

Size Invariance in Visual Object Priming

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The magnitude of priming resulting from perception of a briefly presented picture of an object in an earlier trial block, as assessed by naming reaction times (RTs), was independent of whether the primed object was presented at the same or a different size as when originally viewed. RTs and error rates for “same” responses for old–new shape judgments were much increased by a change in object size from initial presentation. We conjecture that this dissociation between the effects of size consistency on naming and old–new shape recognition may reflect the differential functioning of 2 independent systems subserving object memory: 1 for representing object shape and the other for representing its size, position, and orientation (*metric attributes*). Allowing for response selection, object naming RTs may provide a relatively pure measure of the functioning of the shape system. Both the shape and metric systems may affect the feelings of familiarity that govern old–new episodic shape judgments. A comparison of speeded naming and episodic recognition judgments may provide a behavioral, noninvasive technique for determining the neural loci of these 2 systems.

The “recognition” latency of a shape originally viewed at one size is lengthened when that shape is presented at a different size (Jolicoeur, 1987). This result, and a number of others demonstrating time costs for comparing two simultaneously (or immediately sequential) presented shapes that differ in size (Besner, 1983; Bundesen & Larsen, 1975; Ellis, Allport, Humphreys, & Collis, 1989; Jolicoeur & Besner, 1987; Larsen, 1985; Larsen & Bundesen, 1978) have led to the belief that shapes are stored at a specified scale (Kosslyn, 1987; Ullman, 1989).¹ To achieve matching of the representation of that shape when it is presented at a different size, according to this view, scaling transformations are necessary (e.g., Ullman, 1989). Presumably, the additional time to perform these transformations is the reason why the match of a different-size shape requires more time.

Recognition was placed in quotes in the previous paragraph because, curiously, the effects of size consistency on a relatively direct measure of object classification, basic-level naming, have never been assessed. Jolicoeur’s (1987) measure of recognition was old–new discrimination. Jolicoeur himself cautioned that it was possible that the effects of size inconsistency in his experiment were not reflecting the perceptual representation used for pattern recognition of the object but rather the processes for episodic discrimination.

We report here that Jolicoeur’s disquiet was well founded: Size consistency does not affect basic-level naming reaction times (RTs). We used a picture-priming task where it has been well documented that an object viewed on one occasion

is more quickly and accurately perceived when presented on a second occasion (Bartram, 1974; Biederman & Cooper, 1991, in press; Schacter, Dulaney, & Merikle, 1990). As described later, the design of our experiment allowed separation of a visual component to the priming from a component associated with priming of the general concept or name. We were particularly interested in whether the priming effect on the magnitude of the visual component is dependent on the object appearing at the same size.

Theoretical Issues

This seemingly minor empirical question—whether size consistency affects the magnitude of visual priming of pictures—has profound theoretical implications for how one conceptualizes memory in general and the nature of visual representation for purposes of pattern recognition in particular.

Within limits, we can often remember the shape of an object, its size, its orientation, and where it was in the visual field.² Moreover, there are time costs for comparing shapes

¹ An apparent exception to these results was the absence of an effect of size differences on same–different shape judgments in an experiment by Kubovy & Podgorny (1981). In their experiment, however, only two shapes were used for 800 experimental trials. With such a small set of stimuli, it is possible that subjects derived a low-level strategy that circumvented the effects of size consistency, an interpretation confirmed by Larsen (1985).

² As a rough guide, the aspects of orientation that would be specifiable independent of shape would be those that would be termed viewercentered, rather than objectcentered (Marr, 1982), such as the orientation of the whole object in depth (up to parts occlusion). Orientation in the plane may be specified twice: as part of a shape descriptor of the object-centered relations among parts, namely, TOP–OF, and as a viewer-centered, independently specifiable attribute. There is still some uncertainty as to which aspects of orientation are to be regarded as part of shape descriptions and which are to be regarded as independently specifiable.

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that differ in orientation (Shepard & Metzler, 1971) or for classifying them when they are presented at an unfamiliar orientation (e.g., Tarr, 1989). The studies cited in the first paragraph of this article document similar effects with size. We will refer to the size, position, and orientation in depth as *metric attributes*. There is much speculation as to the neural loci of the various representations presumed to mediate higher level vision (e.g., Kosslyn, 1987; Mishkin & Appenzeller, 1987; Ungerleider & Mishkin, 1982). The implications of the present investigation for this issue will be considered in the General Discussion section.

Integrated Versus Decomposable, Invariant Representations

Integrated representations. One might conclude from such observations that when we look at an object, a single representation specifying object shape, size, position, and orientation is activated so that if the object appeared at another size, position, or orientation, its recognition speed would not be as great as when it occurred at its original size, position, and orientation (Jacoby, Baker, & Brooks, 1989; Kolers & Roediger, 1984; Ullman, 1989). That is, a change in the viewing conditions would result in less priming than when the original viewing conditions were reinstated. From this account, our ability to appreciate the equivalence of two images of one object when they have been seen at different times and at different sizes, positions, and orientations is achieved through the establishment of multiple representations at different viewing opportunities. In general, models that posit precise matching of input values will be compatible with this type of representation. Such models include neural nets (NNs) that posit a single hidden layer between input and output and models that posit matching in pictorial space, with a set of alignment transformations when a new input does not match what is stored in memory (e.g., Lowe, 1987; Ullman, 1989).

Decomposable, invariant representations. In contrast to a representation specifying an integrated perceptual event is one in which shape, for purposes of recognition, is coded independently of size, position, and orientation. Size, position, and orientation invariance of shape priming then would be expected. There are computational advantages in such coding as representations for an object's shape would not have to be duplicated for every retinal position, size, and orientation in which the object was seen. On a priori grounds, it would seem that position, size, and orientation are arbitrary for recognition in that a subsequent encounter with an object would rarely be expected to duplicate the original conditions. Storing an image without independent specification of object shape, in any event, does not solve the problem of how we are able to recognize the identity of two shapes presented at different positions, sizes, and orientations. In particular, if Unit A is used to represent an object at a particular position, size, and orientation, and Unit B is used to represent that object at a different size, position, and orientation, one would still require a process that determines that Units A and B are representing the same object (Hummel & Biederman, in press).

An NN model that yields independent specification of size, position, and orientation in depth from an object's shape has recently been proposed by Hummel and Biederman (in press). The model posits several hidden layers between input units that have receptive fields tuned to orientation and depth discontinuities in the input and output units that are activated by a particular object. The output units are defined as an arrangement (viz., particular relations) of components (Biederman, 1987) independently of the position, size, and orientation in depth of the object projecting the image. Multiple layers in the model are required to achieve descriptors that are translationally, size, and orientation (in depth) invariant.

That the priming of naming RTs may be invariant with position and orientation in depth has recently been reported by Biederman and Cooper (in press) and Biederman and Gerhardstein (1991), respectively.

Size-Sensitive Operations at Input

If it is allowed that shape, for purposes of recognition, might be stored independently of scale, why would it be more difficult to process patterns when they were of different sizes? Results documenting such effects fall roughly into two categories: (a) Stimuli are more difficult to compare in a same-different task (either with simultaneous or successive presentations at brief interstimulus intervals [ISIs]) when they are of different size than when they are the same size (Besner, 1983; Bundesen & Larsen, 1975; Ellis et al., 1989; Jolicoeur & Besner, 1987; Larsen, 1985; Larsen & Bundesen, 1978, Experiment 1) and (b) in tasks that do not necessarily require same-different matching, a trial-to-trial effect has been reported in which a change in the size of the stimulus from the previous trial would result in slower responding (Larsen & Bundesen, 1978, Experiments 2 and 3).

With respect to simultaneous or near-simultaneous same-different matching, it is quite plausible that the comparison of two stimuli could be accomplished with information available at an earlier stage than that required for shape recognition. Thus Ellis and Allport (1986) showed that in the same-different name matching of object pictures, at a 100-ms ISI, there was a sizable advantage in SAME RTs for identical pictures over those trials where the same object was depicted at different orientations in depth. However, this advantage was virtually eliminated at a 2,000-ms ISI. That a relatively early representation might have been responsible for the 100-ms ISI identical advantage was evidenced by the elimination of this advantage when a mask rather than a blank field filled the 100-ms interval (Ellis & Allport, 1986). To cite just one example of an early mechanism, at brief ISIs a change in image size might induce apparent motion with an apparent expansion or contraction of the image.

A trial-to-trial effect in which a change of size from the preceding trial resulted in longer RTs on the subsequent trial was observed by Larsen and Bundesen (1978) for two types of tasks: judging whether a letter was upright or rotated and immediate memory scanning (Sternberg, 1966) for letters. In both tasks, when the letter presented on trial *N* (for judgment of uprightness or as a member of the positive set) differed in

size from the letter that was presented on trial $N - 1$, RTs were lengthened compared with when the letters were of the same size. This was true even when the letters themselves differed.

Larsen and Bundesen (1978) attempted to account for these effects in terms of image and scale transformations. They posited three components in visual recognition: an input image, a set of long-term memory representations specifying the spatial arrangement of pattern elements against which the input image might be matched, and a "variable perceptual reference system" (Larsen & Bundesen, p. 2) that specifies the scale (i.e., the size of the units) for determining the actual points for matching input against memory representation. Scale transformations refer to these variations in the size of the units of the perceptual reference system.

Larsen and Bundesen (1978) hypothesized that image transformations change (a) the size of the image so that it corresponds to a given scale of the perceptual reference system, (b) the size of a visual image generated from long-term memory, or (c) the size of a persisting visual image of the standard (e.g., in a same-different matching task) so that long-term memory could be bypassed. Larsen and Bundesen assumed that both image and scale transformations take time but can proceed in parallel on a given trial. For the most part, Larsen and Bundesen concluded that image transformation costs were generally incurred when performance was based on visual short-term memory (typically in same-different matching tasks), and scale transformation costs were incurred for longer term trial-to-trial size changes.

Larsen and Bundesen's (1978) theoretical interpretation was derived from their assumption that recognition proceeds by point-to-point matching of templates, where size must be specified to determine the locus of points for matching.

An alternative possibility is that the size-change effects are operating as an attentional effect on the initial perceptual coding of the image. Such an attentional effect on stimulus encoding might be regarded as a more parsimonious explanation than image or scale transformation, in that there is ample evidence that people can readily manifest attentional selectivity to different scales (e.g., Martin, 1979; Pomerantz, 1983). Indeed, Larsen and Bundesen (1978) themselves allowed this possibility (p. 19). Moreover, if the memory representation can be in a form that is scale independent, why posit a scale transformation process for its matching? As noted previously, the need to apply a scale transformation to a scale-invariant memory representation derives from the point-to-point matching assumption of template theories.

Naming Versus Familiarity

The possibility that primates may have independent systems for shape and metric attributes raises a serious issue as to how visual "representation" might be assessed with behavioral observations. If the event of perceiving an object activates, say, two representations, one for its shape and the other for its metric attributes, an old-new recognition test could be affected by both representations. After all, the episodic event of seeing an object includes its particular position, size, and orientation in depth. In contrast, speeded naming of an object

need only be determined by the system that represents shape for purposes of recognition. From this perspective, naming RTs might be independent of consistency in size, but old-new judgments might reflect such changes.

Three experiments are reported in this investigation. Experiment 1 used a priming paradigm to assess the effects of image size consistency on object naming RTs. Experiment 2 was a replication of the Jolicoeur (1987) experiment with the object images and viewing conditions used in Experiment 1. Experiment 3 assessed the possibility that the invariance observed in Experiment 1 might have been a consequence of a scale transformation (Larsen & Bundesen, 1978) in which the representations of large and small stimuli were transformed to an intermediate size.

Experiment 1

This experiment assessed the efficiency of size invariance in visual object naming. We used a priming paradigm in which subjects first viewed briefly presented pictures of objects that appeared at one size. Then, in a subsequent block of trials, they had to name the pictures at the original or different size.

Would a representation of shape that was size invariant be expected to manifest itself in this experiment? If limitations of resolution affected different components in small and large images, then it might be the case that the shapes that were initially perceived would differ with different-size images, and invariance would not be expected. Such a case would occur, for example, if in the small images small components would suffer relative to the smaller components of the large images and that in large images the perception of the outer components would suffer because of reduced resolution at greater retinal eccentricities. (Biederman & Cooper, 1991, have shown that it is the components [roughly corresponding to convex or singly concave volumes characterizing the object's parts] that are actually present [and, presumably, perceived] in the image, rather than components inferred top-down, that control priming; see Footnote 3.) They also showed that it was the components [in specified relations] that controlled priming, rather than the image features, namely, lines and vertices, or overall object models, for example, a grand piano.) Fortunately (for the design of this experiment), within several degrees of the center of the fovea, the number of retinal receptors per stimulus component does not vary with variations in image size (O'Regan, 1990). As image size is expanded, for example, the reduced number of cones per unit area is almost exactly compensated by the increased number of cones in the larger area (O'Regan, 1990). So as not to exceed the region where this receptor invariance holds, we used a modest (though quite noticeable) size difference. We also determined that the large and small sizes were indeed of approximately equal difficulty through a calibration study (see the Appendix).

Visual Versus Semantic Priming

In this picture naming task, is it possible that some if not all of the priming could be verbal or conceptual rather than

visual? If a visual component of the priming were size dependent, but verbal and conceptual components were not, then the results could be a consequence of the absence of a visual component in this particular task. The design allowed an assessment of whether there was a visual component of the priming: The priming of identical images was compared with the priming of same-name–different-exemplar images. For example, an upright piano might be displayed on the first block of trials and either that same image or a grand piano displayed on the second exposure. An advantage of the identical images on the second block of trials would indicate that some of the priming was visual rather than verbal or conceptual. However, the advantage of the same exemplar pairs might be attributable to their greater semantic overlap. That the advantage of same exemplar images over different exemplar images is indeed visual is indicated by the results of a recent investigation by Biederman and Cooper (1991). They investigated the priming of naming a complex object image, such as a piano, airplane, or elephant, that had half of its parts (geons) removed. On the second trial block, subjects viewed either the identical image, the complement (composed of the parts that had been deleted in the initial presentation), or a same-name–different-shape exemplar instance (also with half its parts). By any account, more semantic overlap would be associated with the identical and complementary images than with the complementary and different exemplar images. But whereas shorter RTs and lower error rates were associated with naming the identical images, there was no difference between the complementary and different exemplar images. This result suggests that in these picture naming tasks, none of the priming was semantic.³

Method

Subjects. The subjects were 64 native English speakers with normal or corrected-to-normal vision. They participated for payment (\$5 per session) or for research experience points for the Introductory Psychology course.

Stimuli. Each picture was a simple line drawing of a common object or animal with a readily available basic-level name. The stimulus set consisted of 48 pictures, composed of 24 pairs with the same name but different-shape exemplars (e.g., a grand piano and an upright piano, as shown in Figure 1). (Included in this set were four animals—bird, dog, elephant, and rabbit—where the different exemplars were generated by picturing different poses and subspecies of the animal.) In general, the shapes of the different exemplars within a class were more similar than the exemplars from different classes (Biederman & Cooper, 1991), so the difference between identical and different exemplar priming represented a lower bound estimate of the magnitude of the visual component of priming.

The images were created with Cricket Draw and shown on a high-resolution (1024 × 768) monitor (Mitsubishi Model HL6605) controlled by a Macintosh II. Each image was presented in two possible sizes: Small images could be just contained in a circle whose diameter subtended a visual angle 3.5°; large images required a circle with a diameter of 6.2°. The sizes were selected so as to be of approximately equal performance as estimated from the results of a calibration study (see the Appendix).

Procedure. The subject pressed a mouse button to start each trial. A fixation dot would then be presented for 500 ms, followed by either the 50- or 100-ms presentation of the object picture (durations too

brief to make a second eye fixation). The picture was, in turn, followed by a 500-ms mask, a random-appearing arrangement of straight and curved lines. Four such arrangements, selected at random on each trial, were used. On both blocks, the subject named with the basic-level term (e.g., piano) each picture as it was shown. To decrease the likelihood of subjects using other names for the stimuli, prior to the presentation of the experimental stimuli, subjects read the names of the objects from their terminal.⁴ They were told that these were the names of the objects that they were to see in the experiment. Prior to the experimental trials, subjects were given 12 practice trials with images that were not presented in the experimental trials. Two “buffer” trials, with images not used in the experimental trials, were presented at the beginning and end of each block. Data were not collected from these trials. The subjects were told that the sizes of the objects would vary randomly and that the objects that appeared on the first block would also appear on the second block but possibly at a different size or type (or both) but with the same name. They were instructed to ignore such variation. Their only task was to name the object as quickly and as accurately as possible.

The naming RTs were recorded through a voice key. Subjects were given feedback as to the correct name of the object and their response time after each trial. A response was recorded as an error if it was the name for another class (but naming variants such as car instead of auto and phone for telephone were considered correct), a false start, or if it was not made by 2 s.

Design. An initial group of 32 subjects was run at an object exposure duration of 100 ms. In an effort to vary the difficulty of the task, an additional group of 32 subjects was run at 50 ms. The designs for each group were identical. Each subject named 32 briefly presented pictures of objects on each of two blocks of trials, a first priming block and a second primed block. In each block, half the objects were large, and the other half were small. On the second block a given picture could appear at either the identical size as it appeared on the priming block or at the other size. Half the objects on the second block were different-shape exemplars but with the same name as the objects from the first block. One quarter of the objects viewed by each subject were in one of the four size (same or different) and exemplar (same or different) conditions, equally composed of small and large images. Samples of the various conditions are illustrated in Figure 1. The sequences of images were balanced across subjects so that the mean serial position of every object in every condition of size and exemplar type was equal, with all objects appearing equally often in the four conditions at both sizes. Approximately 7 min intervened between the first and second presentations of an object.

Four analyses of variance (ANOVAs) were computed. One was for the RTs and error rates for both blocks of trials, with three fixed

³ The conclusion of the Biederman and Cooper (1991) article was that the all of the visual priming was conveyed by a representation of the geons (corresponding, roughly, to the parts). It was not the case that images missing some contour would not evidence priming. Complementary images constructed by deleting every other edge and vertex from each geon, so the same geons were present in the members of a complementary pair without any overlap in contour, primed each other as much as they did themselves, and both were more quickly and accurately named than different exemplar images. There is also a verbal component of the priming specific not to the availability of the name but, probably, to the act of saying a particular name quickly to a picture.

⁴ In a number of experiments in our laboratory (Biederman, 1987; Cooper & Biederman, 1991) we have never found this manipulation to interact with any perceptual variable or even to have a significant effect on RT or error rates.

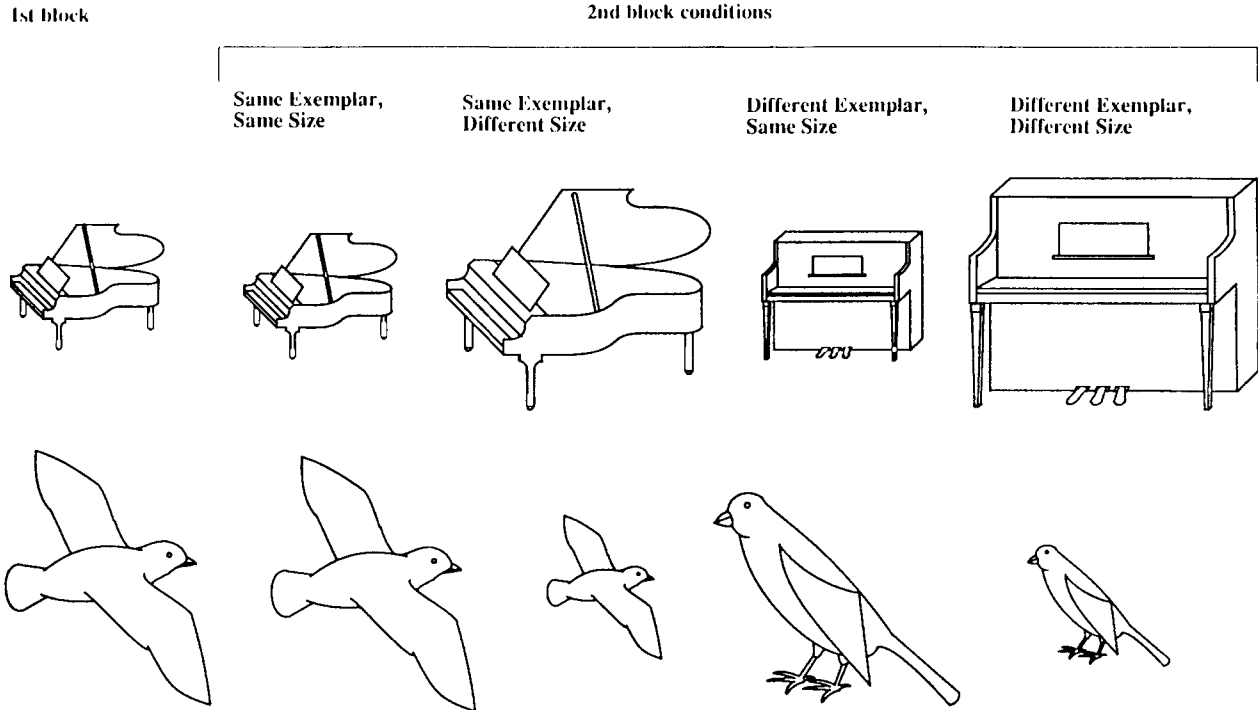


Figure 1. Illustration of the stimuli and experimental conditions for Experiment 1.

factors: duration (50 vs. 100 ms), block (1 vs. 2), and size (small vs. large), and two random factors, subjects and groups. The groups factor had 4 subjects nested within each of 16 groups. These 4 subjects saw exactly the same objects in the same conditions (2 in forward order, 1 at 50 ms and the other at 100 ms; the other 2 in reverse order, again, 1 at 50 ms and the other at 100 ms). Variance between groups included the variance attributable to variations in the difficulty of particular stimuli in particular conditions. The other two ANOVAs (one for RTs and the other on error rates) were run only on the Block 2 data. The factors for these ANOVAs were duration (50 vs. 100 ms), exemplar (same vs. different), and size (same vs. different). The second ANOVA was run because the same and different levels for the exemplar and size variables could not be sensibly assigned to Block 1 data. These ANOVAs included the same two random factors, subjects and groups, as the other ANOVAs.

Results

The results are shown in Figure 2. Mean correct RTs (top of Figure 2) and error rates (bottom of Figure 2) were lower by 79 ms and 5.3% on the second trial block than on the first, $F(1, 15) = 137.83$ and 42.95 for RTs and errors, respectively, both $ps < .001$. The 100-ms exposure duration enjoyed an overall advantage of 17 ms in RTs and 1.2% in error rates. These between-subject effects of duration were not significant for RTs ($F < 1.00$, $MS_e = 21,641$) but close to significant for error rates, $F(1, 16) = 3.67$, $.10 < p < .05$, $MS_e = 0.00278$. The main effect of size was small: Large stimuli were named, on average, 15 ms faster than small stimuli with a 1.2% lower error rate, though these effects fell short of significance, $F(1, 15) = 2.64$ and 3.52 , $.20 < p < .10$ and $.10 < p < .05$, respectively.

On the second block, the mean of the different exemplar trials was 33 ms greater than the mean of the same exemplar trials, $F(1, 15) = 8.72$, $p < .01$, establishing that a portion of the priming, the advantage of the same over the different exemplars, was indeed visual. As noted in the *Method* section, the magnitude of visual priming was underestimated in that the same-name-different-exemplar images tended to be visually similar, so some of the priming in that condition undoubtedly was visual.⁵ That a 33-ms effect was highly reliable also indicates the sensitivity of the experiment for detecting effects of relatively modest magnitude.

There was essentially no effect on second-block RTs or error rates of whether the size on the second block was the same or different from the size on the first block. Overall, there was a 4-ms advantage for objects that were at a different size from those that remained at the same size, $F(1, 15) < 1.00$. A 3-ms advantage for the same-size condition with the same exemplars was balanced by an 11-ms advantage for the different-size condition with the different exemplars, but this interaction between exemplars (same or different) and size (same or different) was nonsignificant, $F(1, 15) = 1.67$, $p > .20$. The overall error rate on the second block was only 1.3%, with none of the F ratios for any of the main effects or

⁵ Other research (Bartram, 1974; Biederman & Cooper, 1991, in press) has shown that the same-name-different-exemplar condition would enjoy a substantial advantage over different-named objects. Thus, part of the reduction in RTs and error rates from Block 1 to Block 2 undoubtedly represents faster access to a specific name, rather than just general practice effects (nonspecific transfer).

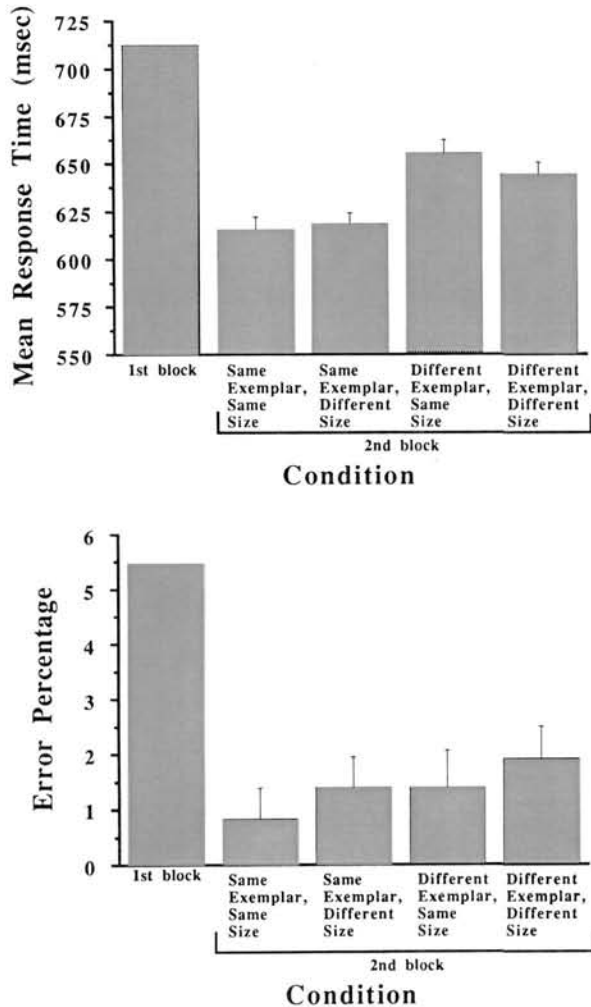


Figure 2. Mean correct naming reaction times (RTs; top) and error rates (bottom) for the effects of changes in size and exemplar shape in Experiment 1. (Data for Block 2 are for those trials where the object was correctly named on Block 1. Inclusion of those trials where the first block was in error did not alter the pattern of the results, although it did increase variability. Error bars on Block 2 show the standard errors of the difference scores between each subjects's mean score on Block 2 and his or her mean score for that condition.)

interactions greater than 1.00. The experiment was sufficiently sensitive to detect as significant an 18-msec effect on RTs and a 1.59% effect on error rates of size changes. M_S s = 2,645 for RTs and 0.002 for RTs and errors, respectively, for the size variable. There was also a significant but uninterpretable three-way Size \times Exposure Duration \times Exemplar interaction, for RTs on the second block, $F(1, 15) = 5.82, p < .05$. For the different exemplars, the same-size condition was slower by 25 ms at the 50-ms exposure duration but slightly faster (by 4 ms) at the 100-ms exposure duration. This ordering was reversed with the identical stimuli in that the same-size stimuli enjoyed an 11-ms advantage at 50 ms and a 5-ms disadvantage at 100 msec exposure duration. The trial-to-trial effects of

size changes (Larsen & Bundesen, 1978) are described in the Results section of Experiment 3.

Experiment 2

This experiment was a replication of Jolicoeur's (1987) Experiment 1c with the stimuli and presentation conditions used in Experiment 1. Jolicoeur's (1987) Experiment 1c used object pictures. In other experiments in that investigation, Jolicoeur replicated the congruency effect with different types of nonsense shapes and at different size ratios (ratio of larger to smaller). Though Jolicoeur found, at best, only a modest effect of different ratios, it is possible that in our experimental arrangement, the size variations used at the brief durations in Experiment 1 were too small to yield an effect on later priming. However, if these variations were shown to affect old-new recognition memory, then it would provide evidence that they were stored but of no influence on priming naming RTs.

There were a number of procedural and stimulus differences between our experiment and Jolicoeur's. Jolicoeur used 20 pictures that were initially shown twice (in two blocks) for 6 s each, with a 1-s intertrial interval. On the recognition memory block, Jolicoeur's pictures remained in view until the subject made a response or 4 s elapsed. We used 24 pictures, shown for 100 ms on both presentation and testing blocks, with a self-paced intertrial interval (which was approximately 1 s for most subjects). Jolicoeur's small and large stimuli subtended visual angles of 5.0° and 39.7°, respectively. Ours were 3.5° and 6.2°. Jolicoeur created his foils from other members of the 10 categories of the Snodgrass and Vanderwart (1980) line drawings. Jolicoeur's foils could, therefore, be distinguished on the basis of basic-level naming. Our foils were the same-name-different-exemplar pictures so that subjects would be forced to make a discrimination of the basic visual characteristics of the object.

Method

Block 1 instructions, stimuli, presentation conditions, and design were identical to those used in Experiment 1. However, on Block 2, subjects were asked to make a same-different judgment as to whether "the object was one of those named earlier." "Same" or "different" responses were made vocally. Subjects were told "The objects which are different will all have the same name as an object you just named, but will look different (for example, a different type of car will be shown, or the dog will be shown in a different position). The correct response for these objects is DIFFERENT. . . . You should ignore any changes in size! The correct response for an object which looks the same but is a different size than when you first saw it is SAME." They were shown examples of the stimulus variations and the correct responses for them. Twenty-four objects were shown in the first block and 48 on the second. No buffer trials were used.

Although the initial design called for 32 subjects as in Experiment 1, the results were so strong that we ceased collecting data after only 16 subjects were run. Consequently, the three-way Object \times Condition \times Serial Position interaction was not balanced, so a given object was always in the same serial position. But all experimental conditions and their two-way interactions were balanced over serial positions.

Results and Discussion

Same responses. First-block object naming performance was roughly comparable to that of Experiment 1 with a somewhat lower mean RT of 654 ms (vs. 702 ms for the 100-ms exposure duration in Experiment 1) but a higher error rate of 7.3% (vs. 3.9% in Experiment 1). A change in the size of the image, from either small to large or large to small, resulted in a striking increase in same-different recognition RTs (Figure 3, top) and error rates (Figure 3, bottom) compared with when image size remained constant. An ANOVA performed on these second-block data revealed no main effects of the size of the picture (large vs. small) on either the first or the second block for either RTs or error rates, all four $F_s(1, 15) < 1.00$. However, the interaction of size and block (i.e., same vs. different size on Block 1 and Block 2) was significant for both RTs, $F(1, 15) = 4.69$, $p_s < .05$, $MS_e =$

5,598, and error rates, $F(1, 15) = 4.55$, $p < .05$, $MS_e = 0.046$. (Undoubtedly, if the originally designed sample of 32 subjects had been run, the effects would have been significant at a much lower alpha level.)

Different responses. Figure 4 shows the data for when the image did not match the shape of its first-block member (correct “different” responses). These data are in striking contrast with those for the “same” responses: There was no effect of whether the size of the picture on the first block was the same or different from the image on the second block, $F_s(1, 15) < 1.00$, for both RTs and error rates, $MS_e = 7,510$ and 0.059, respectively. This result indicates that the effect of size changes observed for the “same” responses (Figure 3) was not carried by the name or the basic-level concept of the object but was completely dependent on the depicted exemplar.

Experiment 3

Experiment 1 provided evidence that naming RTs and error rates were independent of changes in image size from the first to the second trial block. One possible explanation for this result—the one that we favor—is that image shape, for purposes of recognition, is simply stored in a size-invariant manner.

Whatever its plausibility, the scale transformation hypothesis does not account for why such striking effects of size changes were obtained with the episodic memory task (Experiment 2) when they were absent for the naming task (Experiment 1). If the scale was transformed during Block 1, which was identical for both Experiment 1 and Experiment 2, then size change effects should not have been observed in Experiment 2. But let us assume that for some reason, scale transformation did not occur until the second trial block. The scale transformation hypothesis would suggest that best performance on a naming task would be obtained for images in Block 2 that were intermediate in size between the sizes used in Block 1.

There is a qualification to this prediction, however: An intermediate size would be expected to be (slightly) more readily identified merely from the nonprimed relation between image size and RTs shown in Figure A1, if the parabolic fit shown in that figure were appropriate. The scale transformation hypothesis would then predict that RTs to intermediate values would be shorter than those expected from the advantage of an intermediate size based on the overall relation of size and RTs. As can be seen from Figure A1, however, the central data points were variable, so we do not know if, for example, a more precise calibration study would find that the function relating RTs to image size would be relatively flat in that intermediate region. Because the additional calibration study would only be required if there were an advantage of the intermediate size, we elected to repeat Experiment 1 with the modification that on the second trial block, subjects were tested with images that were intermediate in size between the small and the large images of Experiment 1 (and Experiment 2). The experiment also provided an opportunity to replicate the absence of effects of size changes observed in Experiment 1.

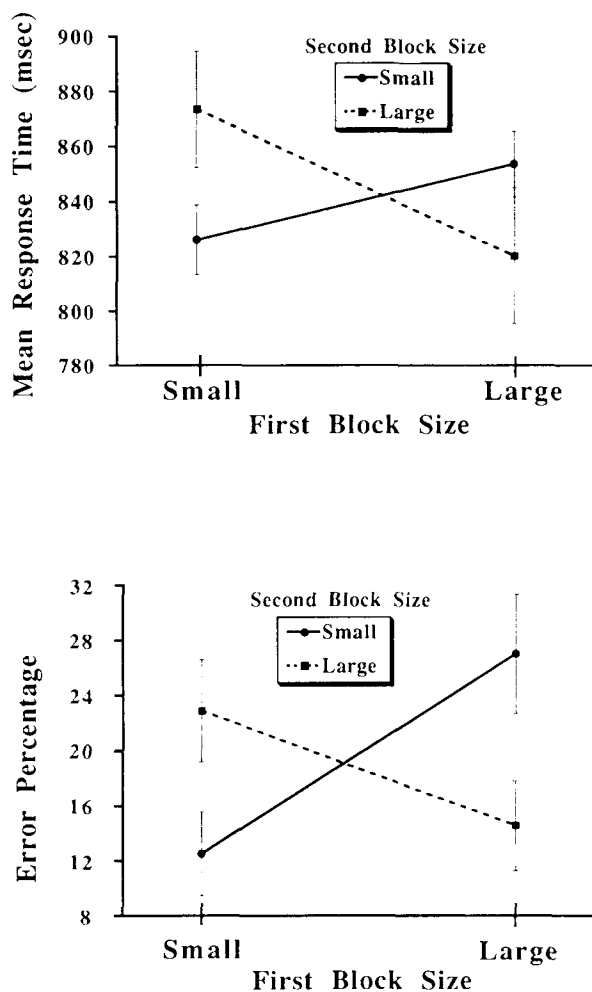


Figure 3. Mean correct same-different recognition memory reaction time (RTs; top) and error rates (bottom) as a function of Block 1 and Block 2 sizes in Experiment 2 for same exemplar stimuli (*same* responses). (Error bars show the standard errors of the difference scores between each subject's mean score on Block 2 and his or her mean score that condition.)

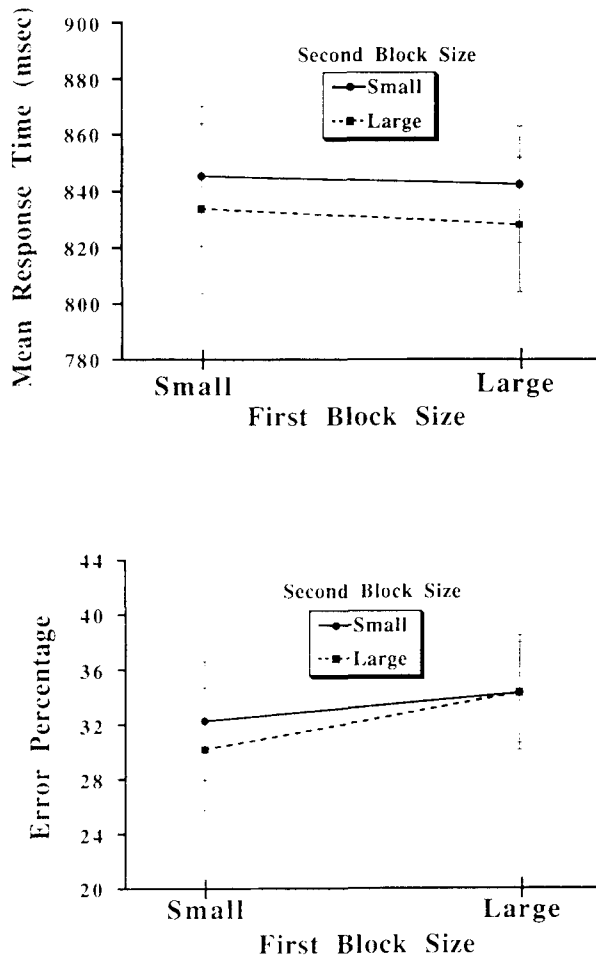


Figure 4. Mean correct same-different recognition memory reaction times (RTs; top) and error rates (bottom) as function of Block 1 and Block 2 sizes in Experiment 2 for different exemplar studies (different responses). (Error bars show the standard errors of the difference scores between each subject's mean score on Block 2 and his or her mean score for that condition.)

Method

The design of this experiment was essentially identical to that of Experiment 1 except that on the second trial block, the stimuli were equally divided among small (3.5°), intermediate (4.85°), and large (6.2°) sizes. Because any given size would constitute only one third of the second-block trials (compared with one half in Experiment 1), to obtain greater power 36 subjects viewed 72 pictures on both blocks, with the 72 constituting the 36 same-name-different-exemplar pairs of images, 24 of which comprised the stimuli in Experiments 1 and 2. (In the prior experiments, a given subject viewed only 24 pictures in each block, 1 from each of the 24 pairs.) That performance on one member of a same-name pair was independent of the size of the other member was supported by the results of Experiment 2, which indicated that there was no effect, even on episodic memory, of the size of a same-name-different-shape image ("different" responses).

The different exemplar pairs in each block were balanced such that, for each subject, all four combinations of sizes between the two members of a pair were evenly represented (small-small, small-large, large-small, and large-large) in the first block, as were all nine

combinations possible in the second block. To reduce the number of subjects necessary for the completion of the design, the interaction of serial position and exemplar size combination in the first block was not balanced (so, for example, when the large grand piano was seen in the same first block as the small upright piano, they were always seen with the grand piano present first). However, across subjects, each exemplar from the pair was presented first as often as second.

Results

Two sets of analyses were performed. One was performed on the data for the fixed factors of size (small vs. large) and block (first vs. second) for the data from the first and second blocks. The second was of the second-block data only and consisted of the fixed factors of second-block size (small vs. intermediate vs. large) and first-block size (small vs. large). Unlike the analyses for Experiment 1, a groups term could not be included in these analyses because no subjects saw exactly the same objects in the same conditions.

Size (small vs. large) \times block analysis (data from both blocks). Second-block RTs were 93 ms shorter and error rates were 3.4% lower than they were on the first block, $F_s(1, 35) = 134.69$ and 42.51 , respectively, both $p_s < .001$. There was a main effect of size in that large stimuli were responded to 15 ms faster than small stimuli, $F(1, 35) = 12.57$, $p < .002$, but there was no effect of size on error rates, nor any interaction between size and block on either RTs or error rates (all $F_s < 1.00$). That a 15-ms effect on RTs and a 3.4% effect on error rates were highly significant documents the sensitivity of this experiment.

Second-block analysis (data from second block only). There was no effect of the consistency of the sizes of the stimuli between first and second blocks on either second-block RTs or error rates, nor was there any main effect of Block 1 size, all $F_s < 1.02$, $MS_e = 2,475$ and 0.002 for RTs and error rates, respectively. Figure 5 shows mean correct RTs (top panel) and error rates (lower panel) as a function of the size of the stimulus on the second block, collapsed over first-block size. Contrary to expectations from the scale transformation hypothesis, there was no advantage of the intermediate-size stimuli. RTs for the intermediate stimuli were identical to those for the small stimuli, although the experiment was sufficiently sensitive for the 15-ms advantage of the large stimuli to produce a significant effect of size, $F(2, 70) = 3.87$, $p < .05$, $MS_e = 1,397$. (The 15-ms effect of size here was for second-block RTs only. In the previous analysis the 15-ms effect of size was for both blocks combined. Obviously, there was a 15-ms effect of size for Block 1 as well.) The effect of size was not significant for the error rates on the second block, $F(2, 70) = 1.60$, $MS_e = 0.002$.

The lack of an interaction between first- and second-block stimulus size on responses to stimuli in the second block provides a replication of the size-invariance finding of Experiment 1. To test that interaction in an analysis more comparable to that used in Experiment 1, an analysis was run without the data for the intermediate-size stimuli. The 15-ms advantage of larger Block 2 stimuli was again significant (here tested only against the small rather than both the small and intermediate-size stimuli as in the previous analysis), $F(1, 35)$

= 5.82, $p < .05$. Performance was virtually identical when the size remained unchanged from Block 1 to Block 2 as shown in Figure 6: RTs for same-size trials averaged 618 ms with an error rate of 2.4%; RTs for different-size trials averaged 620 ms with an error rate of 1.6%. F ratios for the interaction between Block 1 and Block 2 size were less than 1.00 for both RTs and errors. This result provides a strong replication of the invariance of previously experienced size on subsequent object identification.

Trial-to-trial sequential analysis. Larsen and Bundesen (1978) reported that stimuli were more quickly responded to when they were the same size as the stimulus on the previous trial, compared with when there was a change in size. That result comprised the evidential basis for the positing of scale transformation. Table 1 shows the mean RTs and error rates

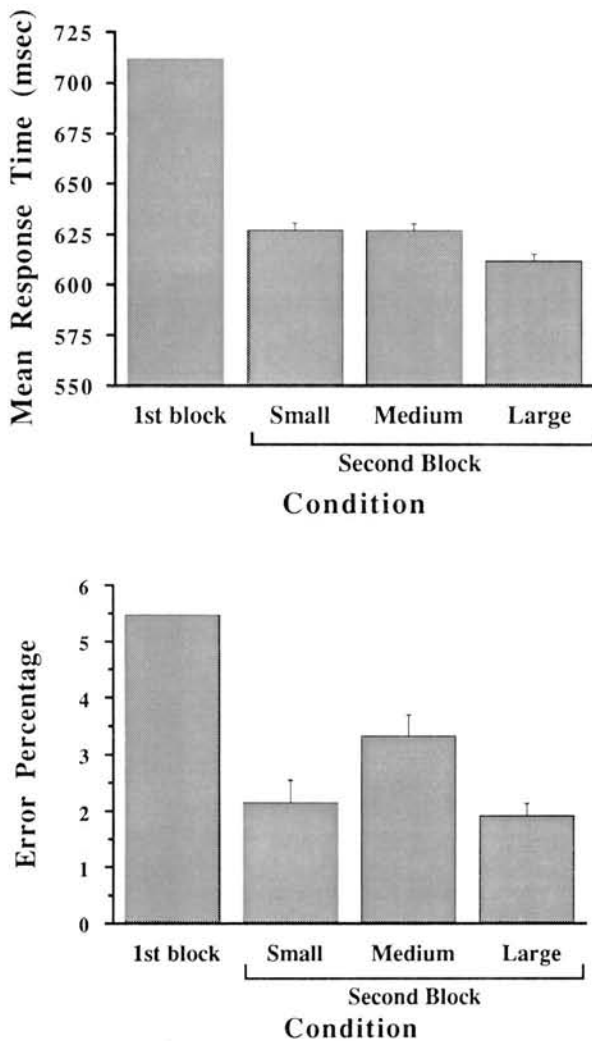


Figure 5. Mean correct naming reaction times (RTs; top) and error rates (bottom) for naming the small and large stimuli on Block 1 and the small, medium, and large stimuli on Block 2 in Experiment 3. (Errors bars on Block 2 show the standard errors of the difference scores between each subjects's mean score on Block 2 and his and her mean score for that condition.)

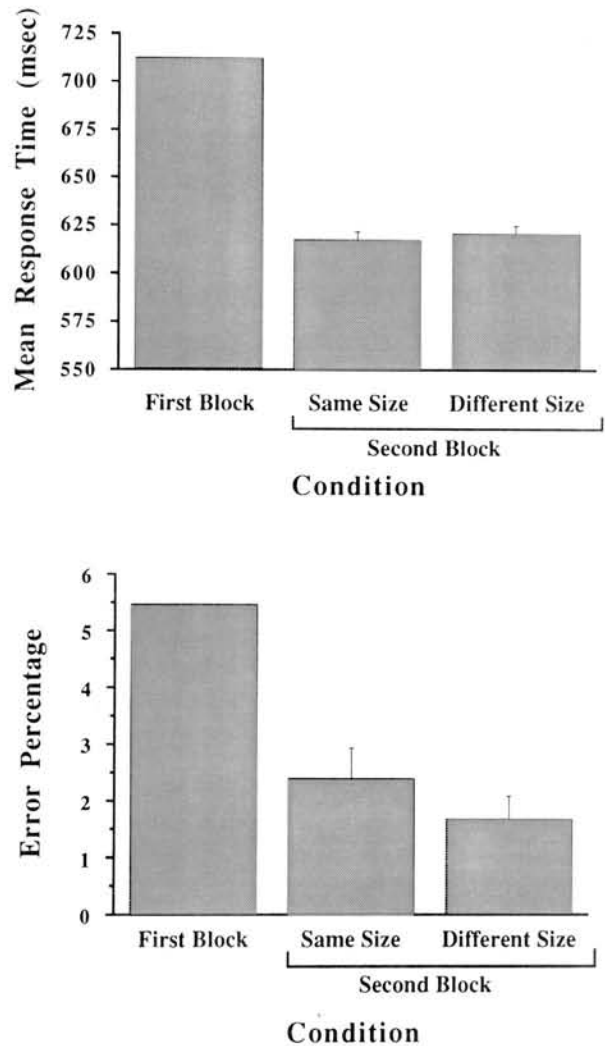


Figure 6. Mean correct naming reaction times (RTs; top) and error rates (bottom) for the effects of changes in size in Experiment 3. (Data for Block 2 are for those trials [small and large stimuli only] where the object was correctly named on Block 1. Inclusion of those trial where the first block was in error did not alter the pattern of the results, although it did increase variability. Error bars on Block 2 show the standard errors of the difference scores between each subject's mean score on Block 2 and his or her mean score for that condition.)

for when the stimulus was of the same size as on the preceding trial or a different size for all three experiments. Performance was nearly equivalent in the two conditions, providing no evidence for a trial-to-trial adjustment in scale. What difference there was, slightly longer RTs when the stimulus was the same size, was in a direction opposite to that expected from the scale transformation hypothesis.

Discussion

None of the expectations of the scale transformation hypothesis were borne out in this experiment in that the intermediate-size stimuli were not more readily identified, and a

Table 1
Sequential Size Effects on Mean Response Time (in Milliseconds) and Percentage Errors Across All Experiments

| Experiment | Block | Size relation between trials n and $n - 1$ | | | |
|------------|-------|--|--------|-----------|--------|
| | | Same | %Error | Different | %Error |
| 1 | 1 | 721 | 5.1 | 693 | 5.6 |
| 1 | 2 | 656 | 5.5 | 687 | 5.4 |
| 2 | 1 | 686 | 11.4 | 634 | 4.2 |
| 3 | 1 | 717 | 5.4 | 708 | 5.7 |
| 3 | 2 | 638 | 3.2 | 625 | 3.1 |
| <i>M</i> | | 684 | 6.1 | 669 | 4.8 |

change in size from the preceding trial did not result in longer RTs or higher error rates compared with when the size remained constant. This latter result was also true of Experiments 1 and 2.

Why were the trial-to-trial size effects not observed in our investigation? One possibility is that Larsen and Bundesen (1978) used a much greater range of sizes, 9:1 for some trials. The ratio of small to large in this investigation was 1.77:1. Although this ratio was large enough to yield sizable episodic memory effects in Experiment 2 (and in Jolicoeur's 1987 experiment), it might have been too modest to elicit trial-to-trial attentional shifts on the basis of scale. Also, 75% of the trials in the Larsen and Bundesen investigation were repetition trials in which the size remained the same. Subjects were instructed as to this feature. It is possible that these aspects of the design and procedure induced size-dependent strategies.

General Discussion

The results from Experiments 1 and 3 document complete size invariance in the naming of briefly presented pictures of objects. That is, viewing the object at a different size resulted in as much priming as when the object was viewed at the same size. The advantage of the identical condition over the same-name-different-exemplar condition in Experiment 1 indicated that a component of the priming was visual.

The lack of an effect of the size consistency on the different-exemplar condition in Experiment 1 indicates that not only was the perceptual component size invariant, it was also not the case that the selection of a name was affected by size associations such that the name "piano," for example, was activated by its association with a stimulus event that was small. Thus, under the conditions of these experiments, we conclude that the activation of the basic-level concept and name was mediated solely through a size-invariant representation of the object, as posited by Biederman (1987) and Hummel and Biederman (in press).

The striking effects on the "same" responses in the episodic memory task in Experiment 2 of size changes indicated that the lack of an effect on naming RTs and error rates in Experiments 1 and 3 could not be attributable to the absence of memory for these changes. The absence of these effects with the different-shape images for the "different" responses

indicates that the episodic tagging effect for the "same" responses was to a visual representation of the object, rather than to its name or basic-level representation.

The dissociation between factors that may affect explicit recognition memory (the "same" episodic shape judgments in Experiment 2) and perceptual processing (the naming in Experiments 1 and 3) is a well-documented characteristic of repetition priming (e.g., Jacoby & Dallas, 1981; Schacter, 1987). Note that the direction of this dissociation in the present investigation differs from the one generally reported in the perceptual priming literature, in which an effect on perceptual processing is not manifested in explicit memory: We found an effect on episodic memory that was not manifested in perceptual processing. We have also found that this effect holds for position (left vs. right or top vs. bottom hemifields) and orientation (facing left or facing right) (Biederman & Cooper, in press). Although Block 1 to Block 2 variations in position and left-right orientation can be readily detected in an explicit test of recognition memory, these variations had no effect on object naming performance.

Relevance to Two Cortical Visual Systems?

Physiological support for the dissociation between (a) the representations of shape for recognition and (b) the use of position information derives from primate cortical ablation experiments establishing different cortical loci for memory for object attributes and responding to position (Mishkin & Appenzeller, 1987; Ungerleider & Mishkin, 1982). Specifically, bilateral ablation of the inferior temporal (IT) cortex in the macaque resulted in gross impairment of the animal's ability to respond on the basis of object identity, irrespective of position, but did not result in significant impairment in the use of a spatial cue. Ablation of the posterior parietal region resulted in the opposite effects. Mishkin and Appenzeller (1987) characterized the functions of the two visual systems as subserving "where" and "what."

It is possible that the dorsal system represents not only location in space, that is, the "where" function, but a number of additional attributes that are critical for motor interaction but largely irrelevant for recognition based on shape. Specifically, we propose that in addition to image location, this system subserves image size and orientation in depth (up to parts occlusion). When we pick up a cup by its handle, our motor movements are exquisitely tuned to the cup's position, size, and the orientation of the handle in depth. Thus in a single skilled movement, we may reach to the right in the direction of the cup, simultaneously bending our wrist if the handle is on the right side (keeping our wrist straight if the handle is directly in front) and making a bridge between our thumb and fingers just wide enough to accept the handle. None of the information critically important for this act appears to be required for speeded object recognition; conversely, the identity of the object need not affect how it is picked up.

A neurological patient, D. F., who suffered extensive damage to (what is likely) the ventral pathway (viz., Areas 18 and 19 and in the parasagittal occipitoparietal region [and portions of the basal ganglia]), offers a striking account of how

clear this dissociation can be (Goodale, Milner, Jakobson, & Carey, 1991). D. F. could not accurately align a hand-held card with a slot in a disk displayed at various orientations, but her performance was indistinguishable from normal controls when she was instructed to "post" the card (as if she were mailing a letter). This deficit was not just a conceptual problem in that she could accurately align the card to an imagined orientation with her eyes closed. Perhaps more relevant to the immediate concerns of the present investigation, she was at chance accuracy in judging the wider of two rectangular plaques: When asked to indicate the width of a plaque through variations in the separation between her thumb and forefinger, her responses were uncorrelated with the width of the plaques (though, again, she could perform the task imaginably). Both tasks were readily accomplished by control subjects. However, when asked to reach out and pick up a plaque, the correlation between the maximum gap between index and forefinger during the trajectory (but well before contact with the plaque) and the width of the plaques matched those for the control subjects.

Damage to the posterior parietal region can result in just the opposite syndrome, in which the patient is quite adept at judging the orientation of a slit but cannot perform the appropriate motor response (Perenin & Vighetto, 1988).

One possibility is that the representations for shape classification are derived in the ventral system, but the representations supporting memory for position, size, and orientation in depth are derived in the dorsal system. However, caution must be exercised about such a conclusion. Almost all of the demonstrations of spatial impairment following lesions of the posterior parietal region have involved real-time motor control, rather than memory for position, size, and orientation. It might seem reasonable to have the system sensitive to these attributes for purposes of motor control also represent them for purposes of memory. However, the alternative also might be reasonable: that the dorsal-ventral systems are organized for purposes of real-time motor control and memory, respectively. Within the ventral system then, there may be two independent visual pathways: one representing shape and the other representing size, position, and orientation.

We propose that the dissociation between naming and episodic memory might allow a noninvasive, behavioral basis for distinguishing the function of the presumed independent cortical visual systems. Specifically, the perceptual processing leading to naming, with allowance for response selection, may allow a relatively uncontaminated assessment of the shape classification system, with its presumed invariance to size, position, and orientation in depth. Episodic shape recognition judgments, based on overall feelings of familiarity (Atkinson & Juola, 1974), likely reflect both the shape and the other system(s). A critical test would investigate performance on the episodic shape recognition memory task (Experiment 2) by using patients with unilateral lesions to either their posterior parietal or inferotemporal systems. Assuming that lateralized presentations are effective, stimuli shown to the damaged hemisphere should show reduced interference effects from changes in size or position. The question is whether this reduction in interference is more pronounced with the temporal or parietal patients.

Naming. The proposal that naming would allow a relatively pure measure of anything would, at first, seem implausible. Naming appears to be a most complex activity, involving major demands on verbal response selection not present in the same-different judgment task. Perhaps the effect of size changes was obscured during the selection of a response in the naming task from the several thousand possible basic-level names that might have been used in this experiment. Although the response selection demands in naming are great, probably occupying most of the latency period, we know of no evidence suggesting that they are not additive with the effects of perceptual variables (Biederman, 1987). For example, the increase in naming RTs closely tracks the perceptibility of an image, as affected by an increasing percentage of contour deletion (Biederman, 1987). Note that despite the demands for selection of a name, naming RTs in Experiments 1 and 3 were dramatically lower (by 225 ms!) and of markedly greater accuracy (by 17.6%) than the two choice episodic same-different judgments of Experiment 2. The longer RTs for the episodic judgments are consistent with our interpretation that they are reflecting a pooling of information from both systems to determine a feeling of familiarity (Atkinson & Juola, 1974).

Scale transformation. We failed to confirm a scale transformation account of the invariance between prime and primed object size. In the introduction, we argued that scale or image transformations were an unparsimonious explanation, relative to attentional effects at input, as to the deleterious effects of size changes. On its face, scale transformation would appear to be implausible. As we go about our daily activities, we view objects at a variety of sizes. What conceivable purpose would be served by referring new inputs, for the purpose of recognition, to some mean size—or any size for that matter—of the objects that we have recently experienced, especially when that size will almost never match the current size? From this perspective, scale transformation could be interpreted as a violation of the Marr (1982) principle of least commitment, as a commitment would be made to a particular scale that would almost never be correct. Note that we are not referring to short-term variations in the scale to which attentional processes might be tuned, but rather to a size at which representations are specified for recognition. Our evidence against a scale-specified representation has broader implications for theories of the representation of shape than the one advanced by Larsen and Bundesen (1978). More recently, Ullman (1989) and Lowe (1987) have proposed machine vision systems that are also based on transformable templates. These models are most effective at discriminating highly similar exemplars for which point-to-point matching can be efficient. However, without an exact model of the image that can be fit by a transformation applied to the whole image, they have little or no capacity to achieve the ready basic-level classification of novel images that is so characteristic of human shape recognition and that was the subject of this investigation.

Conclusions

In conclusion, our results provide evidence for independent representations mediating object recognition and memory for

an image property—size—that, we conjecture, is primarily important for controlling motor interactions with objects. The independence, which most likely originates after V1 (Mishkin & Appenzeller, 1987), has the benefit of obviating the need for transformations of size when the likely possibility arises that a new image of an object differs in size from its previously stored representation. Object size thus joins object position and orientation in depth (up to parts occlusion) as image properties that are (and should be) critically important for a subsystem controlling motor interaction at the same time that they are (and should be) ignored by a visual subsystem performing basic-level pattern classification.

Finally, these results suggest that caution be exercised in attempting to infer characteristics of pattern recognition from either simultaneous (or immediately sequential) same-different judgment tasks or longer term episodic memory paradigms, though for very different reasons. Given the possibility that object recognition might be performed by the shape system (in IT), the sensitivity that simultaneous or near-simultaneous same-different paradigms reveal for consistency in size, position, and orientation might be a consequence of tapping into the visual system at too early a stage. In contrast, episodic judgments appear to be too late: They may be affected by all the factors that comprise the experience of viewing a shape, not all of which may be involved in the processing leading to the actual basic-level classification of that shape in real time. As with Goldilocks and the three bears, speeded object naming, reflecting uncontaminated activation of shape representations, may be just right.

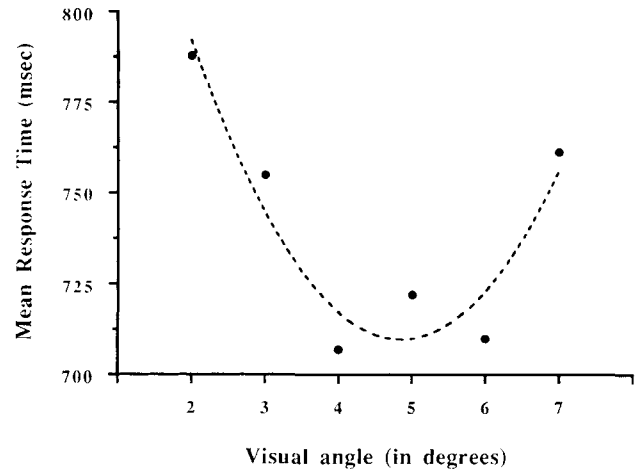
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Appendix

This study was conducted to determine the effect of size on overall performance so that two different sizes of approximately equal difficulty could be selected. Twelve subjects named 30 objects presented for 100 ms followed by a mask. The objects were exposed at sizes (maximum extents) of 2°, 3°, 4°, 5°, 6°, or 7° of visual angle. These sizes defined the diameter of the smallest circle that could contain each object. Each subject named all 30 objects, equally divided among the six sizes. Sizes and objects were balanced such that each object was named at each of the six sizes an equal number of times (twice). These were centered on a mean of 4.5° that appeared to be optimal in a prior investigation. Figure A1 shows the mean correct RTs for each visual angle and the best parabolic fit (which accounted for 89.2% of the variance) to these data. The 3.5° and 6.2° sizes yielded equal predicted RTs. The error rates for this calibration study were low and appeared to be uncorrelated with size in this range.



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Figure A1. Mean correct naming reaction times (RTs) for the stimuli in the calibration experiment as a function of the size of the object pictures. (The dashed line is the best fitting parabola: $RT = 10.1x^2 - 97.8x + 947.3$, where x is visual angle in degrees.)

Change in Convention Audiotape Permission Procedures

Agreement to participate in the APA Convention is now presumed to convey permission for the presentation to be audiotaped if selected for taping. Any speaker or participant who does not wish his or her presentation to be audiotaped must notify the person issuing the invitation or the Continuing Education Office by March 30. All speakers are entitled to a free copy of the tape on site; after the Convention a \$3.00 shipping/handling fee is charged.