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Familiarity does not aid access to features

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Abstract Previous findings have suggested that a familiar pattern and the features within it are perceived better than an unfamiliar pattern. In Experiments 1 and 2, access to within-pattern colors in Stars and Stripes flags was equally efficient in the normal and the inverted orientations, thus suggesting that familiarity does not aid access to within-pattern features. However, in Experiment 3, which focused on the detection of the whole of a flag, rather than within-pattern colors, the selection of upright Stars and Stripes flags was significantly more efficient than that of inverted flags, thus confirming the greater familiarity of the former. I argue that familiarity aids the perception of a pattern only by allowing the whole pattern to be labeled as a single feature and does not directly aid access to features.

Keywords Visual attention · Boolean map · Familiarity

Human visual perception is often faced with a complex scene consisting of many objects. Early vision can efficiently extract a number of basic features in parallel from the whole scene (Treisman & Gelade, 1980; Treisman & Sato, 1990), but only a small subset of these features can be consciously perceived at any instant. Questions such as "What information can fit into this subset?" and "How is this subset selected from the entire scene?" have been systematically explored in the visual attention literature. Among the various questions that have been explored in the field of visual attention, an important one is the role of familiarity; for example, visual searches that are usually serial, effortful, and voluntary become parallel, effortless, and automatic after extended practice (Schneider & Shiffrin, 1977; Shiffrin & Schneider, 1977).

Previous findings that support the view that familiarity aids perception

Among the various ways of studying the relationship between familiarity and attention, one specific question that has been asked is whether familiarity with a pattern aids the perception of within-pattern features. The general conclusion of previous findings has been that familiarity significantly aids the perception of features.

To cite a few examples, (1) Wolfe (1992) reported that a visual search for a configuration of two features is generally inefficient but becomes much more efficient if the particular configuration is a familiar real-world object, such as a house or a snowman; (2) in Donnelly and Davidoff's (1999) study, observers attempted to compare items of different shapes (e.g., two mouths), and the authors found that comparison was facilitated when the mouths were presented in whole faces, rather than in isolation, even if the rest of the faces were completely identical (i.e., not directly useful for a comparison); (3) in word superiority effect studies (e.g., Johnston & McClelland, 1973, 1974), it has been found that a single letter can be perceived better when it is presented in a familiar word, rather than in a meaningless string of letters.

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All of these findings seem to support the notion that familiarity with a pattern aids access to features within it. For simplicity of discussion, this notion will be referred to as the *improved features account*.

An alternative "inverse inference account"

In our recently developed *Boolean map theory of visual attention* (Huang & Pashler, 2007; Huang, Treisman, & Pashler, 2007), we argued that the limits of instant visual awareness boil down to a Boolean map—the linkage of one feature value per dimension with a map (i.e., a set of locations). One prediction that follows from this theory is that there is a strict attentional limit on simultaneous access to multiple features (e.g., multiple colors): Multiple features have to be accessed one at a time. The original presentation of this theory did not explicitly consider the role of familiarity, but if, as we argued, the attentional limit on access is a fundamental constraint on visual awareness, it should follow that this limit on access will not be affected by familiarity with patterns. Therefore, on the surface, the prediction of the Boolean map theory is contradicted by the findings discussed above (Donnelly & Davidoff, 1999; Johnston & McClelland, 1973, 1974; Wolfe, 1992).

Here, to solve this paradox, I propose an *inverse inference account*: Although familiarity can allow a whole familiar pattern to be labeled as a single feature and efficiently selected, *this whole-pattern label provides no access to features that pertain only to one subset of this whole* (Huang & Pashler, 2007, p. 613). In addition, the strict attentional limit on the conscious access to multiple features, as advocated in the Boolean map theory, is not affected by this familiarity. The previously reported advantage (Donnelly & Davidoff, 1999; Johnston & McClelland, 1973, 1974; Wolfe, 1992) is, instead, caused by inverse inference based on the overall label.

The overall label, as conceptualized in the Boolean map theory, is in some sense an *empty* label that provides no visual details about the contents within. For example, a scene may be labeled as "a baseball game," but this label is merely a conceptual label and provides no visual detail at all; nevertheless, one can inversely infer from this label that there are probably baseball players in the scene.

Two issues need to be clarified about the nature of this inverse inference. On the one hand, *inference* here implies only that the label of the whole pattern can provide useful information for making an optimal guess in a task with a within-pattern feature. It does not imply a deliberate inferential process. In other words, it could be an automatic, effortless *perceptual-inference* process.

On the other hand, it should also be stressed that it is *not* the case that any feedback that a whole pattern provides on the within-pattern features counts as an inverse inference. *Inverse inference* refers to a more specific process; it is an inferential process in the sense that, although it probably is, as was mentioned above, implemented perceptually, *it has the same effect as if there were no perceptual effect on the within-pattern features and the observer is only trying to make an optimal guess about these within-pattern features on the basis of the identity label of the whole pattern*.

Below, I exemplify how, in different perceptual tasks, judgments on within-pattern features can benefit from inverse inference.

First, our high familiarity with words allows a whole word to have an overall semantic label but, according to the inverse inference account, does not directly aid access to information about individual letters. When recognizing that a word is *pyramid*, one can inversely infer that its fifth letter is an *m*, thus causing the previously reported word superiority effect; however, access to the letter *m*, per se, is not improved. The inverse inference account could be fairly compatible with the typical explanation for the word superiority effect (e.g., the interactive-activation model; McClelland & Rumelhart, 1981; Rumelhart & McClelland, 1982): The activation of the word detectors contributes to the recognition of letters. This account differs from the improved feature account only in that it specifies that the nature of this contribution is the inverse inference.

As another example, the high familiarity of a human face allows a whole face to have an overall *face type* label, but it does not aid access to information about the shape of facial parts (i.e., nose, mouth, etc.). When recognizing that a face is of a particular type, one can inversely infer that the mouth is of one particular type, thus causing the previously reported whole-face advantage, but access to the shape of the mouth, per se, is not improved. In this case, the relationship between the face type and the shape of facial parts cannot be verbalized as easily as in the first example of words, but it is certainly not implausible that there is such a relationship.

As a third example, familiarity with the Stars and Stripes flag allows the whole flag to have an overall label but does not aid access to the colors of the different regions. When recognizing this flag, one can inversely infer that the smaller region is blue and the larger region is red, but access to the colors, per se, is not improved. This example will be further elaborated below, since Stars and Stripes flags were used as the stimuli in the present study.

Choice of stimuli in the present study

To test the inverse inference account, I needed to use highly familiar objects that are defined by a specific arrangement of features. In this study, for the present purpose of exploring the *general* role of familiarity in the conscious access to features, I chose to use familiar but simple geometrical patterns, rather than words and faces, because both words and faces have their own unique processing mechanisms. Flags contain only a small number of discrete colors, and their different color regions are well segregated; they were therefore appropriate stimuli for the present study. Since the experiments were carried out at the University of California, San Diego, I used images of the national flag of the United States (i.e., the Stars and Stripes) as my stimuli.

To study the role of familiarity, I needed stimuli that had different degrees of familiarity but that were, in all other visual aspects, equal. In this study, to ensure the equalization of these other visual aspects, I manipulated familiarity by comparing the perception of upright flags with that of inverted flags (i.e., 180º rotation). Naturally, observers should be more familiar with the upright flags than with the inverted flags. However, in all other visual aspects, the stimuli were equal.

Distinguishing between the improved features account and the inverse inference account

How is it possible to distinguish between the improved features account and the inverse inference account? The improved features account naturally predicts that, in general, a familiar pattern would improve performance in relation to within-pattern features. The predictions of the inverse inference account, on the other hand, depend on the specific experimental approach.

For some approaches, the identity label of the whole pattern allows one to make a precise guess about within-pattern features. For example, if the task is to judge whether the color yellow or blue is present, seeing the stimuli of a Stars and Stripes flag allows us to guess precisely that blue, not yellow, is present and, thus, improves our performance. Naturally, this type of experiment is *not* useful for distinguishing between the improved features account and the inverse inference account, because both accounts would make the same prediction (i.e., improved performance from familiarity). To the best of my knowledge, the previous reports on the familiarity advantage (e.g., Donnelly & Davidoff, 1999; Johnston & McClelland, 1973, 1974; Wolfe, 1992) generally fall into this category. Therefore, what constitutes the nature of the familiarity advantage (i.e., improved features vs. inverse inference) remains an open question, which I tried to explore in the present study.

To distinguish between the improved features account and the inverse inference account, it is necessary to find a situation in which what inverse inference provides is not useful (i.e., the identity label of the whole pattern cannot be used to make a useful guess about within-pattern features). Then, if, in this situation, familiarity still aids performance on a task related to the features, the improved features account will be supported; otherwise, if familiarity does not aid performance on that task, the inverse inference account will be supported. I created this situation by using feature changes that were *orthogonal to familiarity* (i.e., how the flag is defined). Specifically, in Experiments 1 and 2, for both the red and blue regions of the Stars and Stripes flag, I manipulated whether they were bright or dark and asked observers to make a judgment on this difference. Clearly, the manipulation of brightness was orthogonal to familiarity (i.e., the pattern fitted very well with the definition of the flag regardless of whether the regions were bright or dark). Therefore, the overall label of the flag provided no useful information at all on whether the red and blue regions within it were bright or dark. In other words, when recognizing the Stars and Stripes flag, one can inversely infer that the smaller region is blue and the larger region is red, but one cannot infer whether these regions are bright or dark, and so familiarity with the flag will not aid performance.

To summarize, I tested observers' perceptions of colors in flags that varied in terms of the degree of familiarity. The critical difference between my test and those in previous studies is that, as illustrated above, *in previous tests, an overall identity label could be used to infer the answer to the required task, whereas in the present Experiments 1 and 2, this was not the case.* Therefore, the results of the present Experiments 1 and 2 can tell us whether, when an overall label is of no use, familiarly still aids access to features.

General Method

Participants

The observers in all three experiments were college undergraduate students from the University of California, San Diego. There were 11 observers in both Experiments 1 and 2 and 10 observers in Experiment 3. All of the observers had lived in the United States for at least 5 years, and they all confirmed that they were familiar with the pattern of the Stars and Stripes flag.

Apparatus

The stimuli were presented on a 1,024 × 768 pixel CRT color monitor. The observers viewed the stimuli display from a distance of about 60 cm and entered their responses using a keyboard. The program was written in Microsoft Visual Basic 6.0 and was run on Microsoft Windows XP using timing routines tested with the Blackbox Toolkit.

Stimuli

The stimuli in all three experiments were upright and inverted images of the Stars and Stripes flag. The flags measured 4.9 cm wide and 3.0 cm high. All other geometrical aspects of the flags (e.g., the size of the field of stars; the size, number, and arrangement of the stars; and the width and number of the red stripes) were in correct proportion to the standard flag. On some of the trials, the parts of the flag that are normally red and blue were given different colors, but the color of the white parts was never altered.

Procedure

At the start of each trial, a small white fixation cross was presented in the center of the display for 400 ms. This was followed by a short blank interval (400 ms), after which the stimulus display was presented. The observers had to make one judgment (the specifications of the tasks are explained below in the sections on the methods of the individual experiments) and then press one of two adjacent keys (“j” or “k”) to indicate their response. After a response was made, a pleasant or unpleasant tone sounded to indicate whether the response was correct or incorrect, respectively, and the next trial began 400 ms later.

In Experiments 1 and 3, the stimuli remained on the display until a response was given. The observers were asked to respond as accurately and quickly as possible, and their response times were measured (i.e., speeded response). In Experiment 2, I measured accuracy using briefly presented stimuli, and the observers were asked to respond as accurately as possible but were under no time pressure (i.e., unspeeded response). The observers completed 10 blocks. In Experiments 1, 2, and 3, there were 70, 64, and 90 trials, respectively, per block. In each experiment, the first block was regarded as practice and was excluded from the analysis.

Experiment 1: Equal efficiency in comparing colors in upright and inverted flags

In Experiment 1, I investigated whether the observers' perception of colors was better when the colors belonged to upright flags rather than to inverted flags. A number of flag patterns (upright or inverted) were presented on the left- and right-hand sides of the display, and the observers had to decide whether these patterns matched (i.e., each pattern was compared against the flag on the other side of the vertical midline). If the improved features account is correct, we would expect pattern matching to be more efficient in the upright than in the inverted presentations of the flags. As was illustrated above, if the inverse inference account is correct, we would expect pattern matching to be equally efficient in the upright and inverted presentations of the flags. In Experiment 1, the efficiency of pattern matching was measured by the slope of response times.

Method

Examples of the stimuli used in Experiment 1 are shown in Fig. 1a. The flag patterns were presented on the left- and right-hand sides of the display and were positioned horizontally 4.1 cm away from the center. In each display, there were one, two, or three flag patterns on each side. The patterns were placed in two columns with a gap (0.4 cm wide) between each vertical neighbor. The blue and red parts of each flag pattern were randomly assigned to be either bright or dark. The trials were split 50:50 between match trials, in which the red and blue parts of all of the flags on both sides matched exactly (i.e., each pattern was identical to the flag on the other side of the vertical midline), and nonmatch trials, in which one part of one flag on one side of the vertical midline was altered. The observers decided whether a display was a match or a nonmatch and gave their response. On 50% of the trials, all of the flag patterns were upright; on the remaining 50%, they were all inverted. The upright and inverted trials were intermixed within each block.

Results and discussion

The results of Experiment 1 are plotted in Fig. 1b. On the trials, the response times were roughly equal for the inverted and upright flag patterns; their slopes did not differ, $F(1, 10) = 1.20$, n.s. Clearly, the perception of colors in both types of flag patterns was equally efficient. The error rates in Experiment 1 were consistently very low and, therefore, were not analyzed further.

Experiment 2: Equal successive/simultaneous differences when accessing colors in upright and inverted flags

In Experiment 2, I tried to confirm the conclusion of Experiment 1, using the successive/simultaneous paradigm (Duncan, 1980a, 1980b; Shiffrin & Gardner, 1972). The logic of this paradigm is as follows: For any type of visual information, if two sets of stimuli are presented, either at the same time (simultaneous condition) or one by one (successive condition), with the stimuli durations equated, the performance of observers should be worse in the simultaneous condition if the information from the two sets of stimuli cannot be accessed at the same time but should be equal in both conditions if the information from the two sets can be simultaneously accessed without attentional limitation.

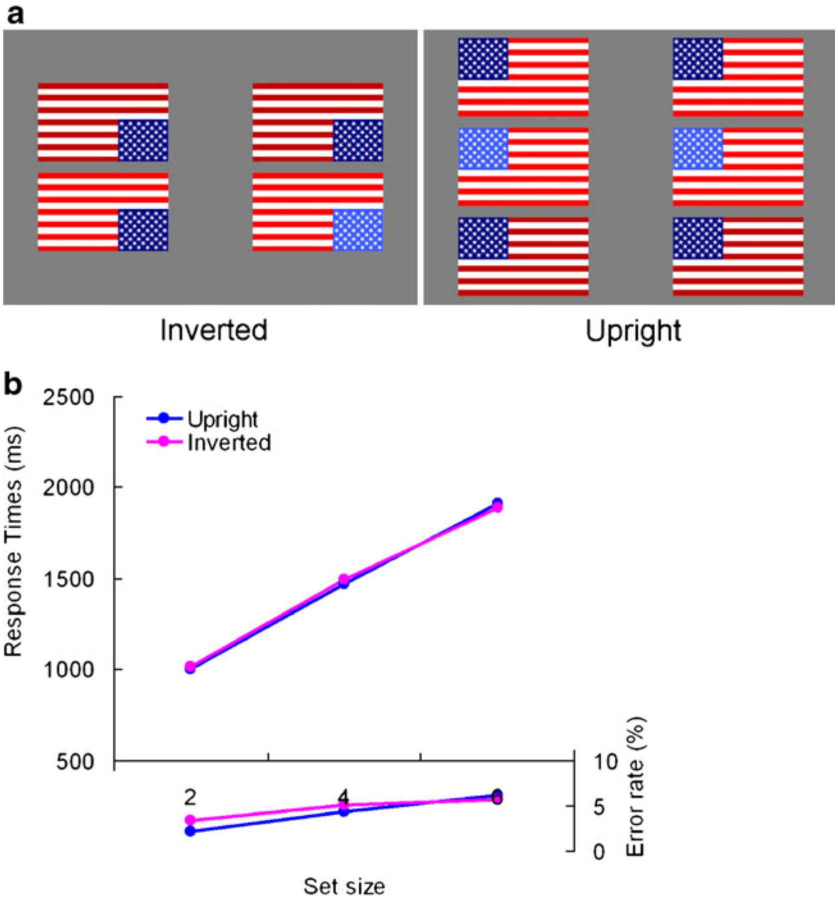

Fig. 1 **a** Method and **b** results of Experiment 1. In Experiment 1, I investigated whether the observers' perception of colors was better when the colors belonged to upright, rather than inverted, flags. The blue and the red parts of each flag pattern were randomly assigned to be either bright or dark. On 50% of the trials, all of the flag patterns were upright; on the remaining 50%, they were all inverted. The observers had to decide whether the patterns on the left- and right-hand sides were an exact match. If familiarity can indeed aid the perception of colors, we would expect the matching to be more efficient on the upright flag trials than on the inverted flag trials. The response times were about equal in both sets of trials, as is shown in the response time slopes (**b**). Clearly, the perception of colors in the upright and inverted flag patterns was equally efficient

Method

Examples of the stimuli used in Experiment 2 are shown in Fig. 2a. On each trial in Experiment 2, one flag pattern was presented in the center of the display. The blue and the red parts of the flag patterns were randomly assigned to be either bright or dark. The trials were split 50:50 between patterns that were presented in one frame (i.e., simultaneous presentations) and patterns that were presented in two frames (i.e., successive presentations); each frame was followed by a mask. Simultaneous and successive presentations were intermixed within each block. The masks were made by interspersing dark and bright segments in both the blue and red regions. The exposure duration of the stimuli was adjusted for each individual observer, so that their overall performances were moderate; this adjustment was implemented by running a staircase. The mean exposure duration was 233 ms (i.e., either the stimuli were presented altogether for 233 ms in the simultaneous condition, or each frame was presented for 233 ms in the successive condition). In the case of patterns presented in two frames, the interframe interval was 700 msec. Each mask remained on the display for 200 ms and then disappeared. Immediately after the offset of the last mask, a test display was presented to test either the color red or blue. The test display showed the two possibilities (i.e., bright or dark) for the tested color (e.g., when blue was tested, bright and dark blue were presented). The observers made a decision on which color had been presented and made a response. On 50% of the trials, the flag pattern was upright; on the remaining 50%, it was inverted. The upright and inverted trials were intermixed within each block.

Results and discussion

The results of Experiment 2 are plotted in Fig. 2b. Performance was substantially better for successive presentations than it was for simultaneous presentations. With regard to the inverted and upright flag patterns, the successive/simultaneous differences were about equal, *F* (1, 10) = 0.31, n.s. This result confirmed that the attentional limit on simultaneous access to multiple features is not reduced by the familiarity of patterns.

One might point out that the manipulation of familiarity in Experiment 2 was valid only for the simultaneous condition. In the successive condition, the patterns were always broken into parts, so even the upright pattern did not appear familiar to the observers. While this is probably true,

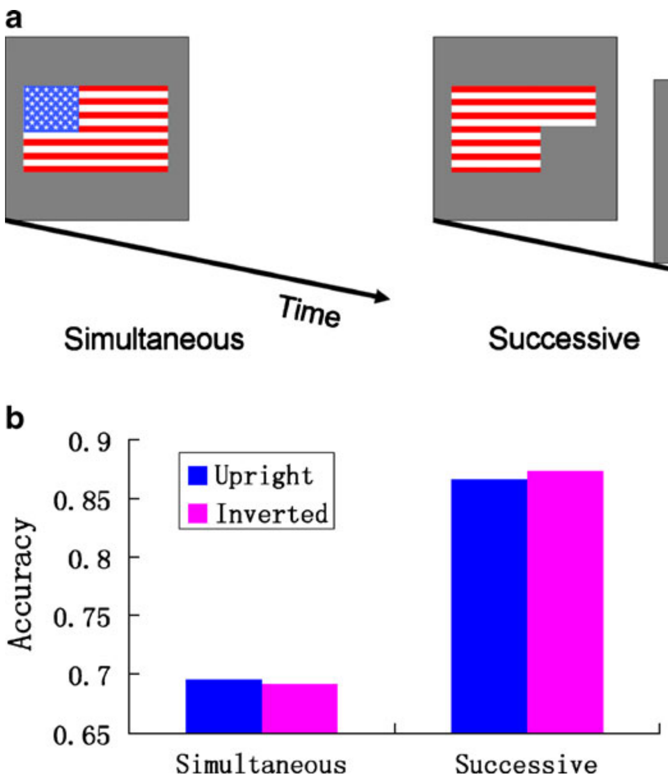

Fig. 2 **a** Method and **b** results of Experiment 2. In Experiment 2, I tried to confirm the conclusion of Experiment 1 using the successive/simultaneous paradigm. The blue and red parts of the flag patterns were randomly assigned to be either bright or dark and were presented in either one or two frames, with a mask following each frame. The subsequent test display showed the two possibilities (i.e., bright and dark) for the tested color (e.g., both bright and dark blue were presented when this color was tested), and the observers had to decide which color was actually presented in the display. The successive/simultaneous differences were about equal on the inverted and upright flag pattern trials; therefore, the attentional limit on the simultaneous access to multiple features in more familiar patterns was not reduced. This confirmed the conclusion of Experiment 1 that familiarity does not aid the perception of colors

this does not undermine my rationale, because it only provides more reasons for the successive/simultaneous difference to be reduced in the upright flag patterns.

Experiment 3: Confirming the greater familiarity of the upright flag

The results of Experiments 1 and 2 showed that the perception of colors was not more efficient when the flag patterns were familiar. A potential challenge to this conclusion is the suggestion that, perhaps, in Experiments 1 and 2, the observers were equally familiar with the inverted and upright flag patterns. Experiment 3 was designed to test this possibility by asking the observers to report on the presence of the whole flags, rather than to distinguish the colors. Specifically, in Experiment 3, the observers searched for an upright or inverted flag with a typical color arrangement among other distractor patterns in which the color of one region had been changed (e.g., red → green or blue → yellow; see Fig. 3a).

It should be stressed that the inverse inference account would predict that in Experiment 3, familiarity should aid the search for the target. Unlike in Experiments 1 and 2, the distractor patterns in Experiment 3 did not fit the definition of the Stars and Stripes flag; therefore, the task could easily rely on inverse inference from the overall label.

Method

Examples of the stimuli used in Experiment 3 are shown in Fig. 3a. Flag patterns were presented on the left- and right-hand sides of the display; the spatial arrangements of these patterns were the same as in Experiment 1. In each stimuli display, only one of the flag patterns had the typical color arrangement (i.e., both a red and a blue part), and this was the target item. There were two types of distractor items; these were created by changing either the blue part to yellow or the red part to green. The observers had to search for the target item, decide whether it was on the left- or right-hand side of the display, and then make a response. On 50% of the trials, all of the flag patterns were upright;

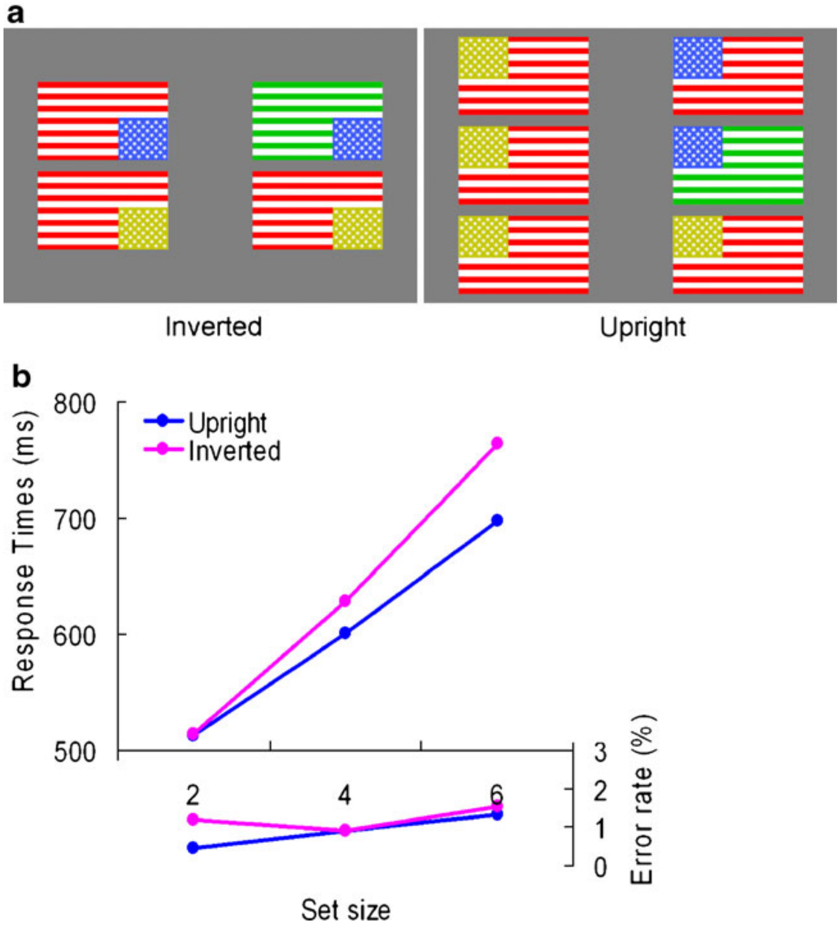

Fig. 3 **a** Method and **b** results of Experiment 3. A potential challenge to my conclusion (i.e., familiarity does not aid the perception of within-pattern colors) is the suggestion that, perhaps, in Experiments 1 and 2, the observers were equally familiar with the inverted and the upright flag patterns. Experiment 3 was designed to test this possibility by asking the observers to report on the presence of the whole flags, rather than to make distinctions between the colors. In each stimuli display, only one flag pattern had the authentic color arrangement (i.e., a red and a blue part), and this item was the target of the search task. The slope was significantly greater on the inverted flag pattern trials than on the upright flag pattern trials. Therefore, the observers were indeed more familiar with the upright, rather than the inverted, flag

on the remaining 50%, they were inverted. The upright and inverted trials were intermixed within each block.

Results and discussion

The results of Experiment 3 are plotted in Fig. 3b. The slope was greater for the inverted than for the upright flag patterns, $F(1, 9) = 9.26$, $p < .02$. A comparison between Experiments 1 and 3 suggested a significant interaction, $F(1, 19) = 6.22$, $p < .05$, between pattern orientation (normal vs. inverted) and task (color matching in Experiment 1 vs. flag search in Experiment 3). It should be pointed out that the ranges of the slopes were very different in Experiments 1 and 3 and, therefore, were not directly comparable. Nevertheless, the same interaction was seen when I used the *inverted/upright slope ratio* to measure the difference between the inverted and upright slopes, $F(1, 19) = 8.14$, $p < .02$. Overall, the results of Experiment 3 suggested that observers were indeed more familiar with the upright flags than with the inverted ones. The error rates in Experiment 3 were consistently very low and, therefore, were not analyzed further.

General discussion

Taken together, the present results suggest that familiarity with a pattern does not help the perception of features within it (Experiments 1 and 2) but does help to determine the presence of the pattern (Experiment 3). Therefore, the limit on simultaneous access to multiple features is not reduced as a result of patterns being highly familiar.

Selection of whole patterns

I mentioned above that labeling a whole familiar pattern as a single feature can allow it to be efficiently selected. One may question how this selection could be achieved without access to the features that define the pattern. The answer to this question lies in the distinction between selection and access made by Duncan (1980a, 1980b; see also Huang 2010c). Plainly speaking, the features that define a familiar pattern are used only by the unconscious underlying processing mechanism and never need to be brought to conscious access; for example, when searching for a particular face, one does not need to explicitly compare the size and shape of different facial parts, although such comparisons probably need to be implemented in the unconscious underlying mechanism.

Another related question is the following: How exactly is the selection of whole patterns improved when the patterns are familiar? This question cannot be answered by the present study, but one can imagine some plausible ways in which it could happen. For example, perhaps selecting a whole pattern as a single feature requires establishing some kind of *target template* in the memory and it is easier to establish or maintain a more familiar template. This and other possibilities need to be explored in future studies. Nevertheless, it is clear from the present study that this improvement, regardless of its nature, is not implemented by improved access to within-pattern features.

Familiar features in other senses

In the present study, I have addressed familiarity only in the sense of a familiar spatial arrangement of features (i.e., the Stars and Stripes flag). One may potentially point out that a more straightforward way of addressing how familiarity affects access to features would be to consider familiarity for the features themselves, rather than for their spatial arrangements.

Although this sense of familiarity is potentially important and worth exploring in future studies, there is reason to believe that the sense of familiarity explored here (i.e., familiar spatial arrangements of features) is more important and more appropriate to the research question. For one thing, although it is very common to study the familiar spatial arrangement of features (e.g., flags, words, or faces, as illustrated above), it has very rarely been reported that familiarity with the presence of features per se can be acquired *regardless of the arrangement*. This is probably because real-world objects can hardly ever be reliably recognized solely on the basis of the presence of features, regardless of the arrangement; therefore, evolution has perhaps given the visual system the inherent algorithm of only becoming familiar with the arrangement of features.

Relation to other Boolean map theory findings

As was discussed at the beginning of this article, the Boolean map theory (Huang & Pashler, 2007) started by emphasizing the distinction between selection and access and then proposed that access can be characterized by the data format of a Boolean map. Huang and Pashler (2007) also proposed that selection and, indeed, all top-down control in general is implemented only by the creation of a Boolean map. We have further tested various aspects of this theory (Huang, 2010a, 2010b, 2010c; Huang & Pashler, 2009).

Although I have approached the present research question as a further development of the Boolean map theory, this question (i.e., how does familiarity affects access to features?) is relatively separate from the main questions addressed in this theory. Therefore, it is conceivable that the present conclusion and the core claims of the Boolean map theory could be true (or false) independently of each other.

Of most relevance to the present study, Huang (2010c) conducted a side-by-side comparison of the Boolean map and the concept of object to see how well each of them could account for the data in a number of experiments. In this study, objecthood was operationally manipulated as lines connecting different items. The findings showed that (1) access to information on two items is the same regardless of whether these items belong to one object or to two separate objects; (2) same-object advantage for two features is significant only when these two features are different dimensions of one Boolean map and does not exist when these features belong to different parts of an object; and (3) among two possible features, cuing the to-be-reported feature has no effect when these features are different dimensions of one Boolean map but does have a significant effect when they belong to different parts of an object. Taken together, these results support the claim that the unit of access is the Boolean map, rather than the object.

The concept of object can be defined either as a low-level property (e.g., a connection between parts) or in terms of past experience. Huang (2010c) showed that an object, in the sense of connected parts, does not affect the limit of feature access but left open the possibility that an object, in the sense of a familiar pattern from the real world, could still affect the limit of feature access. The present study completed this missing part of the puzzle. Together, these two studies have shown that the object concept in general, defined either as a low-level property or in terms of past experience, has no impact on the limit of feature access.

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