSHIPS DECREASE SIZE CONTRAST ILLUSION

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by

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Abstract

We examined the effect of familiar size of objects on size perception. Participants matched the size of a target image to the perceived size of a central image in the Ebbinghaus illusion. The central image was identical throughout all trials (a 25-mm-wide dog), but the annuli varied in physical size (12 mm vs. 37 mm), semantic category (animate vs. inanimate), and familiar real-world size (cat vs. horse for the animate category; shoe vs. car for the inanimate category). Importantly, the familiar size relationship between the center and the annuli was either congruent (e.g., dog surrounded by *small* shoes or large cars) or incongruent (e.g., dog surrounded by *large* shoes or small cars). The illusion was smaller in the congruent conditions than the incongruent conditions for the inanimate category. These results show that perceived size is affected by familiar size relationships.

Keywords: familiar size, size contrast illusion, size perception, Ebbinghaus illusion, relative size, real-world congruency, semantic similarity.

Dedicated to Asia Dalnova.

Acknowledgements

My gratitude goes towards my supervisor Dr. Jody Culham for a fundamental learning experience that has helped me to become congruent with the standards of the Culham lab. Many thanks go to my advisor Dr. Melvyn Goodale who inspired me to re-invent the Ebbinghaus illusion. I am also grateful to Kevin Stubbs who immensely helped me with launching the online study and to my lab mates, friends and family for encouraging me along the way.

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Congruent Familiar Size Relationships Decrease Size Contrast Illusion

In our everyday lives, objects that are larger than others in the real world subtend larger sizes on the retina. For example, a car will be larger in retinal size than a dog when they are viewed at a comparable distance. However, this size relationship is not guaranteed. For example, a car further from a dog may subtend an equivalent retinal angle; alternatively a car picture in a magazine may be the same size as a dog picture. As such, one may wonder whether the visual system takes familiar size (that is, the typical physical size of the object in the real world) into account during object recognition. Certainly, the phenomenon of size constancy (Murray, Boyaci, & Kersten, 2006; Sperandio, Chouinard, & Goodale, 2012) indicates that the visual system takes viewing distance into account in perceiving size; although as noted, typical laboratory experiments (usually on computer screens) often violate the real-world size relationship.

Everyday observations show that people accurately recognize objects depicted in all different sizes and forms from small line drawings to large sculptures. For example, in childhood we easily recognize toy miniature furniture in a dollhouse or a toy model of an airplane. Similarly, we effortlessly identify faces on a huge cinema screen or landmarks such as the Eiffel tower in a postcard even though the combination of physical size, retinal size, and viewing distance is implausible in the real world. Additionally, electrophysiological studies in monkeys found the so-called ‘size-invariant’ neurons in the inferotemporal cortex that respond to objects presented in any size (Ito, Tamura, Fujita & Tanaka, 1995). These neurons ensure that we accurately recognize a dog both from a distance when it subtends a small area on the retina and when it is aiming to lick our face and fills the visual field. Indeed, our effortless ability to recognize objects when they appear both in their familiar and unusual sizes supports the existence of a size-invariant object representation.

However, there is an on-going debate whether neural representations of objects incorporate familiar size. From daily experiences we learn the way familiar objects look, distances at which they appear, and interactions they afford. Based on these experiences, objects become associated with familiar size, distance and affordances. As such, we learn that cars are large, usually are far away (when seen from outside) and are used for transportation; in contrast, shoes are small, appear close and are used as footwear.

Objects of different sizes are typically seen at different distances (e.g., trees are typically seen from a further distance than cups); as such they may be projected upon different parts of the retina and processed in different parts of visual cortex. Specifically, large objects and scenes are usually viewed in the periphery and require low spatial resolution to be recognized, and are therefore processed in occipitotemporal regions associated with peripheral vision (e.g., parahippocampal gyrus); whereas, small objects (such as faces) are usually viewed in the fovea and require high spatial resolution to be recognized, and are consequently processed in occipitotemporal regions associated with central vision (e.g., fusiform gyrus; Malach, Levy, & Hasson, 2002). Importantly, activation in visual brain areas depends more on the familiar size of objects, learned through the real world experiences than the size of the projected image on the retina (Konkle & Oliva, 2012b). Given that familiar size appears to be a critical organizing principle within the visual system, perhaps it has more of an influence on visual perception than previously realized.

Traditionally other features of objects (e.g., form and material properties; Craddock & Lawson, 2009; Hsieh, Vul, & Kanwisher, 2010) have been studied in far greater detail, but recent research suggests that perception of objects is also affected by their familiar real-world size. Konkle, Oliva and their colleagues have conducted a series of behavioural experiments that showed how familiar size affected object perception. In one study they found that, compared to objects that are small in the real world (e.g., an apple), objects that are large in the real world (e.g., a car) are drawn or imagined at a larger size and judged as more aesthetic when shown at a larger size (Konkle & Oliva, 2011). In another study they found that when judging which object is physically larger or smaller on the screen, people are faster to answer correctly when the physical size relationship between the objects is congruent with their familiar size relationship (an effect deemed the “Familiar-Size Stroop Effect”; (Konkle & Oliva, 2012a). For example, participants were faster to respond correctly that an image of an alarm clock was smaller than an image of a horse, than to respond correctly that an image of a horse was smaller than an image of a clock, because the former relationship between the objects’ physical sizes is congruent with their real-world size relationship while the latter is not. The finding suggests that the brain cannot ignore the familiar size relationship between these objects and takes extra time to filter out the familiar size information to focus only on the physical representation of these objects. However, this finding does not answer the question of whether familiar size information actually affects object size *perception* per se or whether the brain simply uses this extra time to form an accurate percept of an object size despite the automatic access of knowledge of its familiar size.

Although the earlier work showed that familiar size influences various cognitive decisions they did not directly test effects on perceived size (Konkle & Oliva, 2011; Konkle & Oliva, 2012a). The aim of the current experiment was to determine whether familiar size of objects in the real world affects the perceived size of these objects in images. A well-established paradigm that allows us to measure the perceived sizes of two targets relative to one another is the Ebbinghaus illusion (sometimes also called the Titchner circles illusion; Girgus & Coren, 1982).In the classic version of this famous paradigm (Figure 1), the perceived sizes of two circles are compared, with one circle surrounded by larger circles and the other surrounded by smaller circles. Even when the two central circles have the identical physical size, the one surrounded by small circles is perceived as larger than the one surrounded by large circles. This illusion suggests participants cannot help but make size judgements relative to other objects in the scene. But is the illusion affected not just by relative physical size, but relative familiar size?

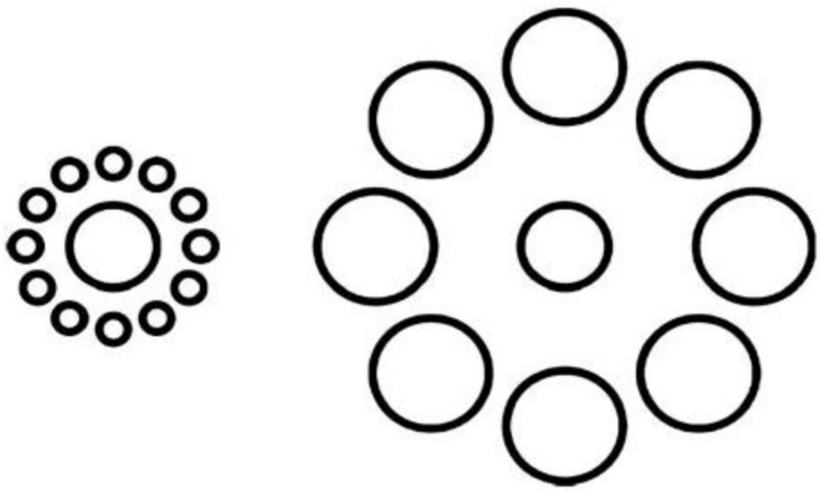

Figure 1. Two physically identical central circles in the Ebbinghaus illusion appear to be different in size when the perceptual system takes into account relative size of the surrounding circles.

In order to study the familiar size effect in the Ebbinghaus illusion, the images need to have a strong familiar size relationship learned from real-world experiences. Conveniently, the Ebbinghaus illusion has been shown to occur for a wide variety of stimuli, from simple geometrical shapes to line drawings of common objects and animals

(Rose & Bressan, 2002; Van Ulzen, Semin, Oudejans & Beek, 2008).For example, when Coren and Enns (1993) used line drawings of animals and man-made objects, they found an illusion of comparable strength to the classic Ebbinghaus illusion with circles. They also found that the illusion strength decreased with the decrease in semantic similarity between the central and surrounding images. For example, when the illusion employed a line drawing of a dog in the center, the size misperception was largest when the surround comprised identical images of the same dog, followed by dogs of other breeds, then other four-legged domestic animals and man-made objects. However, in their study, familiar size of the surrounding and central images was not controlled.

In the current experiment, we investigated whether perceived size of the central image in the Ebbinghaus illusion would be affected by the familiar size of the surrounding images. The task was to estimate perceived size of the central image, which was a line drawing of a Dalmatian dog of a constant physical size. Manipulating the physical size of the surround should induce a size contrast illusion of a regular strength (i.e., ~ 1 mm), with the central image being perceived smaller amongst the physically larger surround than the image amongst the physically smaller surround (e.g., Figure 2, top row).

More importantly, varying familiar size of the surround allowed us to manipulate congruency of the stimuli with the real world. For example, a display with a Dalmatian dog surrounded by physically smaller shoes would be congruent with our experiences in the real world, but a display with a dog surrounded by physically larger shoes would be incongruent. We predicted that the illusion would occur for pairs of stimuli in which the size relationships were incongruent with the real-world relationships (e.g., in Figure 2, a dog surrounded by large shoes should be perceived as substantially smaller than a dog surrounded by small cars) but that the effect of the illusion would be weaker or absent for congruent pairs (e.g., a dog surrounded by large cars may be perceived as similar in size to a dog surrounded by small shoes).

When estimating the size of a central Dalmatian dog amongst identical dogs of a physically larger size, the simplest interpretation is that the central dog is a “mutt” (i.e., smaller than typical size); whereas, when presented amongst identical dogs of a physically smaller size, the simplest interpretation is that the central dog is larger than the average Dalmatian. As such, a robust perceptual size contrast illusion occurs. In contrast, when the dog is surrounded by cars of a physically larger size, the simplest interpretation is that the Dalmatian not a mutt, but simply appears smaller because of the relative real-world sizes; similarly, when the dog is presented amongst shoes of a physically smaller size, again the simplest interpretation is that of a normal-size dog. As such, the size contrast illusion is expected to be smaller or absent. In the incongruent case (e.g., Dalmatian surrounded by small cars or large shoes), the illusion would still be expected to be present or even enhanced.

We also expected to replicate the finding of Coren and Enns (1993) that the semantic similarity would affect the visual size estimation. Specifically, the illusion strength would decrease with the decrease in semantic similarity of images from the same semantic category to other animate and inanimate objects.

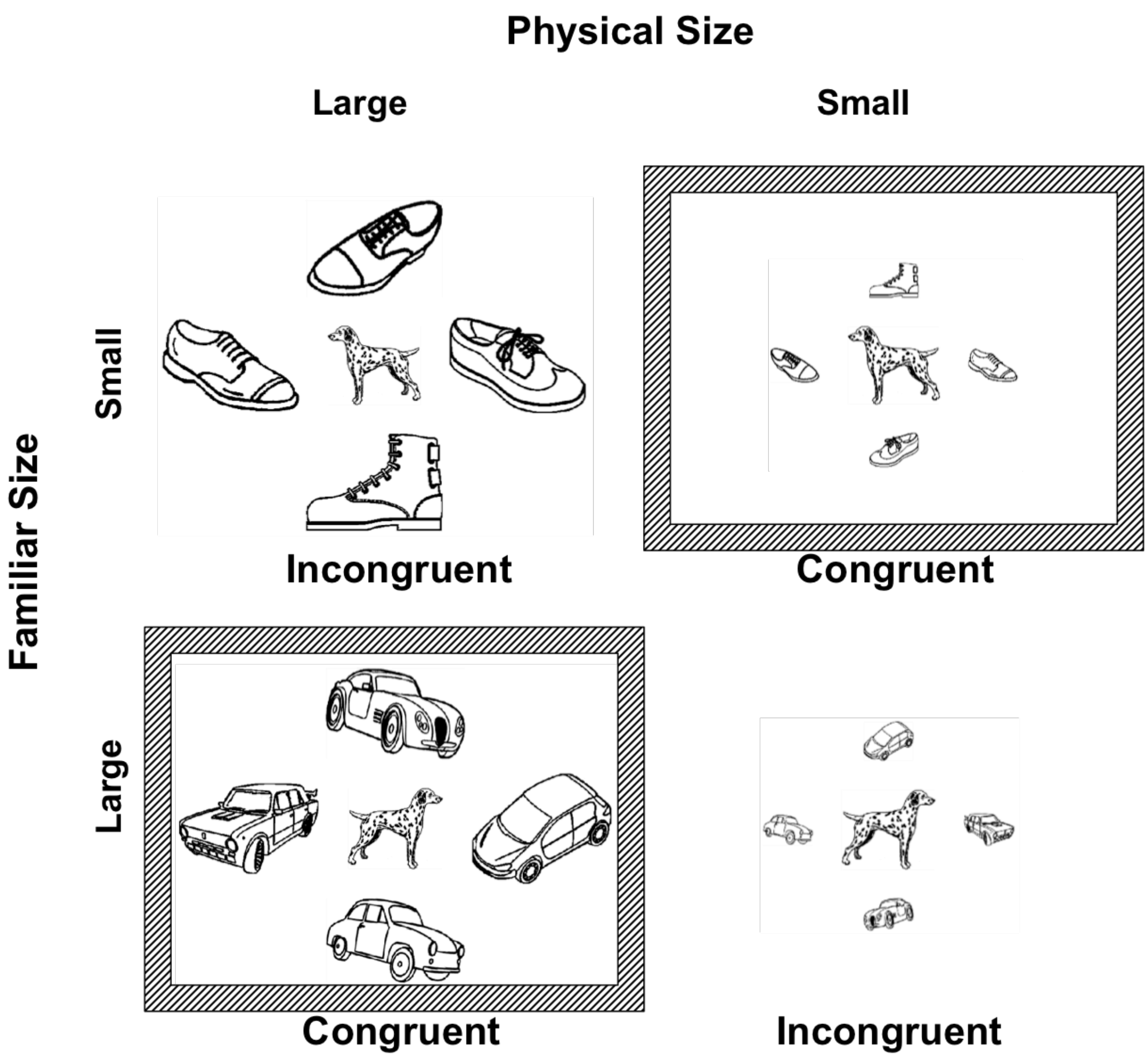

Figure 2. Combinations of the annuli's physical and familiar sizes result in the conditions that are either congruent or incongruent with the size relationships of these objects in the real world. The grated frames indicate the congruent conditions that were predicted to not be affected by the size contrast illusion. The figure shows the inanimate semantic category, but the same combinations were present in the animate category. The ratios of the images and the distances between them are identical to the actual experimental display.

Method

Participants

A total of 140 undergraduate psychology students voluntarily participated in an online study listed on the Western University Department of Psychology participant pool in exchange for half a research credit (mean age =18.39, SD = 0.69; females = 28 out of 77 demographic data points). Participants were instructed to withhold from participation if they had a history of strabismus ("lazy-eye"), so that only volunteers with normal or corrected-to-normal vision were asked to participate. Following data screening (see Data Preprocessing section below), data from 74 participants were included in the final analysis. The study was approved by the Western Non-Medical Research Ethics Board (see Appendix A).

Stimuli

As mentioned earlier, the central image was a line drawing of a Dalmatian dog of constant size (32-mm wide x 27-mm high) in all trials. Our primary manipulation used a 2x2x2 design with surrounding images that varied on three dimensions: (1) physical size was either 17 mm in width for the small annuli or 47 mm for the large annuli; (2) familiar size was either small as in cats and shoes or large as in horses and cars; and (3) semantic categories were animate (cats and horses) and thus in a similar semantic category as the central dog image or inanimate (shoes and cars) and thus in a different semantic category than the dog (Figure 3 shows the categories for the case of the larger physical size only). In addition to the latter manipulation of semantic categories, to replicate Coren and Enns (1993), we also included three other conditions (not part of the primary factorial design): (a) the dog with no surround; (b) the dog surrounded by the identical dogs (semantically and visually identical); and (c) the dog surrounded by other dog breeds (semantically similar but visually different). For each of the six surround types (i.e., identical dogs, other dog breeds, horse, cat, car, shoe) we also included trials in which the physical size of the surround matched the physical size of the central image. These trials made the task less monotonous and ensured that participants did not habituate to the physical size differences between the central and surrounding stimuli in the experimental conditions.

We varied the orientation of the stimuli (whether the elements faced left or right) by using six orientations (each occurring in 16.7% of the trials for each condition, in random order), as shown on Figure 3: all four surrounding and the central images facing left vs. right; the top and bottom images facing left vs. right with the center image following them and the side images facing in the opposite direction; or the side pictures facing left vs. right with the center image following them and the top and bottom images facing in the opposite direction.

The task was to adjust the size of a target image, an outline of the dog (see Figure 4), until it matched the perceived size of the central image. On each trial, the target was presented at a variable starting size and participants used the up and down arrow keys to adjust its size and then pressed the enter key when they were satisfied. The direction of the target always matched the direction of the central image.

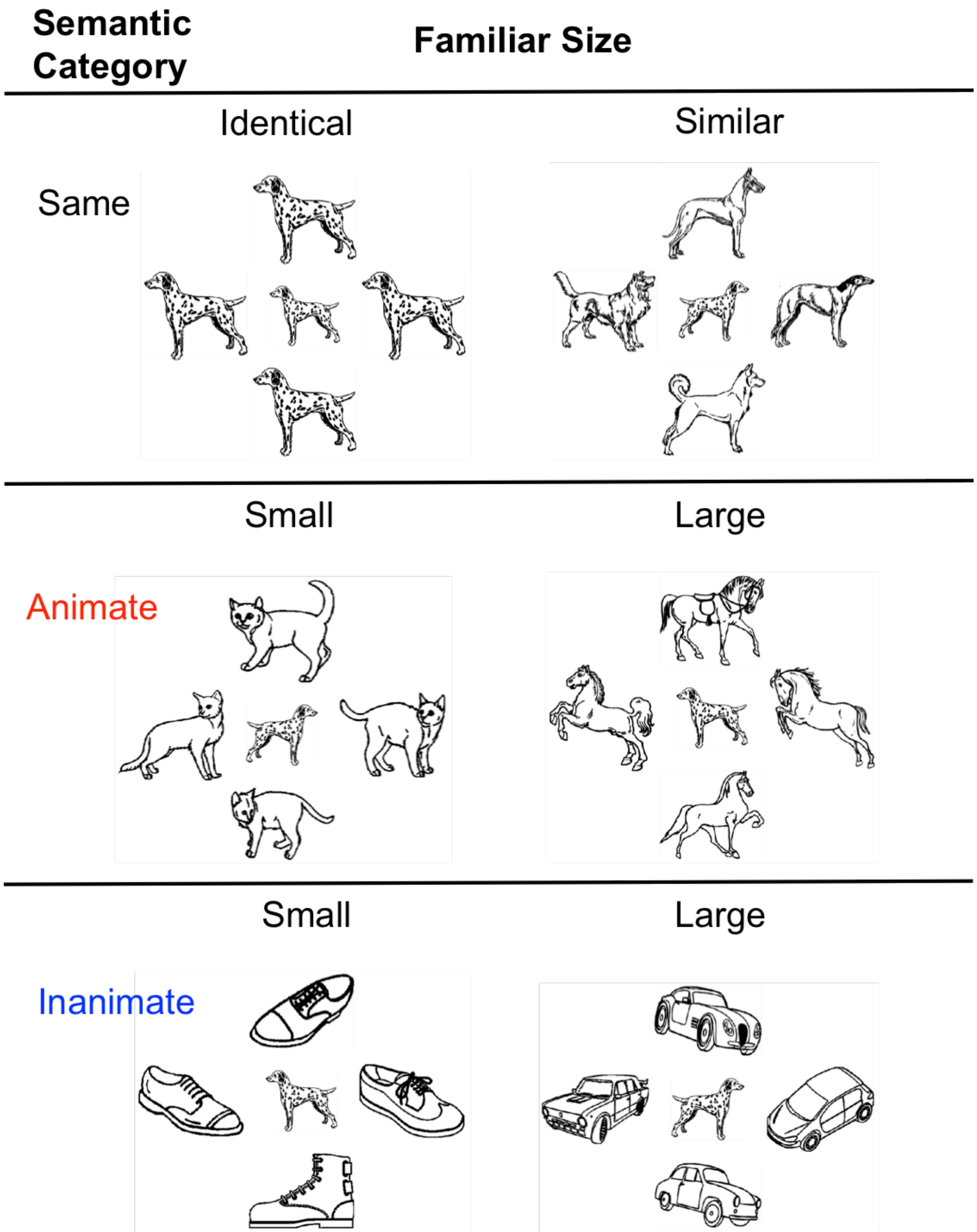

Figure 3. Annuli categories divided by familiar size and semantic category relative to the central image. The annuli from the same category as a central image do not differ by familiar size, while the animate and inanimate categories do. Semantic categories are also arranged by the similarity to the central image from high to low semantic similarity from

same to inanimate. All six possible image orientations of the images are displayed. The displayed annuli belong to the large annuli condition (47-mm wide), but the same conditions were present in the physically small condition (17-mm-wide).

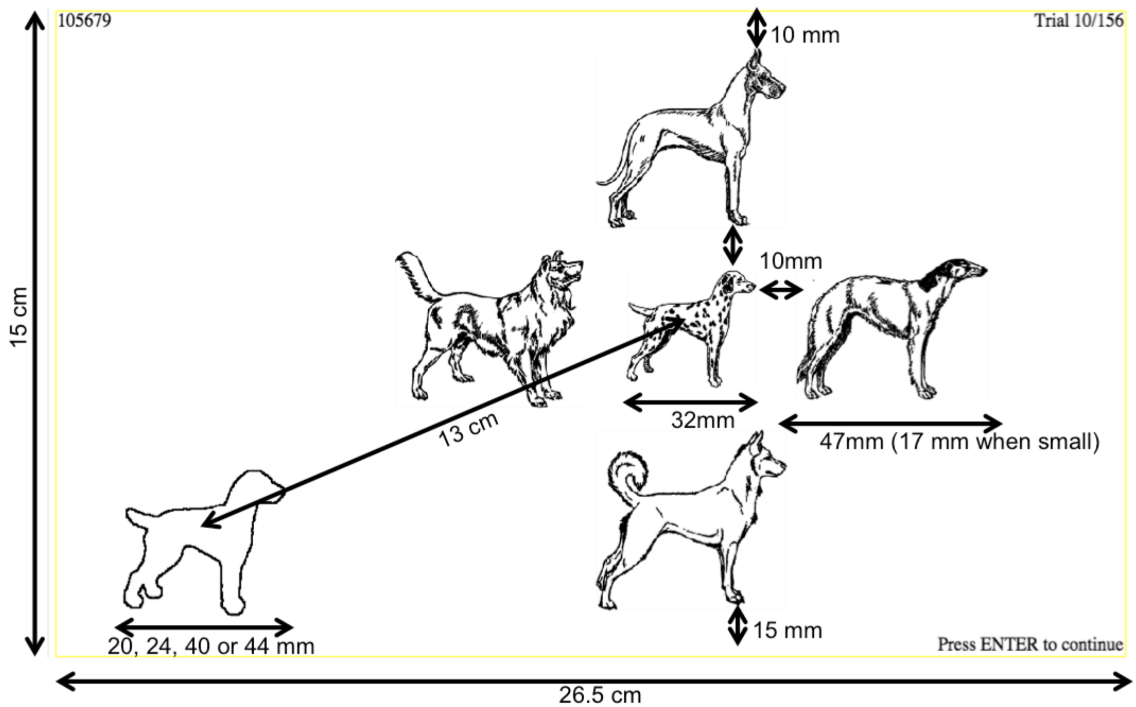

Figure 4. Experimental display with the stimuli sizing. Yellow box served as a self-check for the appropriateness of the participants' monitor size.

Experimental Display

Figure 4 shows the arrangement of the experimental display as it appeared to the participants in the physically large 'identical dogs' condition. The size of the experimental display was fixed at 26.5 cm wide and 15 cm high. The central image was 10 mm away from the edges of the surrounding images and 13 cm diagonally from the center of the target. The target image started off 8 mm or 12 mm smaller or larger than the 32-mm-wide central image (i.e., 20, 24, 40 or 44 mm) on equal number of trials across the conditions (i.e., each starting size occurred 25% in each condition) in random order, with the target randomly occurring between the left and right sides of the display (50% of the trials each for each condition). The top and bottom edges of the annulus were 10 mm and 15 mm away from the borders of the display, respectively. The experiment was programmed using Adobe Flash Professional (2013) and viewed by participants in a web browser.

Procedure

Participants received a link to the experiment once they signed up for the study. After reading the Letter of Information they indicated their consent by pressing a ‘space’ bar on a keyboard, and were asked to provide basic demographic information. In order to advance to the task, participants were required to successfully calibrate their monitor size. They were given three attempts to measure and accurately input the size dimensions of a rectangle that appeared on their monitors. The measures of the rectangle’s size were converted by the program into the monitor size used to resize the experimental display so that it would match between the participants regardless of their monitors’ dimensions. To ensure that the display was resized correctly, the participants measured the second rectangle, the size of which was known to the experimenters and would have been accurate if the first measures were made correctly. If the entries for the second rectangle were incorrect after the third try, the participant was unable to proceed with the experiment. The monitor size information was also used to screen participants with the monitors less than 13” in diagonal. Then, participants were instructed to position themselves at arm’s length from the screen to minimize the intersubject difference in the resulting visual angle of the images. Finally, participants read the instructions and completed one practice trial.

The task was to estimate the size of the central image in the Ebbinghaus illusion by adjusting the size of the outline target image. The up and down arrow keys on the keyboard increased or decreased (respectively) the width of the target image by 0.3 mm per key-stroke (with a proportionate change in height to maintain a constant aspect ratio). To prevent participants from matching the target image to the central image by paying attention to pixels in the particular part of the image, the contours of the target image were slightly rounded so that it did not exactly match those of the central dog. Once the image was adjusted to a satisfactory size, participants pressed the ‘enter’ key to proceed to the next trial. The outline image could have been adjusted to the minimum size of 12 mm and the maximum size of 47 mm in width. Altogether, there were 156 randomized trials with eight trials in each experimental condition and 12 control trials in the “no surround” condition.

Data Preprocessing

Given potential concerns about the quality of data from online studies, we did careful preprocessing of the collected data (140 participants) to ensure that participants completed the study with appropriate care. The data were preprocessed in three major steps. First, we removed the data of eight participants whose computer monitor was too small (i.e., smaller than 13” in diagonal). Second, we cleaned the data on the trial-by-trial basis. The trials on which the number of adjustments differed from the mean (M = 26.8, SD = 9.6) by -/+ 2 SD were removed, namely the trials on which participants adjusted the outline target image by less than 2.1 mm (7 or less adjustments of 0.3 mm) or by more than 14.1 mm (47 or more adjustments). The trials on which participants took 2 SD longer or shorter than the average of 4390.5 ms to complete a single trial were removed, namely those that were below 191.2 ms and above 8589.9 ms. Additionally trials that were shorter than 1500 ms were removed due to the low likelihood of making a sufficient number of adjustments (recall that with starting sizes 8- or 12-mm different from the central item, at least 24 adjustments would be expected on average). After the second step of data cleaning, 120 participants who had more than 10 trials per each image type of both physical sizes remained. For the third step of data cleaning, we removed the participants who experienced an illusion strength of less than 0.6 mm in the 'identical dogs' condition, which included 25 participants with a negative illusion and 21 with a positive illusion less than 0.6 mm, leaving a sample of 74 participants in the final analysis. This latter step ensured that all subjects experienced a robust Ebbinghaus illusion under the most typical circumstances, as expected (particularly considering the online nature of the study); however, inclusion was based on a condition other than the main ones of interest (congruent and incongruent size conditions) to avoid biasing the results of that analysis.

Results

Our key question was whether the Ebbinghaus illusion would be stronger for incongruent than congruent size relationships between the central and the surrounding images. However, to investigate the illusion in general and compare our results to Coren and Enns (1993), we first explored whether the illusion occurred at all in six conditions and how the illusion magnitude varied between the conditions. Figure 5A shows the target size adjusted to match the central dog reflecting its perceived size across all conditions. As seen of the Figure 5A, the illusion occurred for each condition; that is, participants perceived the central image as smaller when surrounded by physically large than small items. However, participants adjusted the target's size closer to the actual physical size of the center in the physically small surround conditions compared to the target's adjusted size in the physically large condition. Additionally, the perceived size of the central image in the control condition with no surrounding was also underestimated relative to the actual physical size of the central image. The data on the Figure 5A suggest that even though the perceived sizes of the central images in the physically large and small conditions were different from each other in the direction consistent with the Ebbinghaus illusion, overall, the target was always under-adjusted. The under-adjustment could have occurred because the target outline did not exactly match the central image (recall that the edges of the target were slightly rounded to prevent participants from utilizing a pixel-matching strategy), which could have resulted in a perceptual distortion.

A 2 (annulus physical size: small vs. large) x 6 (condition: identical dogs, other dog breeds, horse, cat, car, shoe) repeated-measures analysis of variance (ANOVA) showed that across all image types participants estimated the size of the central image surrounded by the physically large annuli smaller than the size of the central image surrounded by the physically small annuli, expressed by a significant main effect of the annulus physical size ($F(1,73) = 179.44$, $p < .001$). There was a main effect of condition ($F(5, 365) = 7.60$, $p < .001$), which was modulated by a significant physical size by condition interaction ($F(5, 365) = 15.88$, $p < .001$), indicating that the participants misestimated certain image types more than others. To interpret the interaction more easily in the context of our hypotheses, we did two further analyses.

Figure 5B summarizes the same data in terms of the illusion size (perceived size of central image for small surround vs. large surround). We collapsed the cat and horse, and the shoe and car conditions into animate and inanimate semantic categories, respectively, to quantify the semantic similarity effect. The post-hoc analyses showed that the illusion magnitude was the strongest when the surround was identical dogs, followed by dogs of other breeds, and by the animate and inanimate categories that were not statistically different from each other. As previously found by Coren and Enns (1993) the illusion strength indeed decreased with the decrease in semantic similarity between the central and surrounding images, with the semantic similarity effect being confirmed by the current replication.

To measure the familiar size effect on size estimation we compared illusion magnitudes between the congruent and incongruent conditions in both animate and inanimate categories. Here, the illusion magnitude was calculated within a familiar size congruency category. For example, the illusion magnitude for the congruent inanimate category was calculated as the difference between the size estimates in the large car and the small shoe conditions. The illusion magnitude for the incongruent inanimate category was calculated as the difference between the size estimates in the small car and large shoe conditions. As seen in Figure 6, the illusion magnitude in the congruent inanimate condition was very low compared to the other conditions. A 2 (congruency: congruent vs. incongruent) x 2 (animacy: animate vs. inanimate) repeated-measures ANOVA showed a significant congruency by animacy interaction, indicating that the illusion magnitude was very low, in fact absent, in the congruent inanimate category but present in the remaining three conditions ($F(1, 73) = 13.57$, $p < .001$). The results showed that the participants perceived the size of the central dog to be the same in the large car and the small shoe conditions, but they estimated the sizes of the central dogs differently in the other three conditions. The difference in the perceived size of the central images in the remaining three conditions went in accordance with the Ebbinghaus illusion with the central image being underestimated in the physically large and overestimated in the physically small annuli conditions (relative to each other) regardless of the congruency with the real world.

In summary, we found that the familiar size of the surround affects the size perception of the central image in the Ebbinghaus illusion by decreasing the size contrast illusion when the familiar size relationship between the central and the surrounding images was congruent with their real-world size relationship.

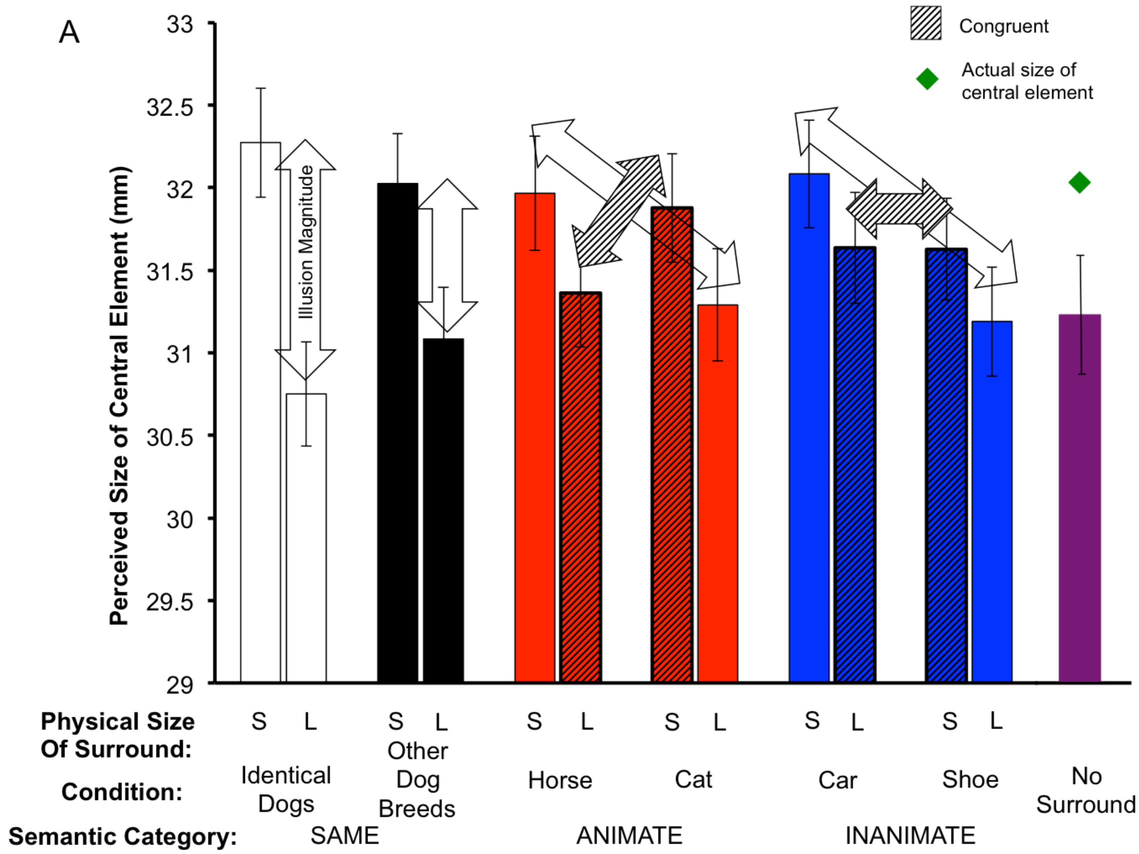

Figure 5. (A) Average perceived size of the central image as a function of the physical size (S = small, L = large) and conditions of the annuli. The grated bars represent conditions with the congruent familiar size relationship. The arrows represent the illusion magnitude expressed by the difference in size estimation between the respective physically small and large conditions. The error bars represent the 95% confidence intervals (CI).

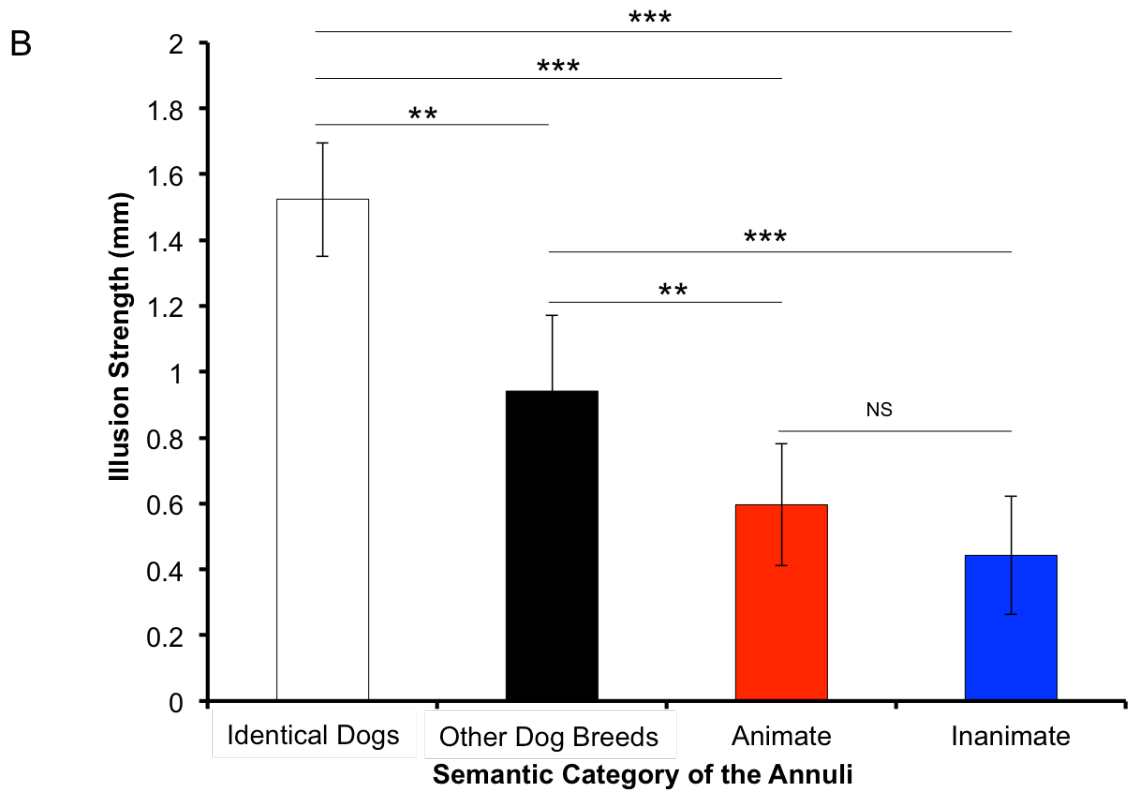

Figure 5. (B) Mean illusion strength as a function of semantic category. The illusion strength was calculated by subtracting the size estimate in the physically large annuli condition from the physically small annuli condition. The animate and inanimate conditions are the averages of the illusion strength in two specific conditions shown in Figure 5A. The error bars represent 95% CI. ** $p < 0.01$, *** $p < 0.001$, NS = not statistically significant.

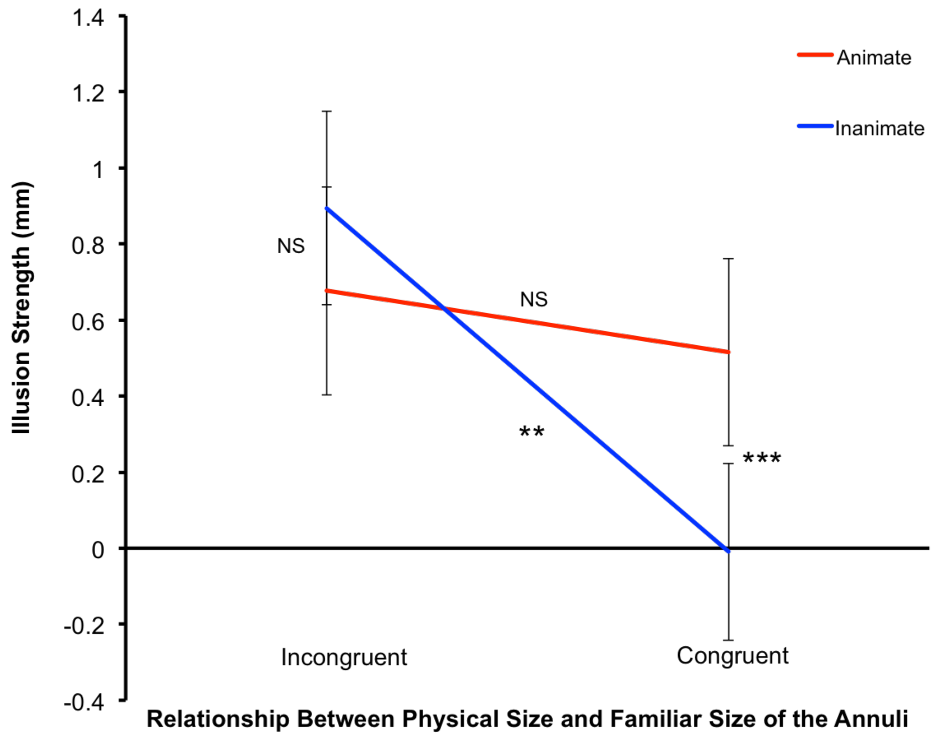

Figure 6. Illusion strength as a function of the congruence and animacy. The error bars represent 95% CI. ** $p < 0.01$, *** $p < 0.001$, NS = not statistically significant.

Discussion

Initially we hypothesized that the size contrast illusion should be weaker when the familiar size relationship between the central and the surrounding images is congruent with their real-world sizes. Indeed, we found that for inanimate objects participants experienced a weaker illusion (in fact the illusion was absent altogether) when the familiar size relationship of the stimuli was congruent, even though they still experienced a strong illusion when this relationship was incongruent. Specifically, the participants did not estimate the size of the dog surrounded by large cars differently from the dog surrounded by small shoes, because these size relationships are congruent with the size of these objects in the real world. Therefore, the visual system was not affected by the size contrast illusion (usually induced using abstract geometrical shapes) when the stimuli had real-world sizes associated with them. Surprisingly, however, familiar size affected only the inanimate conditions but not animate.

Differences Between Inanimate and Animate Stimuli

Retrospectively analyzing why the familiar size affected the semantic categories differently, we noticed a few discrepancies between the stimuli in each category. One of the probable explanations, in our view, for the presence of the familiar size effect only in the inanimate category, is that the animacy may have been confounded with the frequency of co-occurrence in the real world. Namely, participants, who were university students in a relatively big city, may have been more likely to see dogs next to cars and shoes, rather than next to horses and cats, which may be more common in a rural environment. Seeing objects in co-occurrence in the scene builds the knowledge of the objects' familiar size relative to each other; whereas learning particular objects' sizes independently from each other may not completely integrate to produce a strong relative size association.

A second difference between the animate and inanimate stimuli that may have accounted for the results is a difference in the relative familiar size between the objects in the real world. Specifically, the relative size difference between cats and dogs is slightly smaller than between shoes and dogs in the real world; in other words cats are usually smaller than shoes. Similarly, the real-world size difference between horses and dogs is smaller than between cars and dogs. Consequently, stimuli in the inanimate condition had a larger real-world size difference relative to the central image than in the animate condition. However, because the illusion strengths were not statistically different from each other between the animate and the inanimate conditions (irrespective of the congruency), this explanation may not hold.

Third, the stimuli in two semantic categories also slightly differed in size dimensions of the surrounding images between these categories. Specifically, in the physically large condition the animate annuli varied from the central image both in height and width, whereas the inanimate annuli differed from the central image only in its width but were the same in height (see Figure 2). However, it has been suggested that the relative size difference is represented in categorical rather than absolute size differences (Rosielle & Hite, 2009). Therefore, for the familiar size knowledge base to influence the perceived size of the central dog in the Ebbinghaus illusion, neither the dog nor the annuli necessarily need to be depicted in their absolute real-world size, as long as the relative size relationship holds true categorically, that is the dog is smaller than the cars and larger than the shoes.

The last possible explanation is that the relative size differences between the images were not matched for the relative size differences between the real objects. Here the difference between the central and the surrounding images was always 15 mm or 47% meaning that the central dog was 47% smaller than both the large horses and the large cars, and 47% larger than both the small cats and the small shoes. In reality, however, these objects do not differ from each other by this percentage; instead, for instance, the difference between a dog and a shoe is about 80%.

In the follow-up experiments we would like to investigate why familiar size influenced two semantic categories differently in the current experiment by matching the stimuli on the dimensions described above. It would be the most challenging to match the stimuli both for co-occurrence in the real world and for familiarity with these objects. For instance, a display may depict a dog surrounded by tigers versus hedgehogs, but it is unlikely that many participants would have seen these animals in real life, let alone next to each other. Ideally, we will find the objects that are both familiar from daily experiences and that are usually seen next to each other.

Linking and Extending Our Results

Originally, Konkle and Oliva (2012a) found that knowledge of the objects' real-world size affected the size of objects we imagine and prefer to look at and even a reaction time it takes to judge objects' sizes. Specifically, they showed that the reaction times were slower when judging the sizes of objects that were depicted in their incongruent familiar sizes. The current study extends the research on the familiar size effect by quantifying the extent to which familiar size affected object *actual size perception*. Now, having discovered that familiar size affects the actual perceived size of a stimulus, it provides a new paradigm to study these effects, their mechanisms and consequences.

The Ebbinghaus illusion affects our perception by contrasting the size of the central image to the size of the annuli. The visual system judges the size of objects relative to other objects in the scene. The illusion is particularly powerful when the central and surrounding images belong to the same category, because we are literally better in comparing apples to apples. Previous research shows that the size contrast occurs even between objects from different categories (Coren & Enns, 1993), but the current research indicates that the illusion depends on what kind of objects one compares the central object to. Specifically, if the central object is compared to the objects with which it already has a naturally occurring size contrast, then the illusion is much attenuated.

The Ebbinghaus paradigm, however, may not fully tap into the familiar size effect on size estimation, because it does not particularly reflect the real world. That is, in the real world, objects are not arrayed on the frontoparallel plane as they are in the

Ebbinghaus illusion; moreover, the physical size of the items is not appropriate for the viewing distance. Rather, in the real world, objects exist in settings that convey depth (from binocular cues as well as monocular cues such as height in the visual field and linear perspective), and this perception of depth can affect perceived size in a phenomenon known as size constancy. One interesting question is how familiar size and size constancy interact.

One possibility to explore an interaction of familiar size and size constancy on object size perception is to use real objects in the Ebbinghaus illusion. First, such a set up will account for the absence of the visual depth cues in the scene, and second it will provide an opportunity to study the size perception of real objects. Given that objects and images appear to be processed differently in the ventral visual stream (Snow et al., 2011), we would expect a larger effect of familiar size when using real objects because they presumably will activate the object-selective areas (known to be organized by real-world size; Konkle & Oliva, 2012b) to a larger extent than pictures.

Another paradigm that can be adapted to study the familiar size effect by size constancy interaction is the Ponzo illusion, which utilizes pictorial depth cues to induce depth perception (Girgus & Coren, 1982). By introducing the converging lines in the background of objects, the perceptual system automatically calculates the image size in relation to its perceived depth. That is the object that is depicted in the converged end of the lines is perceived farther away and thus appears to be larger than the assumingly closer object.

Interestingly, the Ponzo illusion has been shown to not only affect the size perception but also the brain activation, even at the earliest cortical processing level, V1 (Murray et al., 2006). The brain interprets the size of the figure depicted on the wider and thus closer end of the converging lines to be physically bigger than the identical figure sitting in the narrower and thus farther end at an early stage of visual processing in the primary visual cortex. A larger part of the visual cortex is activated as if the 'further' figure is physically larger than the 'closer' one even though they are identical in retinal size (Murray et al., 2006). If both the size constancy and the familiar size affect object size perception, does familiar size also affect primary visual cortex activation? In the future, we would like to investigate this question using brain-imaging techniques.

In summary, we showed that the size contrast illusion decreased when the familiar size of objects was congruent with their real-world size relationship; however, this effect occurred only for the inanimate annuli. In other words, perception was not affected by the size contrast illusion when the illusory display reflected familiar real-world size difference between the objects. The results suggest that knowledge of the familiar size affects perception of object size. Further, we would like to explore the familiar size effect in a more ecologically valid setting with appropriate depth cues and object sizes.

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Appendix A

File No: 105003 **Project Title:** Perceptual judgments and manipulation of real-world objects and photographs. **Project Work Flow State:** Approval Decision Made

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