PSYCHOLOGICAL SCIENCE

Research Report

SUBLIMINAL VISUAL PRIMING

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Abstract—*Masked pictures of objects were flashed so briefly that only 13.5% of them could be named. Forced-choice accuracy for the unidentified objects was at chance. When the pictures were shown again, about 15 min and 20 intervening trials later, without any indication of possible repetitions, naming accuracy increased to 34.5%. The priming was completely visual, rather than semantic or verbal, as there was no priming of same-name, different-shape images. This is the first demonstration of facilitatory visual recognition priming by unidentified pictures when the subject could not anticipate if, when, or where the previously unidentified picture was to be shown again. A change in the position of the object reduced but did not eliminate the priming, allowing a speculation that the locus of subliminal visual priming is at an intermediate stage in the ventral cortical pathway for shape recognition.*

Perceiving an object once improves the accuracy and speed of its recognition in a subsequent encounter (Bartram, 1974; Biederman & Cooper, 1991; Schacter, Delaney, & Merikle, 1990). A large portion of this facilitation, termed *priming*, can be visual in that an object with the same name but a different shape produces much less facilitation (Bartram, 1974).

In these previous demonstrations of visual priming, observers were generally able to name the stimulus on its first presentation. Can visual priming be evidenced even if the observer cannot recognize the stimulus on the first presentation, or even guess it from among a few alternatives? In one investigation of subliminal processing (Haber, 1969), consecutive repetitions of the same word were found to lead to identification, even though the word could not be identified on its first exposure. However, in these experiments, the same word was presented repeatedly without any intervening stimuli. Under these conditions of low uncertainty (in that subjects knew that the same item was to be presented, and in the same place), observers could selectively attend to different parts of the word, or engage in lexical problem solving based on the information they were able to extract from the preceding presentations. In the study we report here, pictures of objects that were presented too briefly to be recognized (i.e., subliminally) were sufficient to facilitate recognition when they were presented again several minutes and many stimuli later.

In a recent study of subliminal semantic activation (Greenwald, Draine, & Abrams, 1996), a prime word was presented very briefly before the presentation of above-threshold target words. Subjects were required to judge whether the target word was a pleasant or unpleasant word, or whether it represented a male or female name. Their judgments were biased by the subliminal prime. For example, the prime word *kill* biased judgments of the target word *bomb* toward unpleasantness, whereas the prime word *happy* biased the judgment toward pleasantness. This subliminal priming, which was totally semantic (as the prime and the target were different words that could only be semantically related), was found by Greenwald et al. to be extremely short-lived: The target word had to be presented within 100 ms following the prime for the effect to be obtained.

A subliminal presentation of an otherwise neutral stimulus can bias subsequent liking judgments (Zajonc, 1968). In one such study (Kunst-Wilson & Zajonc, 1980), subjects were first presented with irregular octagons for a very brief duration (1 ms). Then, pairs of such octagons, one new and one from the set that had been presented previously, were displayed on the screen for 1 s, and subjects were required to choose the octagon they liked more and judge which of the two octagons they had seen before (old/new judgment). Although performance was at chance in the old/new judgment task, subjects tended to like the old stimuli more than the new ones. Consequently, the authors concluded that the subliminal presentations affected only judgments of liking, and not recognition. However, it is possible that an explicit measure such as old/new recognition might not reveal the gain from subliminal presentations. Therefore, the present study assessed whether identification of an object would be facilitated by its prior subliminal presentation, using the implicit measure of perceptual priming.

We used different exemplars of the same object (e.g., motorboat and sailboat) to distinguish visual and semantic subliminal priming. To test translation invariance, and to possibly gain insights as to the cortical loci of subliminal visual priming, we presented half of the test objects in a position different from where they had appeared in the priming block.

METHOD

Subjects

Thirty-seven individuals (23 females, 14 males; age: 18–33 years) participated for payment or credit in psychology courses at the University of Southern California. All had normal or corrected-to-normal vision. None were aware of the purpose of the experiment.

Stimuli

The objects were line drawings of tools, furniture, animals, clothes, means of transportation, and other objects, drawn with black lines 2 pixels wide on a white background. The drawings were 4.8° to 15.6° (mean = 11°) in their largest dimension. The images were presented on a Macintosh 16-in. Color Display, with a resolution of 832 × 624 pixels and a refresh rate of 75 Hz. Presentation of stimuli was controlled by a Macintosh Quadra 950, using the Picture Perception Lab (PPL) software.

Design

On each trial, a single, masked line drawing was presented. Each subject had 70 trials: 20 practice trials with images that were not

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presented again, two blocks of 20 experimental trials each, and two blocks of 5 control trials each. The objects in the first experimental block repeated in the second block in one of four possible conditions: at the same or a different position, and with the same shape or as a different exemplar (different shape) with the same name (e.g., an office swivel chair and a four-legged kitchen chair).

The control blocks were presented one before and one after the experimental blocks. The control images all had different names, and they were never used as experimental images. Any improvement in naming control objects in the second block, compared with naming the control objects in the first, would represent general improvement over the course of the experiment rather than priming by the specific images or names.

The subjects were never informed about possible repetitions, nor was the onset of the second block of experimental images signaled in any way. Twenty images and 15 min, on average, intervened between the first and second presentation of the same object. All stimuli (experimental, control, and practice) were randomly presented in one of the nine possible areas created by dividing a 26.6° × 19.5° screen into a 3 × 3 grid. Stimuli in the translation conditions were presented in the second block with an average shift of 4.9° from their position in the first block (range: 1.9°–10.5°).

All the experimental images were balanced across subjects so that every object appeared an equal number of times as prime and test stimuli, in the same versus translated positions, and as identical versus different-shaped exemplars. Each of the experimental blocks was presented first or second, and in a forward or reversed order, an equal number of times. In addition, the two sets of control stimuli appeared equally often in the first and second blocks. There were thus 32 sequences of stimuli required for a complete balancing. The data from 5 subjects whose accuracy was under 5% in both experimental blocks were dropped, and they were replaced with 5 new subjects so that there would be data from the 32 subjects required for balancing.[1] A given object appeared in four of the nine possible positions, one for each of the four conditions.

Procedure

After the subject pressed a mouse button, a fixation point appeared on the screen, followed by a picture of an object and then a mask custom-designed to be highly effective for that object[2] (Fig. 1). The exposure durations ranged from 42 ms to 56 ms (average of 47 ms), individually adjusted to each object on the basis of pilot work.[3]

Following each stimulus presentation, subjects were required to identify the object by name, even if they had to guess. Subjects then chose from four object names in a four-alternative forced-choice (4AFC) test. The 4AFC test was composed of four types of items: the correct response (e.g., "hammer"), an object of the same superordinate class but of a different shape (e.g., "nail"), an object that had been confused with that object in pilot experiments (e.g., "scissors"), and an object that was visually and categorically unrelated to the stimulus (e.g., "dog"). The 4AFC test was used to assess subjects' awareness of the identity of the objects, and to provide some information as to what could be extracted from unidentified presentations. Specifically, a subject who could not name an object might have still gained enough information to be able to choose the correct name out of four alternatives. In neither the naming attempt nor the 4AFC test was feedback provided as to the correctness of the response.

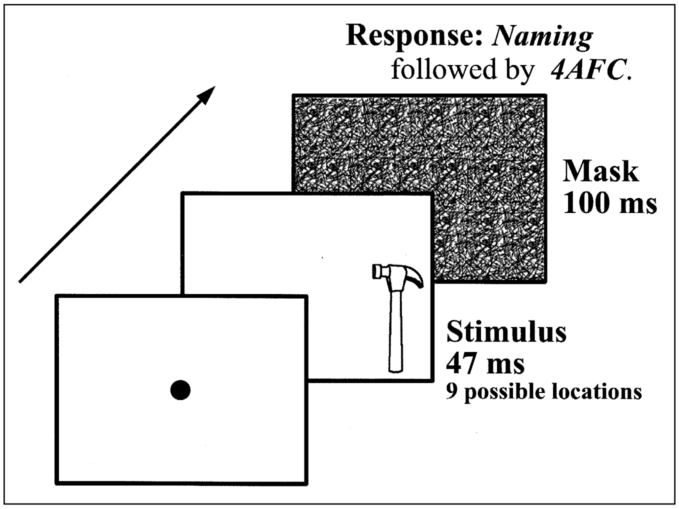

Fig. 1. Illustration of the sequence of events on a single trial. A line drawing of an object could appear in any of nine possible positions on the screen, defined by partitioning the total screen area into three rows and three columns. The masks were custom-designed to be highly effective with each object. Following each stimulus presentation, subjects tried to name the object and then chose a name in a four-alternative forced-choice (4AFC) test.

RESULTS

Figure 2 shows the percentage of trials on which objects were named correctly, and Figure 3 shows the percentage of correct responses on the 4AFC test for trials on which objects were named incorrectly (correct naming of an object was always followed by a correct response on the 4AFC test). Only 13.5% of the experimental images could be named on their first presentation. When subjects could not correctly name the stimulus, their performance on the 4AFC test was near chance (28.5%; see Fig. 3). Naming accuracy on the second block was unrelated to whether that object was guessed correctly on the 4AFC test on the first block, given that it was not initially named prior to the 4AFC test. Naming accuracy increased substantially, by 21% (from 13.5% to 34.5%), for objects of the same shape when they repeated at the same location in the second block. (All the objects named correctly in the first block were also named correctly in the second when they were repeated at the same position.) Accuracy of naming the control objects increased 4% over the course of the experiment. This increase must be attributed to general factors that were independent of repetition of specific stimuli (i.e., priming). The 17% advantage of the same-shape, same-position objects compared with the second block of control objects was, therefore, a consequence of subliminal priming, $t(31) = 4.55$, $p < .001$. This reliable increase in

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[1] Inclusion of the dropped data would reduce the magnitude of the effects, but not influence their pattern.

[2] The masks and stimulus objects were drawn with lines of similar thickness and similar contrast. The image of an object was usually unrecognizable when the mask was superimposed over it.

[3] The pilot experiments had the same design and procedure as the experiment reported here, varying only in the exposure durations for individual stimuli.

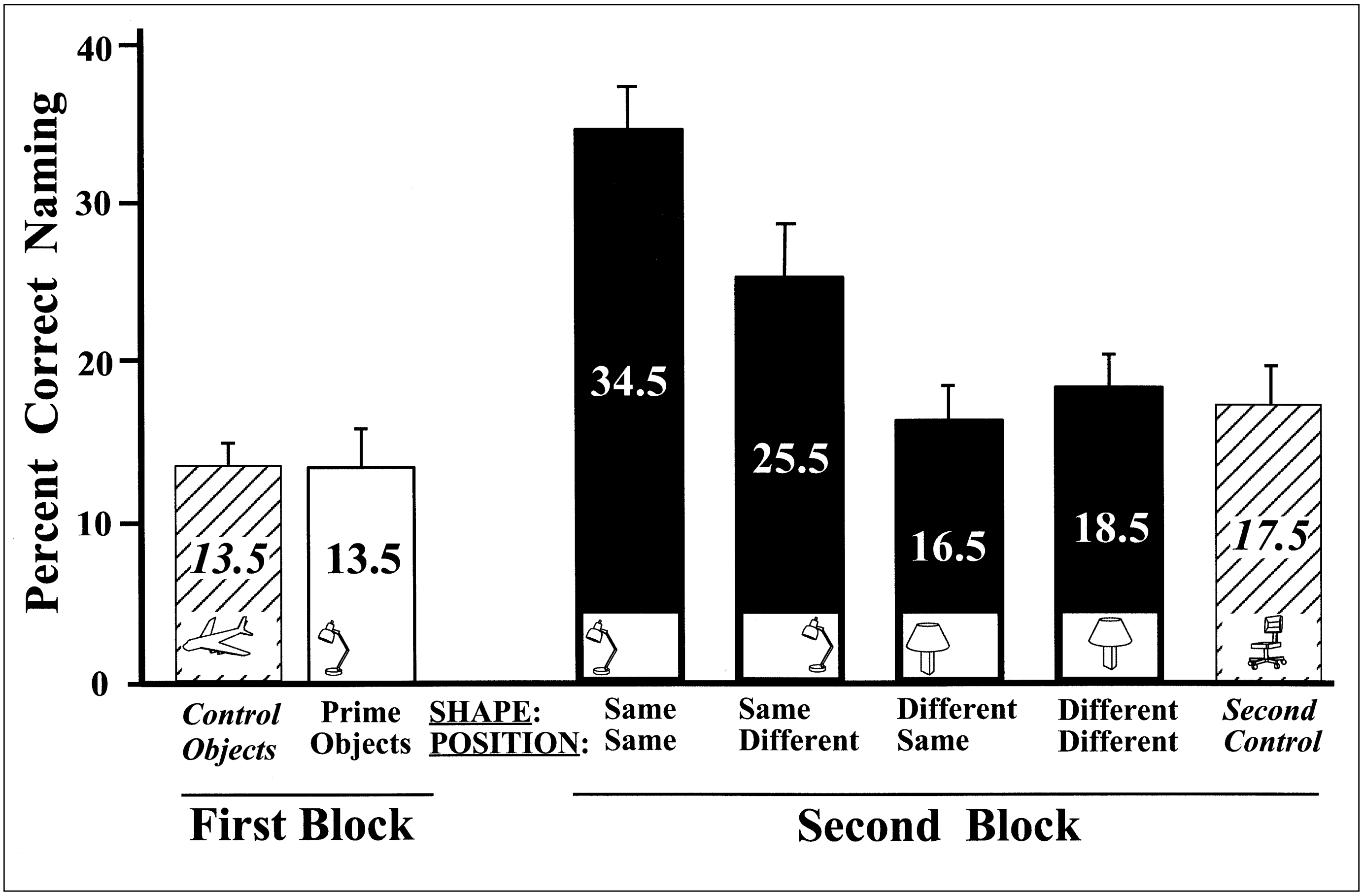

Fig. 2. Percentage of correct naming by 32 subjects on the control and experimental blocks. Objects in the first experimental block (prime objects) repeated in the second experimental block in one of four conditions: at the same or a different position, and with the same shape or as a different exemplar (i.e., different shape) with the same name. Error bars show the standard error of the mean for each condition computed from the deviation scores of each subject for that condition around his or her own overall mean. Between-subjects variability is thus removed from these measures of variability.

accuracy was also obtained when the analysis was done over objects, rather than subjects, $t(19) = 6.03$, $p < .001$.

On the second block, the advantage in identifying the same-shape images over the different-shape images was highly reliable, $F(1, 31) = 20.25$, $p < .001$, as assessed by a 2 × 2 analysis of variance (Shape × Position) of the second-block naming scores. This result indicates that at least some of the priming was visual and not just verbal or conceptual. In fact, all the priming in this experiment was visual, because second-block naming accuracy of the same-name, different-shape stimuli was equivalent to that of the second-block control images, $t(31) < 1.00$. The equivalence of these conditions indicates that none of the priming was verbal or conceptual.

Translating the same-shape stimuli reduced the magnitude of priming to approximately half of what it was in the same-position condition (8% vs. 17%), leading to a significant interaction between shape and position, $F(1, 31) = 5.91$, $p < .05$. (The main effect of translation fell short of significance, $F[1, 31] = 1.91$, $p = .18$, likely because of the slight advantage of translation in the different-shape conditions.) Tukey's HSD post hoc test revealed that for the same-shape stimuli, translation produced a significant reduction in accuracy ($p < .05$). These same-shape, different-position stimuli still evidenced priming, as shown by their advantage over the second-block control stimuli, $t(31) = 2.26$, $p < .05$.[4]

DISCUSSION

These results demonstrate subliminal visual priming that is resilient to intervening stimuli but impaired by translation. Was part of the

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[4] In general, the amount of priming was directly related to the extent of translation. However, because the magnitude of the translation and the positions to which objects were translated could not be completely balanced over objects and positions, no conclusions are offered as to these variables.

Objects presented at the center were more easily recognized than images in other positions (22% vs. 12%). However, because the central position was used equally often as the other positions (11% of the trials), and because the design was balanced so that the prime and test blocks were switched for half of the subjects, this difference in perceptibility could not influence the pattern of the results.

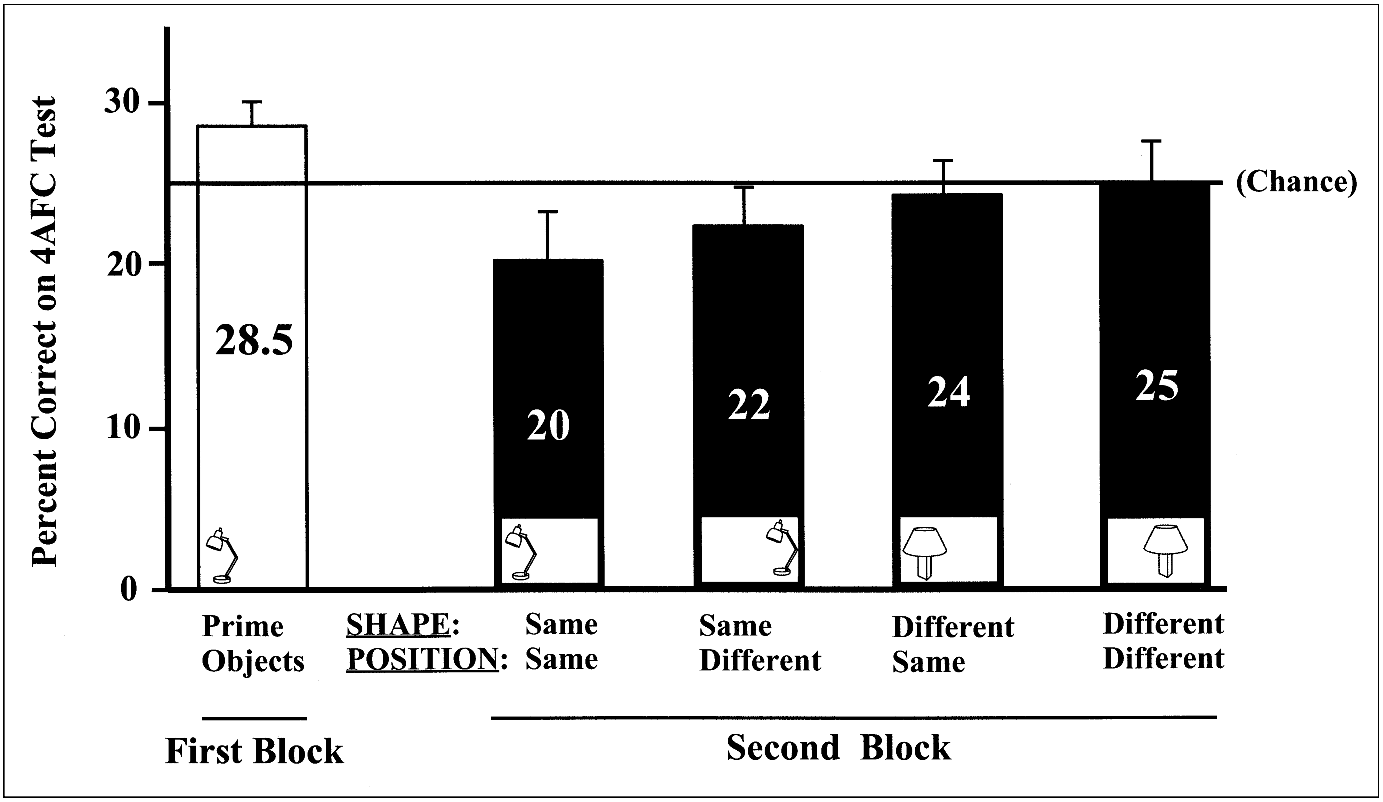

Fig. 3. Percentage of correct responses on the four-alternative forced-choice (4AFC) test, given that the naming attempt was in error. (When subjects correctly named the object, they always chose the correct 4AFC alternative. Those trials are not included here.) The 4AFC test was not administered on the control trials. Error bars were calculated as in Figure 2.

improvement a consequence of increased name availability from the 4AFC test in Block 1? As a part of another study, we ran a priming experiment under similar conditions,[5] but the 4AFC test was not administered. Whereas the magnitude of visual priming for identical, same-position stimuli was 17% in the present experiment (in which subjects were exposed to the names in the 4AFC test), the magnitude of priming was somewhat greater, 20%, in the experiment without the 4AFC test. Consequently, there is no evidence that the improvement attributed to visual priming in the present experiment was a function of the exposure to the correct name in the 4AFC test.

Unlike the transitory subliminal semantic priming of words reported by Greenwald et al. (1996), subliminal visual priming has been shown in the present study to persist for at least 15 min and 20 intervening stimuli. Visual and semantic priming of supraliminally presented stimuli, in contrast, have both been found to be long-lasting: Priming of object naming, for example, can last 48 weeks after a single exposure to a picture (Cave, 1997), and priming in semantic memory tasks such as word-fragment completion can last as long as 16 months (Sloman, Hayman, Ohta, Law, & Tulving, 1988). However, unlike these findings that were obtained with identifiable primes, the findings reported here suggest that subliminal visual priming lasts longer than subliminal semantic priming. The comparison is exceedingly clear, as the priming in Greenwald et al. (1996) was completely semantic, and the priming reported here was completely visual.

Consistent with the robustness manifested by subliminal visual priming are studies using negative priming (e.g., DeSchepper & Treisman, 1996). Negative priming is the reduction in the recognition of a stimulus that was earlier ignored because of instructions to attend to a competing stimulus. Whereas negative-priming paradigms employ selective-attention manipulations, in our study, stimulus availability was limited by exposure duration and masking. Studies comparing the effects produced by attentional misdirection and perceptual limitation will be required to determine whether the different tasks have the same underlying basis.

As noted in the introduction, subliminal presentations in Kunst-Wilson and Zajonc's (1980) experiment did not affect old/new recognition judgments, but did bias affective judgments. This bias may be considered subliminal affective priming. The contribution of subliminal presentations to object recognition, however, might not be revealed by an explicit task such as old/new judgments, as it may not be indexed by subjective reports of familiarity (Nissen & Bullemer, 1987). One implication of our study is that a second brief presentation of the same stimuli in Kunst-Wilson and Zajonc's study might have resulted in recognition priming, despite the chance performance on old/new recognition following the first presentation.

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[5] The experiment did not include the translation and different-shape variables, and used only four randomly alternating, generic masks.

A SPECULATION REGARDING THE CORTICAL LOCUS OF SUBLIMINAL VISUAL PRIMING

The partial position dependency of subliminal visual priming—that priming was only reduced but not eliminated by a shift of 4.9°—allows a speculation as to the locus of its effect along the cortical pathway for object recognition.

Cells along the temporal visual pathway in the macaque are ordered in a rough hierarchy along at least two dimensions: Cells in more anterior areas tend to have larger receptive fields (RFs), and they prefer more complex features. Thus, cells in the primary visual cortex (V1) have small RFs (typically less than 1°; Roe & Ts'o, 1995) and are sensitive to very simple stimuli (e.g., oriented lines). In contrast, cells in the inferior temporal cortex (IT) have large RFs (averaging 26°; Desimone & Gross, 1979) and are sensitive to complex stimuli (e.g., faces). Lesion studies in IT indicate that its posterior part (TEO) is important for pattern discrimination, whereas its anterior part (TE) is crucial for object memory (Iwai & Mishkin 1968, 1969). In addition, stimulus familiarization affects the tuning of IT cells (Ringo, 1996), and object naming produces enhanced positron emission tomography signals in that area (Martin, Wiggs, Ungerleider, & Haxby, 1996). Therefore, area IT has been suggested to have a central role in visual object recognition (Kobatake & Tanaka, 1994; Miyashita, 1993).

There is some uncertainty as to what the human homologue of IT might be. Results from imaging studies suggest an organization in humans that reflects the functional distinction between TEO and TE in monkeys (Tootell, Dale, Sereno, & Malach, 1996). For example, human lateral occipital cortex (area LO; Malach et al., 1995) is exclusively sensitive to objects, and responds considerably less to scrambled pictures and visual noise. Because area LO is anterior to V4, it might be the human homologue of monkey TEO. It is likely that semantic knowledge about objects, however, is handled farther along this pathway (e.g., area TE or prefrontal cortex; Wagner, Desmond, Demb, Glover, & Gabrieli, 1997).

Thus, one possible interpretation of our results is that the 86.5% of the first presentations that were not identified did not activate a sufficient number of those cells representing that object in the human homologue of TE. It is, therefore, possible that the subliminal priming was a consequence of a change in prior intermediate areas. These intermediate representations might not have been available for conscious report, such as naming. When they were combined with the activity of a second presentation of the same stimulus, the resultant activity might have been sufficient for identification of the object.

This hypothesis is consistent with the size of RFs of cells in the ventral visual pathway and the effect of translation on subliminal visual priming.[6] Because cells with larger RFs have a greater chance of being reactivated by translated presentations, and cells in different visual areas have RFs of different sizes, priming different areas will result in different degrees of position invariance. For example, supraliminal visual priming—in which most of the objects were recognizable also on the first block, and priming was manifested by shorter response times on the second block—has been shown to be completely translation invariant for a translation extent of 4.8° (Biederman & Cooper, 1991). Supraliminal visual priming is thus likely to affect an area with RFs large enough to fully accommodate the translation (e.g., IT). The shift of 4.9° that was used in the present experiment cannot be accommodated by the small RFs of cells in early areas such as V1 and V2, and would be fully accommodated by the large RFs of cells in IT (resulting in a complete translation invariance). Therefore, the partial position dependency reported here suggests that the effect of subliminal visual priming may be concentrated in a cortical area where cells have RFs of intermediate size. A likely candidate is the human homologue of area V4, where the RF size, 0.7° to 10° (Tanaka, Weber, & Creutzfeldt, 1986),[7] would straddle the 4.9° shift.

This hypothesis can be tested by contrasting the characteristics of subliminal visual priming with known physiological properties of cells in intermediate visual areas. For example, it is believed that the RFs of cells in V4 and TEO, unlike area TE, are confined to a single quadrant of the visual field, with little or no overlap across quadrants (Boussaoud, Desimone, & Ungerleider, 1991; Gattass, Sousa, & Gross, 1989). Indeed, we recently provided further support for the present proposal that an intermediate visual area is the locus of subliminal priming, as translation within quadrants resulted in significantly more subliminal priming than translation between quadrants, although the translation was of the same extent and eccentricity in both conditions (Bar & Biederman, 1998).

Crick and Koch (1995) advanced a hypothesis that humans are not aware of visual activity in the primary visual cortex, V1. Our results suggest that humans may not be aware of visual activity that is associated with object identity even higher in the ventral visual pathway (viz., V2 and V4). Awareness of a stimulus may thus entail its translational invariance.

Acknowledgments—We would like to thank C. Koch, R. Desimone, J.D. Gabrieli, N. Kanwisher, M.C. Potter, S. Subramaniam, and two anonymous reviewers for helpful comments, and M. Sapera for assistance in running the experiments. Portions of this work were presented at the annual meeting of The Association for Research in Vision and Ophthalmology, Fort Lauderdale, Florida, April 1996. This work was supported by Grant DAAH04-94-G-0065 from the Army Research Office and Grant N0014-95-1-1108 from the Office of Naval Research.

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[6] We assume that priming requires reactivation of some portion of the cells that were initially activated by the prime, and that translation invariance is obtained when the new stimulus position allows activation of a high proportion of the previously activated cells. The function relating proportion of reactivated cells and magnitude of priming may be nonlinear (e.g., ogival), with little or no priming manifested at very low proportions, and near maximum levels of priming with higher proportions.

[7] We assume that RF size is similar in humans and monkeys.

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(RECEIVED 2/24/97; REVISION ACCEPTED 4/30/98)