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Visual Search for Object Orientation Can Be Modulated by Canonical Orientation

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The authors studied the influence of canonical orientation on visual search for object orientation. Displays consisted of pictures of animals whose axis of elongation was either vertical or tilted in their canonical orientation. Target orientation could be either congruent or incongruent with the object's canonical orientation. In Experiment 1, vertical canonical targets were detected faster when they were tilted (incongruent) than when they were vertical (congruent). This search asymmetry was reversed for tilted canonical targets. The effect of canonical orientation was partially preserved when objects were high-pass filtered, but it was eliminated when they were low-pass filtered, rendering them as unfamiliar shapes (Experiment 2). The effect of canonical orientation was also eliminated by inverting the objects (Experiment 3) and in a patient with visual agnosia (Experiment 4). These results indicate that orientation search with familiar objects can be modulated by canonical orientation, and they indicate a top-down influence on orientation processing.

Recognition of familiar objects in everyday life is a seemingly effortless process, yet many studies have demonstrated that object recognition is influenced by stimulus factors such as stimulus orientation. For instance, the time to name familiar objects may increase when the objects are rotated away from the familiar upright (e.g., Jolicœur, 1985; Lawson, Humphreys, & Jolicœur, 2000). However, the detection of shape orientation can be influenced by familiarity (e.g., Shen & Reingold, 2001; Tong & Nakayama, 1999; Wang, Cavanagh, & Green, 1994). These findings have led to the suggestion that the coding of object orientation and identity may be linked (see below). The coding of object orientation may then not only be based on a coarse image analysis that preserves the global or main axis of an object, it may also be affected by whether the main axis of the object corresponds to its upright or canonical orientation. In the present article, we investigate this proposal by studying the effect of canonical orientation on the coding of object orientation.

The study of visual orientation processing has typically been framed in theories of visual object processing that postulate several hierarchical processing stages (e.g., Biederman, 1987; Marr, 1982; Treisman & Gelade, 1980). At early stages, simple visual properties such as orientation, size, and color are extracted from the retinal image. Later stages act to combine these basic features into representations that can be matched with stored representations of objects. With multipart objects, the orientation codes that might be derived at an early stage may be based on some low-spatial-frequency analysis of the image that provides a first pass for subsequent processing (e.g., Watt & Morgan, 1985). Such codes, typically corresponding to the main physical axis of the object, may then be used to support object recognition. On this account, early vision should be sensitive to differences in orientation between the main physical axes of objects. It should not be sensitive to whether the main physical axis of an object corresponds to the canonical orientation that the object usually has.

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An empirical procedure used to analyze what visual information is processed at different stages—and how—is visual search. A visual target that differs from distractors on the basis of a unique feature (e.g., orientation or color) may be detected efficiently and with minimal effects of the number of distractors. Features that generate highly efficient search functions (i.e., are unaffected by the presence of distractors) are typically assumed to be computed in parallel at early stages (e.g., Treisman, 1985, 1993; Treisman & Gormican, 1988). Prior studies of orientation search have shown that performance is influenced by categorical differences in orientation between stimuli (e.g., *steep* versus *shallow*, *oblique* versus *vertical*), and from this it has been concluded that early vision codes orientation in terms of a few categorical distinctions (Wolfe, 1994, 1998). Visual search performance for local orientation also shows an asymmetry. In particular, a line segment tilted slightly (e.g., 15°–30°) from the vertical (or the horizontal) can be detected efficiently among vertical (or horizontal) distractor lines, but when the target and distractor orientations are reversed, search becomes inefficient (Foster & Ward, 1991a, 1991b; Foster & Westland, 1995; Marendaz, Stivalet, & Genon, 1991; Treisman, 1985, 1993; Treisman & Gormican, 1988; Wolfe, 1998). One account of this *orientation search asymmetry* is that search is determined by orientation differences relative to vertical and horizontal axes, which provide a standard frame for orientation coding. Deviations from these cardinal orientations pop out in search, whereas the cardinal orientations themselves do not (e.g., Treisman & Gormican, 1988). Some theories explain this as the result of differential activation of local orientation filters tuned to cardinal orientations (the vertical and the horizontal) in response to vertical and tilted lines (Foster & Ward, 1991a, 1991b; Foster & Westland, 1995; Marendaz et al., 1991).

Other studies, however, have indicated that the coding of orientation in search tasks is more complex than is suggested by a simple feature-map account. For example, orientation coding can be influenced by vestibular cues and by the visuospatial context: Altering the posture of observers or the perceived direction of gravity (e.g., by having displays viewed from a supine position or in a centrifugation room) can change the amplitude and direction of orientation search asymmetry (Marendaz, Stivalet, Barraclough, & Walkowiac, 1993; Stivalet, Marendaz, Barraclough, & Mourareau, 1995). Similarly, orientation search asymmetry can be influenced by embedding a target and distractors in a visual context, such as a square frame, that is aligned with either the target or the distractor orientations (Marendaz, 1998; Treisman, 1985; Treisman & Gormican, 1988). Furthermore, orientation asymmetries in search can be influenced by derived shape properties not directly present in the edges of an image. Boutsen and Marendaz (2001), for example, showed an orientation search asymmetry with 2-D shapes that was based on the orientation of the main axis of symmetry and/or elongation of the target shape, not on the orientations of the bounding contour (see also Found & Müller, 1997). These last studies suggest that visual search may not provide direct insights into the information coded at the very earliest stages of vision, and, indeed, access may only be gained to outputs derived after image contours have been initially computed. Similar reservations about the ability to access stimulus properties coded in early vision come from studies in which observers were asked to attend to a physical property of a shape and to ignore associative properties. For example, Boucart and Humphreys (1992, 1994, 1997) had observers attend to, and make judgments of, the global size, orientation, or color of shapes. Although only attention to a physical property was required in each case, performance was affected by whether the stimulus was semantically related to other items in the displays. Boucart and Humphreys (1994, 1997) proposed that observers could not gain isolated access to the early stages of vision, making perceptual decisions vulnerable to associative information that was accessed automatically during the task.

In the present study, we sought to assess whether the associative properties of objects infiltrate visual search tasks in which responses should be based on the physical orientations of the stimuli. Our experiments examined whether search for an orientation-defined target was influenced by whether the object appeared in its canonical orientation. Prior research has indicated that object recognition can vary as a function of whether objects are depicted in their normal, canonical orientations (see Jolicœur, 1985, for effects of 2-D orientations; S. Palmer, Rosch, & Chase, 1981, for effects of rotation in depth; and Lawson et al., 2000 for both processes). However, no study has hitherto examined whether an object's canonical orientation influences responses to its physical orientation. To test this, we had participants search for a target object whose main axis of elongation was physically vertical or tilted. The distractors were examples of the same object, with the main axis of elongation being, respectively, tilted or vertical. Two classes of objects were used, varying in whether their principal axis was vertical or tilted when the objects appeared in their canonical (upright) orientations. Figure 1 presents examples of each type: A vertical canonical object (a seahorse) and a tilted canonical object (a pigeon). The canonical orientation of an object could be *congruent* with its physical orientation in two situations: when a vertical canonical object was presented with a vertical main axis (e.g., the seahorse in Figure 1A) or when a tilted canonical object was presented with a tilted main axis (e.g., the pigeon in Figure 1B). In contrast, the canonical orientation of an object was *incongruent* with its physical orientation when a vertical canonical object was rotated such that its main axis was tilted (e.g., the seahorse in Figure 1B) or when a tilted canonical object was rotated such that its main axis was vertical (e.g., the pigeon in Figure 1A).

The congruency between canonical and physical orientation for the two object types allowed us to investigate the role of canonicalness in object orientation discrimination in visual search. In

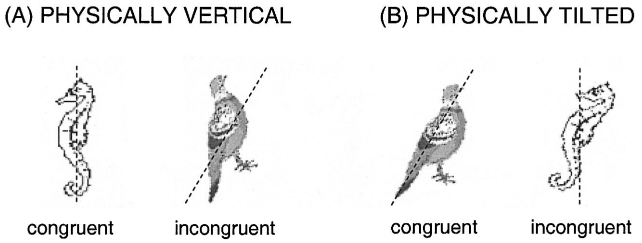

Figure 1. Vertical (the seahorse) and tilted (the pigeon) canonical objects in vertical and tilted orientations. The dashed lines (not shown during the experiments) correspond to the main axis of elongation for each animal in its canonical orientation, which could be either congruent or incongruent with its physical orientation.

particular, different effects can be hypothesized. If search is merely sensitive to the physical orientation of an object's main axis relative to the orientation of the distractors—regardless of whether these orientations are canonical—then performance should not be influenced by the congruency between an object's physical and its canonical orientation. In terms of orientation search asymmetries, this hypothesis would predict search asymmetries in favor of targets with a tilted main axis, regardless of whether the target possessed a vertical or a tilted canonical orientation. However, if search for object orientation does not preclude access to the canonical orientation of the target object, then effects of congruency between physical and canonical orientations can be predicted. In particular, there may be opposite orientation search asymmetries for vertical and for tilted canonical objects, favoring target orientations that are incongruent with the target's canonical orientation. This prediction is based on the assumption that search asymmetries occur in favor of feature values that deviate from a standard value (e.g., Treisman & Souther, 1985; Wolfe, 1998); in this case, the canonical orientation is the default, and incongruent orientations deviate from this standard. The critical point here concerns a stimulus that has a tilted main axis when it is presented in its canonical orientation. This stimulus should generate more efficient search when its main axis is vertical (i.e., noncanonical) and the distractors are tilted (i.e., canonical) than when its main axis is tilted (i.e., canonical) and the distractors are vertical (i.e., noncanonical). This finding would be consistent with an influence of canonicalness on object orientation discrimination in visual search.

We tested the above hypothesis in four experiments. In Experiment 1, we found that search for object orientation was affected by the congruency between an object's canonical and its physical orientation. In particular, there was a *standard* orientation search asymmetry (i.e., more efficient search performance with tilted than with vertical targets) with objects whose canonical axis was vertical. In contrast, this search asymmetry was reversed (i.e., there was more efficient search with vertical than with tilted targets) for objects whose canonical axis was tilted. In both cases, the search asymmetry favored a target in its noncanonical orientation. In further experiments, we demonstrate that this effect was eliminated when objects were low-pass filtered (Experiment 2), thus rendering them unrecognizable, or inverted (Experiment 3), rendering them in unfamiliar (noncanonical) orientations. Finally, in Experiment 4, we repeated Experiment 1 with a visual agnosic patient (H.J.A.) who had impaired object recognition. In contrast to 2 control participants and the participants in Experiment 1, H.J.A. did not show an effect of canonical object orientation; instead, his search performance was determined by physical orientation. The results suggest that the appropriate physical properties of the stimuli were present in the image to generate a standard orientation asymmetry in search (i.e., faster search for a tilted target among vertical distractors than vice versa). These properties were used when the stimuli were low-pass filtered, when they were inverted, and when a brain lesion prevented object recognition. Despite this, participants were affected by an object's canonical orientation when the object could be recognized. The results demonstrate that visual search does not provide a "pure" measure of early visual processing and that associative properties of objects (here, familiar orientation) can modulate performance.

Experiment 1

Participants searched displays containing line drawings of animals for a target whose main axis of orientation differed from that of the distractors (which all had the same orientation). There were four search conditions, determined by the congruency between the physical orientation of each object's main axis (vertical or tilted) and whether that orientation was canonical (see Figure 1). Either the target had a congruent and the distractors an incongruent orientation, or the distractors had a congruent and the target an incongruent orientation.

Method

Participants. Forty-eight undergraduate psychology students from Université Pierre Mendès France, Grenoble, France, participated in the experiment for course credits. All participants reported normal or corrected-to-normal vision; they were unfamiliar with the stimuli and with the aim of the experiment.

Stimuli and apparatus. The experiment was run on a personal computer with a Pentium processor. The stimuli were displayed on a 17-in. (43.18-cm) SVGA monitor with a vertical refresh rate of 60 Hz in a graphics mode of 800 × 600 pixels. Stimulus displays were composed of drawings of one of four different animals (kangaroo, pigeon, seahorse, and penguin; see Figure 2 for examples). The animals were grouped in two categories on the basis of whether, in their upright (canonical) orientation, their main axis of elongation was vertical or tilted (see Figure 1). The kangaroo and the pigeon were *tilted canonical* objects because their main axes were slightly tilted (by about 23°) from the vertical when they were presented in their canonical orientations. The seahorse and the penguin were *vertical canonical* objects because their main axes were vertical when they were presented in their canonical orientations (see Figure 1A). All animals subtended approximately 1.0° (height) × 0.5° (width) of visual angle. The length of the main axis of elongation of each animal was about 1.0°.

The selection of the objects for the search displays was guided by several criteria. First, the objects had to have a main axis of elongation when presented in an upright, canonical orientation. Second, when presented in a canonical orientation, each object's main axis had to have an unambiguous orientation, either vertical (the seahorse and the penguin) or tilted (the pigeon and the kangaroo). Third, when rotated away from their canonical orientation by the same amount, the objects with a vertical main axis had to appear physically tilted, and the objects with a tilted main axis had to appear physically vertical. Finally, in these new orientations, the objects had to appear in a less familiar orientation. These criteria necessarily limited the choice of available objects, for they excluded objects that were not elongated along a vertical or tilted axis as well as objects that are polyoriented (e.g., elongated tools), in that such objects appear familiar in a variety of orientations. In addition, we wanted to ensure that orientation discrimination was guided by the principal axis of an object rather than by salient orientations of local object features (e.g., an animal's feet or tail); this criterion further constrained our selection of objects. As a result, we selected pictures of four animals—pigeon, kangaroo, seahorse, and penguin—that were mono-oriented and had a vertical or a tilted axis of elongation.

To verify whether participants would judge these pictures to have unambiguous main axes of elongation in the required orientations, we conducted a pilot experiment. A group of 15 undergraduate students were shown pictures of all of the animals in five orientations in the image plane (0°, 45°, 90°, 135°, and 180°, with 0° corresponding to the canonical orientation) and asked to manually draw the main axis in the picture (see Quinlan & Humphreys, 1993). In a separate task, these participants were presented again with each animal in a different orientation and asked to rotate the picture such that the animal appeared in a familiar orientation.

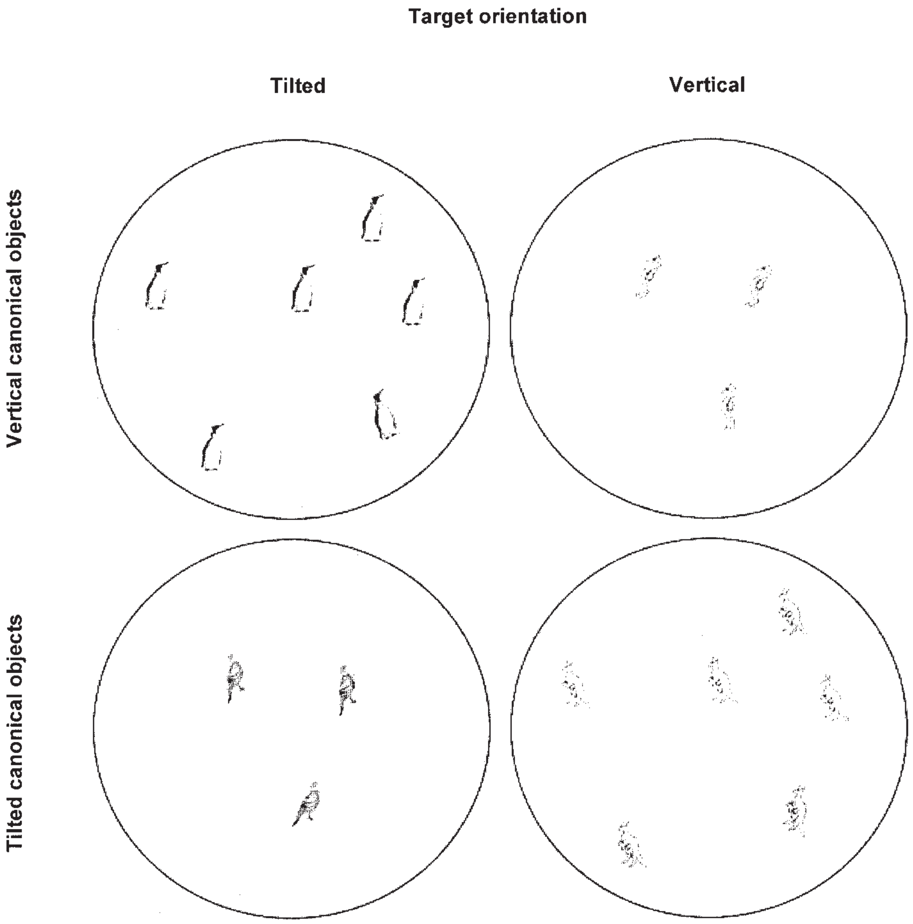

Figure 2. Examples of the stimulus displays used in Experiment 1.

The results showed that in the axis-drawing task, participants consistently drew axes of elongation that were tilted when tilted objects were shown in their canonical orientation and vertical when vertical objects were shown (see the axes drawn in Figure 1). The angle of departure from the vertical of a tilted axis of elongation was 23° on average. Furthermore, judgments of the canonical orientation of the objects were highly consistent between participants. The results thus confirmed that the tilted and vertical canonical objects possessed main axes that were perceived as tilted and vertical, respectively.

Each search display was composed of elements depicting the same animal and consisted of either three or six elements with the target, if present, included. In target-present displays, the target and distractors differed only in orientation: A vertical target was presented among tilted distractors, or a tilted target was presented among vertical distractors. In target-absent displays, all elements had the same orientation (vertical or tilted). The spatial separation between elements in the search displays was at least 1.5°. The positions of the search elements were chosen randomly from eight possible locations within a circular area subtending 10°.

Design. The design of the experiment included four factors: object type (vertical canonical or tilted canonical), target orientation (vertical or tilted), target presence (present or absent), and set size (three or six elements). Object type was manipulated between participants: We tested search performance for each of the four animals with a separate, randomly selected group of 12 participants. The other factors (target orientation, target presence, and set size) were manipulated within participant. For each animal, there were two versions of the search task: search for a vertical target or search for a tilted target. Each participant performed both tasks in two blocks of trials. The order of the blocks was counterbalanced between participants. Within each block, the set-size and target-presence conditions were equally probable and were presented in a random order. For each animal, each condition (Target Orientation × Target Presence × Set Size) was tested 16 times for each participant, yielding a total of 128 trials per experimental session.

Procedure. The participants were tested individually. Each participant sat in front of the computer screen at a distance of 120 cm in a darkened room. To reduce the influence of contextual orientations as much as possible, we had each participant view the stimuli through a black-painted metal cone of 10° diameter positioned and centered in front of the screen. All stimuli were viewed binocularly. The participant's head was upright and stabilized by a chinrest.

On each trial, the search display was preceded by a black central fixation dot for 1.5 s and was followed by a white screen for 2.0 s. The display remained visible until the participant responded. Participants were given detailed instructions and examples. Their task was to detect, as quickly and as accurately as possible, whether the search display contained a target that was an animal presented in a different orientation from the distractors. Participants responded bimanually by pressing, with the thumb, a trigger control held in each hand. Half of the participants pressed the left trigger when the target was present and the right trigger when the target was absent. This response mapping was reversed for the other half of the participants. On each trial, reaction time (RT) was measured from the onset of the search display to the nearest millisecond, and accuracy was measured. No feedback was given after a response was made.

Each individual session consisted of 8 practice trials followed by 128 experimental trials, divided into two blocks according to the target orientation (see the *Design* section). Participants were allowed to take a short break between the two blocks; each session lasted about 45 min.

Results

For each participant, we computed a cutoff value set at 2 standard deviations above and below the mean correct RT for each animal in each condition (Target Orientation × Target Presence × Set Size); this led to the exclusion of 4.98% of correct responses. We calculated mean RTs for the remaining data per participant for each object in each target-orientation, set-size, and target-presence condition; these data were submitted to further analyses. Error rates were marginally positively correlated with RTs ($r = .119$, $p < .10$), indicating that there was no trade-off between speed and accuracy of responding. In total, 3.01% errors were made. Analyses of error rates per condition, run in parallel with the RT analyses, revealed either no reliable effects or reliable effects that were similar to those found in the RT analyses. Therefore, we do not report these error analyses.

Of main interest was performance for vertical (seahorse, penguin) and tilted (pigeon, kangaroo) canonical objects in each target orientation. Figure 3 presents the mean RTs (collapsed across object type, target presence, and set size) to vertical and tilted canonical targets as a function of target orientation. As can be seen from Figure 3, there was an asymmetry in RT performance as a function of the canonical and the physical orientation of the objects in the search tasks. With vertical canonical objects (seahorse and penguin), responses were faster when the target was tilted than when it was vertical. In contrast, tilted canonical objects (kangaroo and pigeon) showed the opposite pattern: Here, responses were faster when the target was vertical than when it was tilted. These search asymmetries can be described in terms of the congruence between canonical orientation and physical orientation: Search was more efficient when the target's physical orientation was incongruent with its canonical orientation (see Figure 3).

We confirmed the effects of canonical and physical orientation in an analysis of variance (ANOVA) on the RTs with object type as a between-participants factor and target orientation, target presence, and set size as within-participant factors. There was a reliable effect of object type, $F(1, 46) = 7.76$, $MSE = 466{,}960$, $p < .008$; RTs were shorter to vertical canonical than to tilted canonical objects (829 vs. 1,024 ms). It is important to note that there was no reliable effect of target orientation ($F < 1$), but there was a Target Orientation × Object Type interaction, $F(1, 46) = 29.17$, $MSE = 75{,}489$, $p < 0001$. This confirms the interaction between canonical orientation and physical orientation described above, yielding the opposite search asymmetries for target orientation (see Figure 3).

To verify to what extent the search asymmetries for target orientation occurred for each individual animal, we performed an ANOVA with object (animal) as a between-participants factor and target orientation, target presence, and set size as within-participant factors. It is important to note that there was a reliable Object × Target Orientation interaction, $F(1, 44) = 10.46$, $MSE = 75{,}282$, $p < .0001$ (no other effects involving orientation were reliable). The RTs for each animal as a function of target orientation are presented in Figure 4. We performed planned comparisons to examine effects of target orientation for each animal separately. These showed an effect of target orientation for the kangaroo, $F(1, 44) = 8.58$, $MSE = 75{,}282$, $p < .01$, and for the pigeon, $F(1, 44) = 6.10$, $MSE = 75{,}282$, $p < .02$): For these tilted canonical objects, RTs were shorter to vertical than to tilted targets. Target orientation had an effect in the opposite direction for the two vertical canonical objects: For both the seahorse, $F(1, 44) = 13.79$, $MSE = 75{,}282$, $p < .001$, and the penguin, RTs were shorter to tilted than to vertical targets, although the orientation effect was not reliable for the penguin, $F(1, 44) = 2.90$, $MSE = 75{,}282$, $p < .096$. This analysis demonstrates that reliable search asymmetries for target orientation occurred for at least three of the four individual objects.

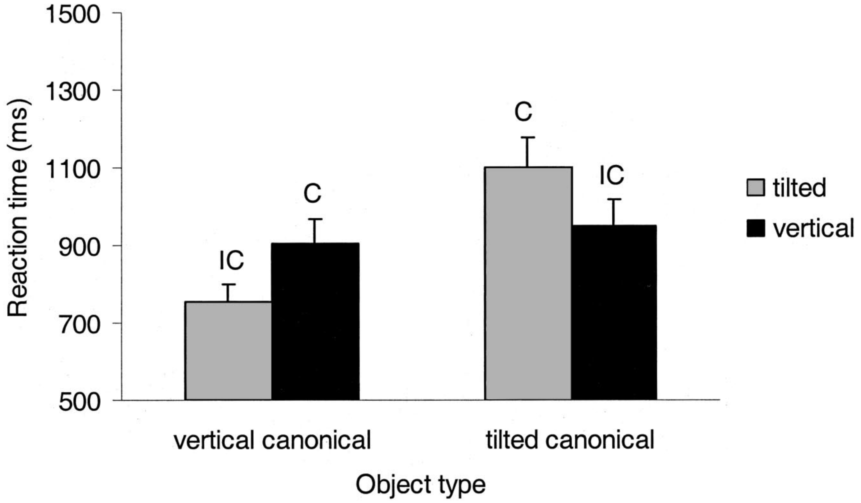

Figure 3. Mean reaction times for detection of vertical and tilted targets per object type in Experiment 1. Error bars represent one standard error of the mean. IC = physical orientation of target was incongruent with object's canonical orientation; C = physical orientation of target was congruent with object's canonical orientation.

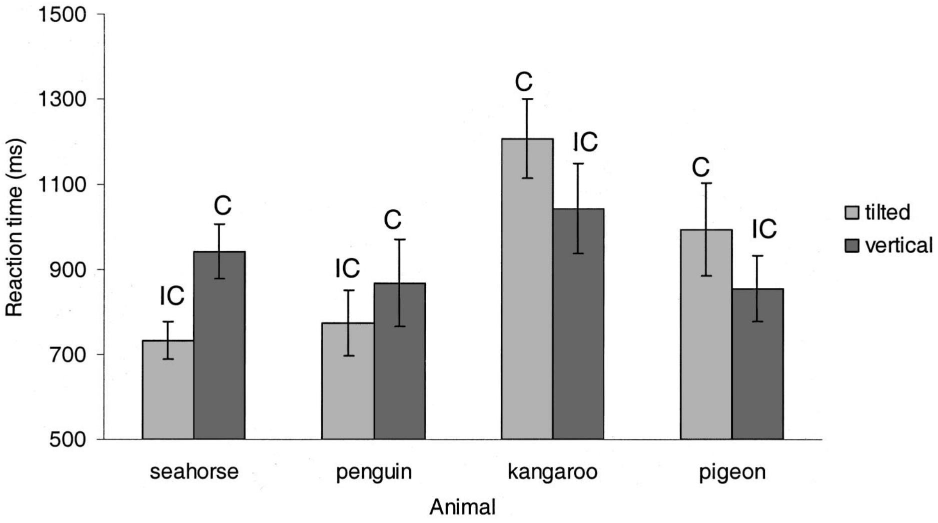

Figure 4. Mean reaction times for detection of vertical and tilted targets per object (Animal) in Experiment 1. Error bars represent 95% confidence intervals. IC = physical orientation of target was incongruent with object's canonical orientation; C = physical orientation of target was congruent with object's canonical orientation.

We analyzed the efficiency of target search by computing search slopes (the rate of increase of RT as a function of set size, milliseconds/item) and RT intercepts; these are presented, alongside error percentages, for each condition (Object Type × Target Presence × Target Orientation) in Table 1. Inspection of the slopes suggests that search efficiency was influenced by target orientation and object type. For instance, search with vertical canonical objects was more efficient when the target was tilted than when it was vertical (see Table 1); in contrast, search with tilted canonical objects showed the opposite pattern—that is, more efficient search with vertical than with tilted targets, at least on target-present trials. In other words, search slopes revealed an interaction between canonical orientation and physical orientation similar to that shown for RTs (see also the RT intercepts in Table 1). The ANOVA on RTs confirmed this pattern of results. There was a reliable Object Type × Target Orientation × Set Size interaction, $F(1, 46) = 4.44$, $MSE = 12{,}301$, $p < .041$. Although vertical canonical objects showed more efficient search slopes for tilted than for vertical targets (40.2 vs. 64.8 ms/item, across target presence), $F(1, 46) = 3.31$, $MSE = 12{,}301$, $p < .03$, tilted canonical objects showed no difference between orientations (106.3 vs. 99.1 ms/item; $F < 1$).

Finally, performance showed general effects of target presence and set size that suggest that search was relatively inefficient. The ANOVA on RTs showed reliable effects of target presence, $F(1, 46) = 10.98$, $MSE = 41{,}243$, $p < .002$, and set size, $F(1, 46) = 129.47$, $MSE = 40{,}198$, $p < .0001$. RTs on target-present trials were shorter than they were on target-absent trials, and RTs became longer with increasing set size (see Table 1). In general, these results suggest that target detection in all conditions was relatively inefficient and dependent on the number of distractors.

Table 1
Reaction Time Intercepts, Search Slopes, and Error Rates for Experiment 1

Target condition	Intercept (ms)	Slope (ms/item)	Errors (%)
Vertical canonical objects			
Absent			
Vertical	607	62.6	2.08
Tilted	548	52.2	1.56
Present			
Vertical	620	67.0	3.65
Tilted	598	28.2	1.56
Tilted canonical objects			
Absent			
Vertical	548	105.8	3.13
Tilted	667	106.7	2.60
Present			
Vertical	455	92.4	3.65
Tilted	574	106.0	5.86

Discussion

The main result of Experiment 1 is that orientation search with familiar objects showed asymmetries in search performance as a function of the canonical orientation of the objects: Search was more efficient (in terms of RTs and search slopes) when the target object was presented in a noncanonical orientation than when it was presented in a canonical orientation. A control analysis demonstrated that this effect was reliable for three of the four individual objects. This finding suggests that in search for a target defined by the orientation of its main axis relative to distractors, performance is affected by whether the object appears in its canonical orientation. This indicates that observers do not gain unfettered access to orientation information coded at the earliest stages of vision (which, presumably, is indifferent to associative knowledge about whether an object is in its familiar orientation). Apparently, when the physical orientation judgment was made, information about the canonical orientation was available to influence decision making. This finding is consistent with other studies showing higher level influences (e.g., of semantic knowledge) on judgments of physical dimensions of objects (see Boucart & Humphreys, 1994, 1997).

Although information about the target's canonical orientation was important, we cannot conclude that this information was computed in parallel, because search was relatively difficult (although search efficiency improved when targets appeared in noncanonical orientations). Steep search functions such as the ones we found are often interpreted as reflecting serial processing of each item in the display (see Wolfe, 1998). Nevertheless, even if each item was inspected serially, the crucial point is that participants could not restrict their judgments to the physical orientations of the stimuli. At least for individual stimuli, information about the canonical orientation of an object is available early enough to affect decisions about a fundamental physical property. This effect of canonical orientation increased as the number of items searched increased.

However, before we can conclude that the canonical orientations of the objects were critical here, we need to show that the physical information about the orientation of the main axis of elongation was available and could be used by participants. This was the aim of Experiments 2–4. In Experiment 2, we applied spatial-frequency filtering to the search displays to disrupt access to object identity. In Experiment 3, we investigated search for recognizable objects (as in Experiment 1), but now they were presented only in noncanonical orientations. Access to associative knowledge about the objects should be disrupted by such manipulations, whereas low-level physical information about object orientation should be preserved. In Experiment 4, we tested search in a visual agnosic patient with impaired object recognition. If these manipulations spare low-level physical information about object orientation but affect access to information about canonical orientation, then we would expect to find the standard search asymmetry: Search should be easier for a tilted target among vertical distractors.

Experiment 2

In Experiment 2, we manipulated access to object identity of the stimuli by applying spatial filtering to the search displays. In particular, we compared search performance to high-pass-filtered and low-pass-filtered stimulus displays. Examples of each type of spatial filtering are shown in Figure 5. In low-pass-filtered displays, low spatial frequencies in the image are preserved while high spatial frequencies are removed. As a result, the objects become unfamiliar shapes while their global orientations (the orientations of their main axes) remain perceptible (see Figure 5B). In contrast, with high-pass-filtered displays, in which low spatial frequencies are removed and high frequencies are retained, the identities of individual objects as well as their global orientations are preserved (see Figure 5A). We hypothesized that if the modulation of orientation search asymmetries in Experiment 1 involved accessing information on canonical object orientation, then this modulation should be preserved when the objects are high-pass filtered but not when they are low-pass filtered; for low-pass-filtered objects, search asymmetries would be based on the physical orientations of the shapes and, probably, on their global (axis-based) orientations (see Boutsen & Marendaz, 2001). In contrast, if search was not modulated by canonical orientation in Experiment 1, then high-pass filtering would be expected to have an effect on orientation search asymmetries similar to that of low-pass filtering.

Method

Participants. Fifty-six undergraduate psychology students from Université Pierre Mendès France participated in the experiment for course credits. All participants reported normal or corrected-to-normal vision and were naive as to the aim of the experiment.

Materials. The stimuli consisted of the search displays for two of the animals used in Experiment 1: the seahorse (vertical canonical object) and the pigeon (tilted canonical object).[1] Each of these search displays was subjected to two types of spatial-frequency filtering: low pass (<1.19 cycles per degree of visual angle) and high pass (>6.00 cycles per degree of visual angle; see Figure 5 for examples stimuli).

Design and procedure. The design was identical to that of Experiment 1 except that there were two objects (the seahorse and the pigeon) presented in two filtering conditions: high-pass and low-pass filtered. Object type and spatial filtering were manipulated between participants, whereas target orientation, target presence, and set size were manipulated within participant. Target search in each Object Type × Spatial Filtering condition was performed by a separate, randomly selected group of 14 participants. For each object in each filtering condition, each condition (Target Orientation × Target Presence × Set Size) was tested 16 times with each participant, yielding 128 trials per session. The procedure was identical to that in Experiment 1. Participants were instructed to search for the target element that differed in orientation from the distractor elements. Following the experiment, each participant was asked to describe and name the element that he or she had to search for. No participant in the low-pass-filtered condition could identify the items as familiar objects, but all participants in the high-pass-filtered condition correctly identified the items.

Results

Overall, 3.18% errors were made to high-pass-filtered displays, and 2.99% errors were made to low-pass-filtered displays; these error rates are similar to those in Experiment 1. We inspected correct responses, detecting and excluding RT outliers according to the same procedure used in Experiment 1. There were 4.33% RT outliers with low-pass-filtered images, and 4.32% RT outliers with high-pass-filtered images. We analyzed the remaining RTs for correct responses separately for low-pass- and high-pass-filtered displays to examine search performance as a function of object type and target orientation. There were no reliable correlations between error rates and RTs for high-pass ($r = -.028$, $p > .763$) or low-pass ($r = .079$, $p > .403$) conditions, indicating that there were no speed-accuracy trade-offs. Mean RTs to vertical and tilted targets for each object type are shown in Figure 6 for high-pass- and low-pass-filtered images. Measures of search efficiency (search slopes, RT intercepts, and error rates) for each spatial filtering condition, object type, target orientation, and target presence are presented in Table 2.

High-pass-filtered images. Mean RTs as a function of object type and target orientation are shown in Figure 6A. We performed an ANOVA on RTs with target orientation, target presence, and set

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[1] The reduction of the stimulus set and the selection of the seahorse and pigeon were motivated by practical considerations only; we would not expect different results if the other animals were included.

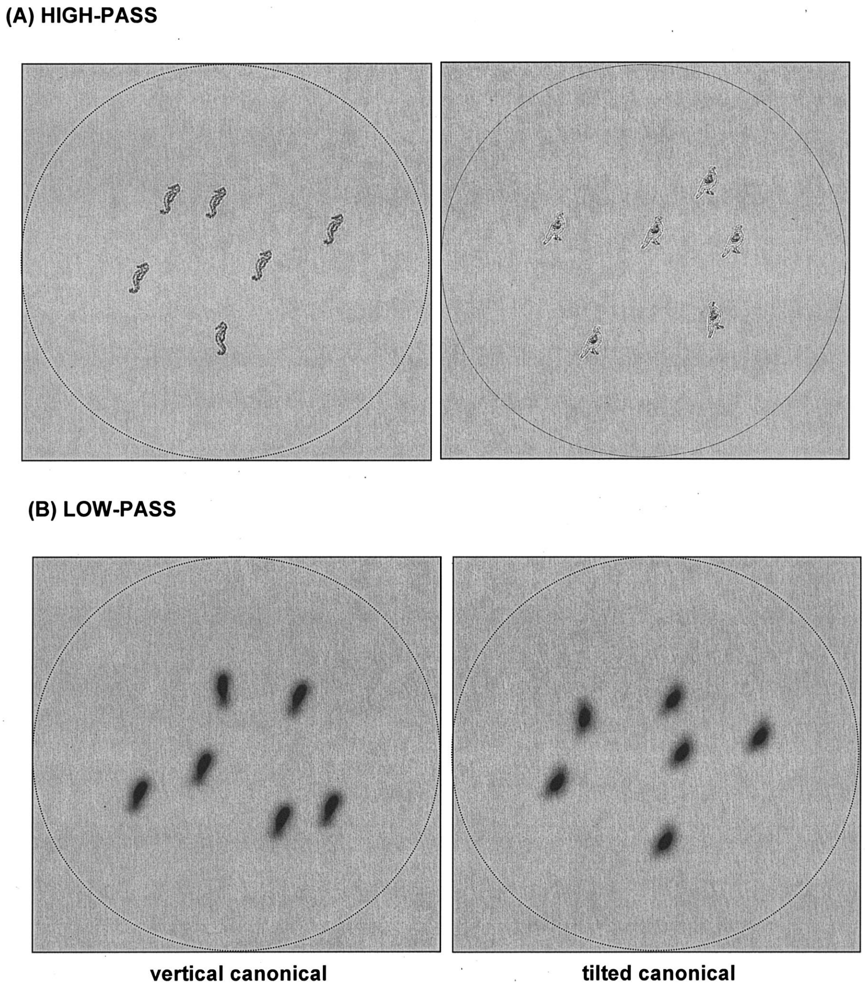
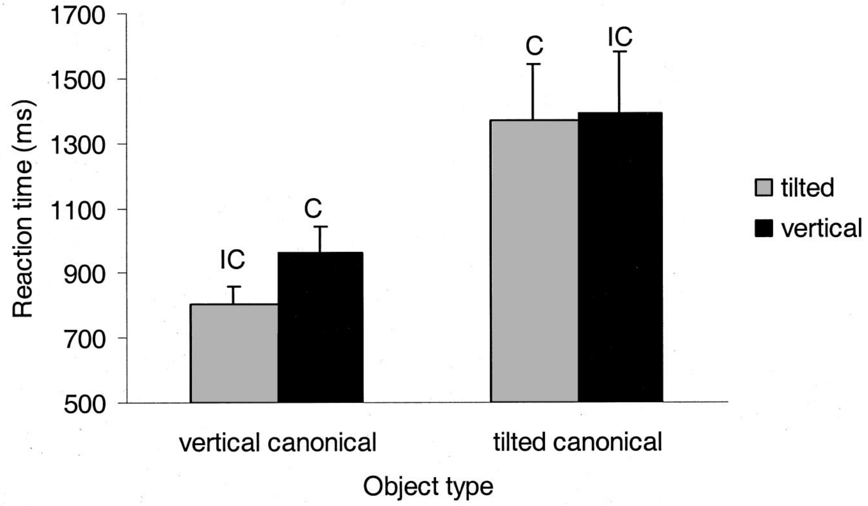


Figure 5. Examples of the high-pass- and low-pass-filtered stimulus displays used in Experiment 2. (For the purpose of illustration, image contrast has been slightly enhanced.)

size as within-participant factors. Responses to the seahorse (vertical canonical object) were faster than responses to the pigeon (tilted canonical object; 884 vs. 1,381 ms), *F*(1, 26) = 11.46, *MSE* = 1,207,306, *p* < .006. Also, object type seemed to interact with target orientation: For the vertical canonical object, responses to tilted targets were 159 ms faster than responses to vertical targets (804 vs. 963 ms), *F*(1, 26) = 8.87, *MSE* = 79,621, *p* < .007; for the tilted canonical object, this RT advantage for tilted over vertical targets reduced to only 23 ms and was not significant (1,369 vs. 1,392 ms; *F* < 1). However, the Object Type × Target Orientation interaction was not reliable, *F*(1, 26) = 3.25, *MSE* = 79,621, *p* < .084. There was a reliable main effect of target orientation, with shorter RTs to tilted than to vertical targets (1,086 vs. 1,178 ms), *F*(1, 26) = 5.82, *MSE* = 79,621, *p* < .024.

Search efficiency measures (search slopes, RT intercepts, and error rates) are shown in the upper sections of Table 2. Search was more efficient for the vertical canonical object than for the tilted canonical object (76.4 vs. 215.1 ms/item; see Table 2), as shown by a Set Size × Object Type interaction, *F*(1, 26) = 22.62, *MSE* = 107,192, *p* < .0002. Set size also interacted with target orientation: Search was more efficient for tilted targets than for vertical targets (127.1 vs. 164.4 ms/item), *F*(1, 26) = 12.66, *MSE* = 13,825, *p* < .0016. There was no reliable Object Type × Target Orientation × Set Size interaction (*F* < 1); however, there was a reliable Object Type × Target Orientation × Target Presence × Set Size interaction, *F*(1, 26) = 13.06, *MSE* = 4,425, *p* < .0014. This effect can be related to an interaction between object type and target orientation on target-present trials (see Table 2): On target-present trials, for the vertical canonical object, search was more efficient for a tilted target than it was for a vertical target (38.8 vs. 77.7 ms/item), *F*(1, 26) = 18.83, *MSE* = 34,723, *p* < .0002; for the tilted canonical object, search was equally (in)efficient for both tilted and vertical present targets (165.7 vs. 161.2 ms/item), *F*(1, 26) = 2.56, *MSE* = 34,723, *p* > .12. On target-absent trials, search was more efficient for tilted than for vertical targets for both object types. Overall, search slopes in all conditions were steep and indicated inefficient search. A comparison of these search slopes with those of Experiment 1 (see Table 1) suggests that search slopes for high-pass-filtered displays were elevated compared with those for unfiltered displays. This was also confirmed by effects of

(A) High-pass



(B) Low-pass

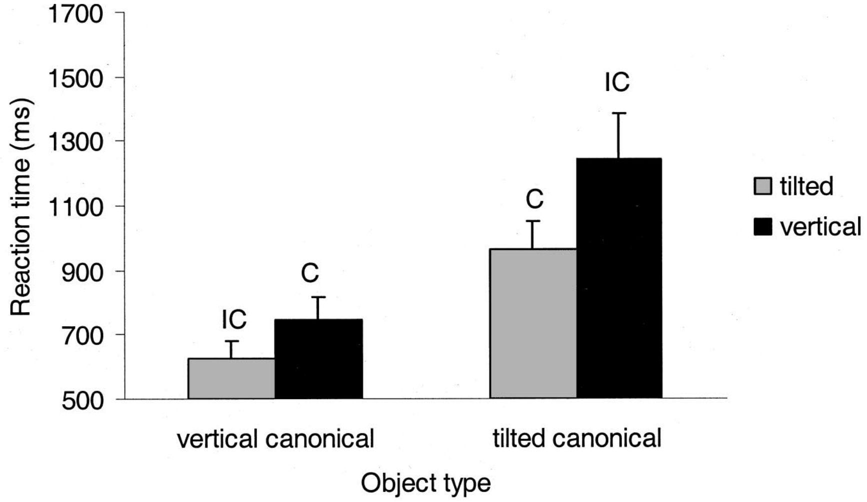


Figure 6. Mean reaction times for detection of vertical and tilted targets per object type for high-pass- and low-pass-filtered search items in Experiment 2. Error bars represent one standard error of the mean. IC = physical orientation of target was incongruent with object's canonical orientation; C = physical orientation of target was congruent with object's canonical orientation.

set size: All two-way and three-way interactions involving set size (with the exception of Object Type × Target Orientation × Set Size) were reliable (*F*s > 8.67, *p*s < .007). Finally, it should be added that when questioned after the experiment, all participants correctly identified the animals from the high-pass-filtered displays (see Figure 5A).

Low-pass-filtered images. Mean RTs as a function of object type and target orientation are shown in Figure 6B; measures of search efficiency are presented in the lower sections of Table 2. It should be noted that because the search elements in the low-pass-filtered displays were effectively unrecognizable (see Figure 5B), the labels referring to the object types (*vertical canonical* and *tilted canonical*) are not strictly applicable to these stimulus conditions. Nevertheless, we use these labels to facilitate comparison of the present results with the results for high-pass-filtered images and with those of Experiment 1. We performed an ANOVA on RTs with target orientation, target presence, and set size as within-participant factors. Responses to the filtered vertical canonical object were faster than responses to the filtered tilted canonical object (686 vs. 1103 ms), $F(1, 26) = 12.85$, $MSE = 757{,}610$, $p <$

Table 2
Reaction Time Intercepts, Search Slopes, and Error Rates for Experiment 2

Target condition	Intercept (ms)	Slope (ms/item)	Errors (%)
High-pass-filtered vertical canonical object			
Absent			
Vertical	492	112.7	2.46
Tilted	553	76.4	4.02
Present			
Vertical	578	77.7	5.58
Tilted	536	38.8	1.56
High-pass-filtered tilted canonical object			
Absent			
Vertical	253	306.0	2.23
Tilted	481	227.5	1.56
Present			
Vertical	428	161.2	2.46
Tilted	488	165.7	5.58
Low-pass-filtered vertical canonical object			
Absent			
Vertical	555	40.6	5.13
Tilted	567	15.8	1.56
Present			
Vertical	634	26.4	4.69
Tilted	575	8.9	2.68
Low-pass-filtered tilted canonical object			
Absent			
Vertical	837	91.5	2.23
Tilted	702	69.3	0.22
Present			
Vertical	741	110.4	4.46
Tilted	684	50.2	2.90

.0015. Responses were also faster to tilted targets than to vertical targets (794 vs. 964 ms), $F(1, 26) = 19.15$, $MSE = 116{,}874$, $p < .0003$. Figure 6B suggests that the RT difference between target orientations for the filtered tilted canonical object (281 ms; vertical = 1,243 ms; tilted = 962 ms) was larger than that for the filtered vertical canonical object (119 ms; vertical = 745 ms; tilted = 626 ms). However, this Target Orientation × Object Type interaction was not reliable, $F(1, 26) = 3.14$, $MSE = 116{,}874$, $p < .088$. Note that although a similar unreliable interaction was observed for high-pass-filtered images, it went in the opposite direction (i.e., there was a smaller orientation effect for the tilted canonical object).

Measures of search efficiency (search slopes, RT intercepts, and error rates) are presented in the lower sections of Table 2. A Set Size × Object Type interaction showed that search with the tilted filtered canonical object was more efficient than search with the filtered vertical canonical object (22.9 vs. 80.4 ms/item), $F(1, 26) = 16.42$, $MSE = 25{,}318$, $p < .0005$. The effect of set size was also smaller for tilted targets than for vertical targets (36.1 vs. 67.2 ms/item), $F(1, 26) = 16.38$, $MSE = 7462$, $p < .0005$. In contrast with the high-pass-filtered displays, there were no other reliable interactions involving set size (Fs > 1.69, ps $> .205$). In general, search slopes were more shallow than they were for high-pass-filtered displays, especially for the vertical canonical object, with which, for example, search for a tilted target showed a rather shallow slope (<10 ms/item on target-present trials; see Table 2). Thus, compared with search with high-pass-filtered displays, search with low-pass-filtered displays appears to have been more efficient.

High-pass versus low-pass filtering. To examine the differences in RT performance between low-pass- and high-pass-filtered displays more directly, we performed an additional ANOVA on the RTs with filtering condition as a between-participants factor. This showed a reliable main effect of filtering condition: RTs to low-pass-filtered displays were shorter than RTs to high-pass-filtered displays (894 vs. 1,132 ms), $F(1, 52) = 6.45$, $MSE = 982{,}458$, $p < .0142$. In general, RTs did not differ reliably as a function of object type and filtering condition ($F < 1$). The Target Orientation × Filtering Condition interaction was not reliable, $F(1, 52) = 3.38$, $MSE = 98{,}248$, $p < .0716$: Although RTs were shorter to tilted targets than to vertical targets with both high-pass-filtered displays (200 ms), $F(1, 52) = 4.71$, $MSE = 98{,}247$, $p < .04$, and low-pass-filtered displays (91 ms), $F(1, 52) = 22.78$, $MSE = 98{,}247$, $p < .0001$, this search asymmetry was more pronounced with low-pass filters (see Figure 6).

It is important to note that there was a Filtering Condition × Object Type × Target Orientation interaction, $F(1, 52) = 6.32$, $MSE = 98{,}247$, $p < .0152$. With tilted canonical objects, the RT benefit in detection of a tilted target (as shown in the ANOVA for each filter condition) was more than 12 times as large when the objects were low-pass-filtered than when they were high-pass-filtered (281 vs. 23 ms; see Figure 6), $F(1, 52) = 9.48$, $MSE = 98{,}247$, $p < .004$. However, vertical canonical objects showed similar benefits in the detection of tilted targets when they were low-pass or high-pass filtered (119 vs. 123 ms; $F < 1$).

Search efficiency (in terms of search slopes; see Table 2) was also influenced by the filtering conditions. Search slopes were steeper with high-pass- than with low-pass-filtered displays (145.8 vs. 51.7 ms/item), corresponding to a reliable Filtering Condition × Set Size interaction, $F(1, 52) = 33.7$, $MSE = 66{,}255$, $p < .0001$. This interaction also depended on object type, $F(1, 52) = 6.27$, $MSE = 66{,}255$, $p < .0154$: Although both filtering conditions showed more efficient search for vertical canonical objects, this effect was more pronounced for high-pass-filtered displays. In sum, search efficiency was reduced in high-pass-filtered displays compared with that in low-pass filtered displays. This was further underlined by the observation that all interactions involving filtering condition and set size (with the exception of Filtering Condition × Target Orientation × Set Size) were reliable (Fs > 5.66, ps $< .021$).

Discussion

The results of Experiment 2 show that high-pass and low-pass spatial-frequency filtering had differential effects on the search asymmetries for object orientation. We hypothesized that if search displays with high-pass-filtered objects still enabled access to canonical object orientation, then canonical orientation could be expected to modulate the orientation search asymmetries in the same way that it did for the stimuli in Experiment 1: Search for a target object in a noncanonical orientation would be faster and more efficient than search for a target object in a canonical orientation; in other words, opposite search asymmetries would be expected for vertical canonical objects and tilted canonical objects. The results partially confirm this hypothesis: Although we found no evidence for opposite search asymmetries, the search asymmetry in favor of a tilted target was more pronounced (in terms of RT and slope differences) for the vertical canonical object than for the tilted canonical object (see Figure 6A and Table 2). Had there been no effect of object type, one would expect to see equal-sized orientation asymmetries for both objects; this, however, was not observed. The results with the high-pass-filtered displays therefore suggest that canonical object orientation had an effect on search performance in the present experiment similar to the one that it had in Experiment 1.

Furthermore, low-pass-filtered displays showed a different pattern of search performance than high-pass-filtered displays: Here, large search asymmetries occurred in favor of tilted targets, regardless of object type (see Figure 6B). Because information about object identity was unavailable in the low-pass-filtered displays, the search asymmetry occurred as a function of the object's physical orientation. This was also confirmed by the search efficiency measures: Search was generally faster and more efficient with low-pass-filtered images. Nevertheless, there was an effect of object type even with low-pass-filtered displays in that search was faster and more efficient with the vertical canonical object than with the tilted canonical object. We suggest that this advantage was due to the larger salience of the global orientation of the vertical canonical object (the seahorse) than of the tilted canonical object (the pigeon) when they were low-pass filtered: Because the seahorse had a larger height-to-width ratio than the pigeon (2.4 and 1.7, respectively), its vertical and tilted orientations were easier to discriminate (see Figure 5B). A direct comparison of high-pass- and low-pass-filtered displays also demonstrated that search performance was qualitatively different in both filtering conditions. Search was faster and more efficient with low-pass-filtered displays, and search with high-pass-filtered displays showed a larger advantage in performance for vertical canonical than for tilted canonical targets (see Figure 6).

Could spatial filtering, rather than the identifiability of the items, have influenced perceived stimulus orientation and, therefore, explain the observed pattern of results? We suggest not. Although both filtering conditions showed an interaction between object type and target orientation, this interaction produced different benefits for tilted canonical items. For example, tilted canonical objects showed a substantial benefit for tilted targets only when they were low-pass filtered, not when they are high-pass filtered; however, vertical canonical objects showed similar benefits for tilted targets regardless of the filtering condition. It is difficult to attribute these effects to changes in perceived stimulus orientation per se. Rather, it seems that the identifiability of the items can account for the observed pattern of interactions in each filtering condition. The fact that the items were correctly identified by all participants in the high-pass- but not in the low-pass-filtering conditions supports this interpretation.

The results of Experiment 2 demonstrate that disrupting access to object identity through spatial-frequency filtering affects search asymmetry as a function of canonical orientation. When access to object identity was prevented (through low-pass filtering), the effects of canonical orientation were completely eliminated, and search performance was determined by the physical orientation of the target, resulting in search asymmetries in favor of tilted targets. With high-pass-filtered images, object identity was relatively preserved, and the search asymmetry as a function of target orientation was influenced by object type, as in Experiment 1, with only a weak search asymmetry for the tilted canonical object compared with that for the vertical canonical object. However, the results with high-pass-filtered images were not identical to those of Experiment 1, because the search asymmetries for target orientation were not reversed in the two object types. It could be that access to object identity was moderately affected even by high-pass filtering, thereby preserving the relative influence of physical orientation. This possibility is consistent with other studies showing that high-pass spatial filtering affects object recognition (e.g., Morrison & Schyns, 2001). Nonetheless, search with high-pass-filtered displays was more similar to performance in Experiment 1 than was search with low-pass-filtered displays; this further suggests that object identity influenced performance.

Can the influence of object identity and canonical orientation on object orientation discrimination be modulated under conditions in which access to object identity is preserved and visual information from the objects is not degraded—that is, without spatial-frequency filtering? In Experiment 3, we tested this possibility by presenting the objects unfiltered and in noncanonical orientations only.

Experiment 3

In Experiment 3, we tested whether search for object orientation would still be influenced by object identity when objects were presented in unfamiliar (noncanonical) orientations. To do this, we inverted the search displays used in Experiment 1. It is well-established that rotating objects away from their familiar orientation in the picture plane slows down subsequent recognition (e.g., Jolicœur, 1985). These costs of rotation suggest that object recognition is mediated through representations that include information about canonical object orientation. We hypothesized that if the effect of canonical orientation observed in Experiment 1 implies access to stored knowledge of the object, this effect may be diminished when the objects are presented in unfamiliar orientations. Instead of observing search asymmetries in favor of canonical orientations, we would expect search asymmetries to be a function of the physical orientation of the objects (i.e., to favor tilted targets).

Method

Participants. Twenty-four students from Université Pierre Mendès France participated in the experiment for course credits. All participants reported normal or corrected-to-normal vision and were naive as to the aim of the experiment.

Materials, design, and procedure. The stimulus displays consisted of the search displays of two animals (the seahorse and the pigeon) used in Experiment 1, presented upside down so that the search elements were rotated 180° from the orientations in which they appeared in Experiment 1 (see Figure 2). The design was identical to that of Experiment 1: Object type (vertical canonical or tilted canonical) was manipulated between participants (12 participants per object type), and target orientation, target presence, and set size were manipulated within participant. Each participant completed 128 trials. The procedure was identical to that of Experiment 1. Participants were instructed to detect the target object that differed in orientation from the distractors.

Results

Participants made 1.85% errors in total. The proportions of error within in each condition were positively correlated with RTs ($r = .285$, $p < .004$), indicating that there was no speed–accuracy trade-off. We inspected correct responses, detecting and excluding 5.34% of RT outliers according to the same procedure used in the previous experiments (i.e., per participant per condition). We analyzed the remaining RTs in an ANOVA as a function of object type, target orientation, target presence, and set size. Figure 7 shows the mean RTs for each object as a function of target orientation, and search efficiency in the different conditions is shown in Table 3.

Inspection of Figure 7 indicates that there was a main effect of orientation: Responses were faster to tilted targets than to vertical targets (1,025 vs. 1,257 ms), $F(1, 22) = 26.22$, $MSE = 98{,}970$, $p < .0001$. It is important to note that this facilitation for tilted targets was similar for both vertical and tilted canonical objects (257 and 208 ms, respectively): There was no reliable Target Orientation × Object Type interaction ($F < 1$). There was a trend toward faster responses for the vertical canonical object (the seahorse) than for the tilted canonical object (the pigeon; 829 vs. 1,024 ms), $F(1, 22) = 3.12$, $MSE = 1{,}679{,}148$, $p = .091$, that was not reliable.

RT intercepts and search slopes showed similar effects (see Table 3). Search for a tilted target was more efficient than search for a vertical target (95.4 vs. 126.7 ms/item), $F(1, 22) = 7.99$, $MSE = 13{,}200$, $p < .001$. There was a trend for more efficient search for the vertical canonical object than for the tilted canonical object, although it was not reliable (78 vs. 144.1 ms/item), $F(1, 22) = 3.59$, $MSE = 131{,}585$, $p = .071$. There were no other reliable set size effects involving object type or target orientation (Fs < 1.91, ps $> .18$). In general, search was rather inefficient, with steep search slopes (see Table 3); this was confirmed by reliable effects of set size and of a Set Size × Target Presence interaction (Fs > 10.33, ps $< .005$).

We carried out a direct comparison of the present results with the results of Experiment 1 for the same stimuli (i.e., for the search displays containing the seahorse or the pigeon only) through an ANOVA with experiment and object type as between-participants factors. There was a main effect of experiment: RTs were shorter with displays containing canonical orientations (Experiment 1) than they were with displays containing noncanonical orientations (Experiment 3; 881 vs. 1,141 ms), $F(1, 44) = 6.32$, $MSE = 1{,}026{,}978$, $p < .0157$. There was also a reliable Experiment × Target Orientation interaction, with a larger search asymmetry in favor of tilted targets in Experiment 3 than in Experiment 1 (RT benefits = 233 and 35 ms, respectively), $F(1, 44) = 12.28$, $MSE = 76{,}379$, $p < .0011$. Finally, a reliable Experiment × Object Type × Target Orientation interaction, $F(1, 44) = 6.96$, $MSE = 76{,}379$, $p < .0115$, indicated that the search asymmetries in Experiments 1 and 3 differed, as can be seen from a comparison of Figures 3 and 7. These results directly illustrate the effect of canonical orientation on search asymmetries.

Discussion

Inverting the objects had a profound effect on search performance: Search was faster and more efficient for a tilted target than it was for a vertical target. It is important to note that this search asymmetry for the physical orientation of the target was not influenced by object type: Both vertical and tilted canonical objects showed the same asymmetry in search performance (see Figure 7). This result stands in contrast to Experiment 1, in which search asymmetry varied as a function of canonical, rather than physical, orientation. This finding is consistent with our hypothesis that inversion affects access to object identity and that this should reduce any influence of canonical orientation on search performance. A comparison between the results of Experiment 3 and those of Experiment 1 also suggests that inverting the objects produced qualitatively distinct effects on object orientation search.

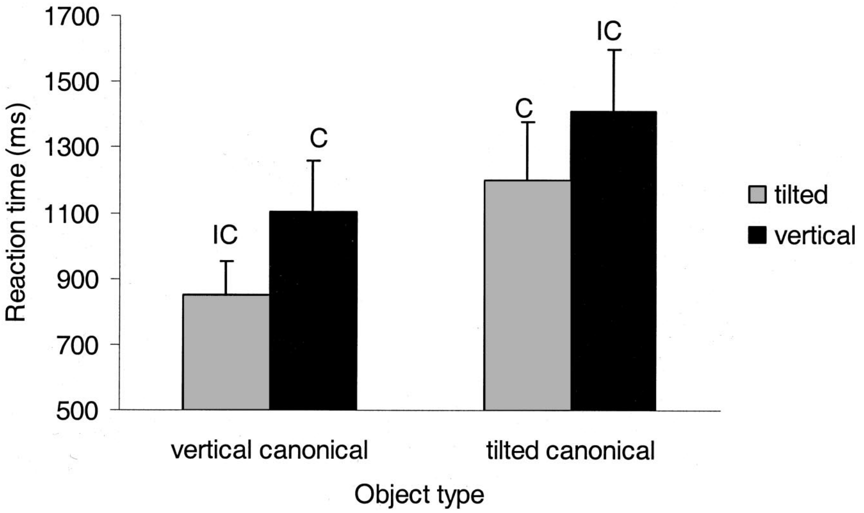


Figure 7. Mean reaction times for detection of vertical and tilted targets per object type in Experiment 3. Error bars represent one standard error of the mean. IC = physical orientation of target was incongruent with object's canonical orientation; C = physical orientation of target was congruent with object's canonical orientation.

Table 3
Reaction Time Intercepts, Search Slopes, and Error Rates for Experiment 3

Target condition	Intercept (ms)	Slope (ms/item)	Errors (%)
Vertical canonical object			
Absent			
Vertical	588	119.5	2.60
Tilted	556	68.4	0.78
Present			
Vertical	759	71.9	3.65
Tilted	596	52.1	0.26
Tilted canonical object			
Absent			
Vertical	682	194.6	2.86
Tilted	537	181.2	2.08
Present			
Vertical	720	120.6	2.34
Tilted	692	80.0	0.26

These results (in addition to those of Experiment 2) suggest that effects of the canonical orientation of stimuli on search are contingent on efficient access to stored knowledge: When access to object identity is relatively impaired (through rotation), orientation discrimination between the target and distractors is determined by the physical orientation of the stimuli, not by knowledge of their canonical orientation. The results from the between-experiment comparison also show that orientation search with stimuli as complex as familiar objects was rather inefficient in both cases, although a general facilitation in RTs occurred for displays containing objects in canonical orientation (in Experiment 1). Although the results of this between-experiment comparison should be interpreted with some caution, because the comparison did not involve all of the stimulus types used in Experiment 1, they seem to indicate that canonical orientation can have a facilitatory influence on search performance, although not at an early stage of visual processing (see the steep search slopes).

In the final experiment, we investigated the role of canonical orientation in object orientation discrimination in a brain-damaged patient with impaired object recognition (visual agnosia). We reasoned that if the effect of canonical orientation on search for object orientation implies access to object identity, then this effect may be reduced or absent when access (through visual information) to stored object representations is impaired, as in visual agnosia. As a result, we might expect search for object orientation to be influenced by only the physical orientation of the target. To the extent that orientation discrimination in the patient is normal (save for a possible influence of object identity and canonical orientation), we might expect an asymmetry in search performance favoring physically tilted targets to vertical targets.

Experiment 4

In Experiment 4, we examined visual search for object orientation, using the same task and stimuli as in Experiment 1, in a patient, H.J.A., who suffered from visual agnosia following brain damage. H.J.A. had impaired object and face recognition (Humphreys & Riddoch, 1987; Riddoch & Humphreys, 1987; Riddoch, Humphreys, Gannon, Blott, & Jones, 1999), although early stages of visual processing, including orientation discrimination, were relatively intact. For example, H.J.A. was able to discriminate the orientation of simple visual stimuli such as line segments (Humphreys & Riddoch, 1987). However, although H.J.A. may have shown normal discrimination of physical orientation, his awareness of the canonical upright orientation of real-world objects was likely impaired because of his recognition deficit.[2] We therefore hypothesized that H.J.A.'s object recognition deficit might eliminate the effect of canonical orientation on search for object orientation while preserving any influence of physical orientation.

Case History

H.J.A. (born June 30, 1920), a right-handed, retired businessman, was 78 years old at the time of the testing (1998). In 1981, H.J.A. suffered a cerebral stroke, resulting in bilateral damage to occipitotemporal cortical regions (see Humphreys & Riddoch, 1987, chap. 2, for further biographical information, and Riddoch et al., 1999, for an MRI scan). Following the stroke, H.J.A. showed a number of deficits, including visual object agnosia (impaired visual recognition of objects), prosopagnosia (impaired recognition of faces, including his own), alexia (letter-by-letter reading), and achromatopsia (loss of color vision). He also showed problems in spatial orienting and way finding (Humphreys & Riddoch, 1987). H.J.A.'s visual acuity was intact, although he had an upper altitudinal defect of both visual fields.

H.J.A.'s most prominent visual impairments involved high-level vision, in particular object and face recognition. H.J.A. often failed to recognize objects from vision despite being able to copy drawings of objects and to match pictures of objects depicted from different viewpoints (Humphreys & Riddoch, 1984, 1987; Humphreys et al., 1992; Riddoch & Humphreys, 1986, 1987; Riddoch et al., 1999). His long-term knowledge of objects was preserved, although some decline had been reported over a period spanning 15 years (Riddoch et al., 1999). H.J.A.'s prosopagnosia involved impaired face recognition (Humphreys, Donnelly, & Riddoch, 1993; Humphreys & Riddoch, 1987) and abnormal face processing in tasks that did not require explicit recognition. For example, in matching faces for visual identity, H.J.A.'s performance was unaffected by face inversion (cf. the face inversion effect in unimpaired observers; Farah, Tanaka, & Drain, 1995; Rhodes, Brake, & Atkinson, 1993); in addition, contextual information had an adverse effect on his matching performance (Boutsen & Humphreys, 2002). In contrast to his impairments on high-level visual tasks

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[2] It should be noted that knowledge of object orientation and (implicit or explicit) access to object identity can be selectively impaired. For example, patients with object orientation agnosia may be able to recognize objects while being unable to judge their orientations, whether physical or canonical (e.g., Karnath, Ferber, & Bülthoff, 2000; Turnbull, Beschin, & Della Sala, 1997; Turnbull, Laws, & McCarthy, 1995). These cases provide important information about the nature of representations of objects and their orientations. However, our patient did not show such a dissociation. H.J.A. showed a preserved ability to discriminate between the physical orientations of objects but an apparent inability to determine the canonical, upright orientations of objects. The latter impairment regarding canonical, object orientation was consistent with his object agnosia.

such as object recognition, H.J.A.'s performance on lower level visual tasks was relatively normal. In particular, H.J.A.'s responses to salient orientation-defined targets in visual search were normal (Humphreys et al., 1992).

In addition to H.J.A., we tested 2 male control participants (henceforth, *controls*), aged 79 and 86 years (henceforth, *Control 1* and *Control 2*, respectively). The controls had levels of education similar to H.J.A.'s; they reported corrected-to-normal vision and recognized the objects used in the experiment without difficulty. It should also be noted that the controls were less experienced than H.J.A. in taking part in visual perceptual experiments.

Method

H.J.A. and the controls performed the same task as Experiment 1, with the exception that search displays composed of only two animals—the seahorse or the pigeon—were presented. Search tasks were blocked by animal and target orientation and contained 128 trials per animal (256 trials in total). Search tasks with each animal were administered in separate sessions. Each control participant performed two sessions (128 trials per session), one for each animal condition; thus, data from 256 trials were collected from each control. For H.J.A., search in each animal condition was administered twice on consecutive days, resulting in a total of 512 trials. The order of the two sessions with H.J.A. was reversed from the first day to the second. For both H.J.A. and the controls, the order of the orientation task (search for a vertical or a tilted target) was counterbalanced between sessions.

Results

H.J.A. made 6.64% (34/512) incorrect responses. His error rate was higher than that of Control 1 (1.95% [5/256] errors), $\chi^2(1, N = 768) = 7.78$, $p < .005$, but similar to that of Control 2 (5.46% [14/256] errors; $\chi^2 < 1$). Control 2 also made more errors than Control 1, $\chi^2(1, N = 512) = 4.42$, $p < .035$. Because the error rates were low, we focused our analyses primarily on RT performance. Mean RTs as a function of object type and target orientation are presented in Figure 8 for H.J.A., Control 1, and Control 2. Search slopes, RT intercepts, and error rates as a function of object type, target presence, and target orientation are presented in Table 4 for H.J.A. and in Table 5 for the controls (data for Control 1 and Control 2 are collapsed).

We analyzed RTs as a function of the different stimulus conditions for H.J.A. and for the controls. We entered RTs for correct responses not exceeding 2 standard deviations of the mean RT for each participant (excluding 2.27%, 3.98%, and 4.95% of correct RTs for H.J.A., Control 1, and Control 2, respectively) into an ANOVA with participant, object type, target orientation, target presence, and set size as within-participant factors. This method allowed a direct comparison of performance between H.J.A. and the controls. The ANOVA was run on individual RTs per participant per stimulus condition and therefore constitutes an items analysis.[3] The results of the ANOVA were inspected for interactions between participants and the stimulus variables.

Inspection of RTs as a function of object type and target orientation (see Figure 8) shows a main difference between H.J.A. and the controls. H.J.A. responded faster to tilted targets than to vertical targets for both the vertical and the tilted canonical object (RT differences = 251 and 254 ms, respectively). In contrast, the controls showed a facilitation for tilted targets for the vertical canonical object (Control 1: 691 ms; Control 2: 250 ms) but not for the tilted canonical object. Instead, with the tilted canonical object, each control showed the opposite effect—namely, faster responses to a vertical target than to a tilted target, although this difference was much larger for Control 1 than it was for Control 2 (554 vs. 51 ms). This difference in performance was confirmed by the ANOVA, which showed a reliable Participant × Object Type × Target Orientation interaction, $F(2, 884) = 36.66$, $MSE = 208{,}479$, $p < .0001$. Although each control showed an interaction between object type and target orientation, there was no such interaction for H.J.A., only a main effect of target orientation.

H.J.A.'s facilitation in performance for tilted targets, regardless of object type, was also observed in terms of search slopes and error rates (see Table 4). On target-present trials, H.J.A. made more errors with tilted targets than with vertical targets for both object types (see Table 4). His search was also more efficient with tilted targets than with vertical targets on target-present trials, with search slopes for tilted targets below 80 ms/item (compared with at least 119 ms/item for vertical targets).

The error rates and search slopes of the control participants (see Table 5) also showed a pattern similar to that of their RTs. On target-present trials, the controls made fewer errors with tilted targets than with vertical targets for the vertical canonical object, but with the tilted canonical object, the opposite result was observed. Search slopes followed a similar pattern, although this was less pronounced. Search with the vertical canonical object was more efficient with tilted targets than with vertical targets, but this benefit was restricted to target-absent trials (250.8 vs. 346.1 ms/item; target-present trials: 135.4 vs. 131.6 ms/item; see Table 5). However, search with the tilted canonical object was more efficient with vertical targets than with tilted targets, but here the benefit was restricted to target-present trials (169.6 vs. 216.8 ms/item; target-absent trials, 351.6 vs. 327.0 ms/item). Despite these less pronounced effects for target-present and target-absent trials, the controls showed a pattern of performance similar to that of the participants in Experiment 1, and it is important to note that their performance differed from that of H.J.A., in particular with the tilted canonical object (see target-present trials, Table 5). The performance of the controls, however, was generally as inefficient as H.J.A.'s, with RT slopes on target-present trials exceeding 130 ms/item.

Apart from the interactions between object type and target orientation, the ANOVA on RTs showed other differences be-

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[3] In our analysis, we followed guidelines for comparing patient and control data in a single ANOVA when group sizes and variability differ (Mycroft, Mitchell, & Kay, 2002). We compared data from 1 patient with data from 2 controls. Moreover, the variability of RTs for correct responses of H.J.A. was smaller than that of the control participants: *SD*s = 480 ms (H.J.A.), 739 ms (Control 1), and 707 ms (Control 2). Mycroft et al. suggested the use of revised *F* criteria, depending on the size of the control group and on the ratio of patient variance to control variance; this reduces the proportion of Type I errors for a conventional significance level (e.g., .05). However, with a control group smaller than 5, no revised *F* criteria were available. Therefore, we used an items analysis with participant (the patient and the controls) as an additional factor. We interpret statistically reliable interactions between participant and the stimulus variables as evidence for differences in performance between the patient and the controls.

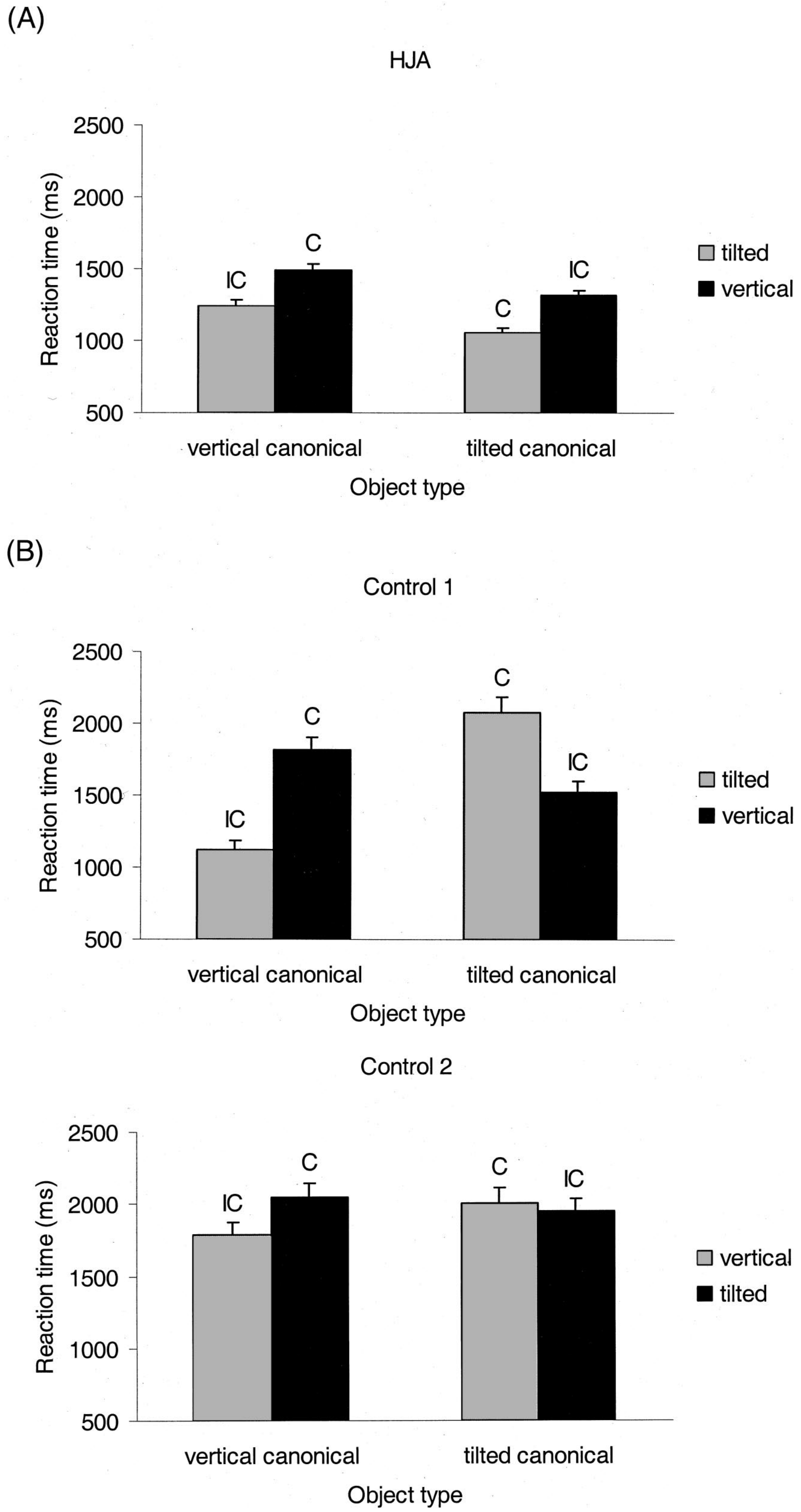

Figure 8. Mean reaction times for detection of vertical and tilted targets per object type for H.J.A. and for the control participants in Experiment 4. Error bars represent one standard error of the mean. IC = physical orientation of target was incongruent with object's canonical orientation; C = physical orientation of target was congruent with object's canonical orientation.

tween H.J.A. and the control participants. For instance, H.J.A. and the controls differed in their responses to vertical and tilted canonical objects, $F(2, 884) = 24.58$, $MSE = 208{,}479$, $p < .0001$, with H.J.A. showing faster responses to the tilted canonical object than to the vertical canonical object (1,183 vs. 1,361 ms) and Control 1 showing the opposite effect (1,798 vs. 1,467 ms); Control 2's performance was equally fast with both object types (1,975 and 1,916 ms, respectively). There was also a Participant × Target Orientation interaction, $F(2, 884) = 3.96$, $MSE = 208{,}479$, $p < .0196$, indicating that H.J.A. showed a main effect of target orientation, whereas the control participants did not (see Figure 8). In general, H.J.A. responded faster than the controls (H.J.A.: 1,272 ms; Control 1: 1,633 ms; Control 2: 1,946 ms), $F(1, 884) = 170.96$, $MSE = 208{,}479$, $p < .0001$. Search efficiency (in terms of overall search slopes) also differed among the participants, $F(2, 884) = 23.25$, $MSE = 208{,}479$, $p < .0001$, with H.J.A. and Control 1 showing similar search efficiencies (138 and 182 ms/item, respectively) and being more efficient than Control 2 (307 ms/item).[4]

It should be noted that when questioned after the experiment, H.J.A. was unable to recognize the animals. For example, he misidentified the snout of the seahorse as a bird's beak. Although he did identify the pigeon as a "bird," he was unable to give its basic-level name: He added that he had never seen such a bird and that it seemed to him to be "a rare bird that lives in a faraway country." In contrast to H.J.A., the control participants correctly identified the animals.

Discussion

The main result of Experiment 4 is that although H.J.A. was able to discriminate the physical orientations of the target objects, his performance was not influenced by their canonical orientations. In contrast, the orientation discrimination of the control participants was influenced by the objects' canonical orientations in the same manner as observed in Experiment 1 (with more objects and participants): Search was faster and more efficient when the target was presented in a noncanonical orientation (i.e., vertical for the tilted canonical object and tilted for the vertical canonical object). Because H.J.A. was unable to recognize the objects (due to his well-documented visual agnosia) but was able to discriminate the physical orientations of the objects, the absence of an influence of canonical object orientation suggests that his performance in this task did not imply automatic access to canonical orientation.

Because of H.J.A.'s visual agnosia, it seems likely that his impaired access to object identity was accompanied by an inability to retrieve information about canonical object orientation. In contrast to H.J.A., the control participants (who correctly recognized the objects) showed search asymmetries in orientation discrimination that were a function of the canonical orientation of the objects, as did the participants in Experiment 1. This again supports the notion that orientation search with familiar objects is modulated by canonical orientation. It should be noted that the discrepancy between H.J.A. and the controls cannot be explained by any general differences in performance, because H.J.A.'s performance (in terms of speed and accuracy) was comparable to (and sometimes even better than) that of the controls.

As we noted earlier, H.J.A.'s visual agnosia disrupted his access to stored knowledge about visual objects (Riddoch & Humphreys, 1987; Riddoch et al., 1999). We propose that H.J.A.'s impaired access to stored object knowledge prevented an influence of canonical orientation on his discrimination of physical orientation. Instead, H.J.A. relied exclusively on the physical orientation of the objects, producing a standard asymmetry in search performance favoring physically tilted targets. In other words, there was no evidence of a higher order influence on H.J.A.'s discrimination of object orientation. The observation that visual agnosia can modulate access to knowledge of canonical object orientation also suggests that this information is implicated in the representations that are accessed during normal object recognition.

Table 4
Reaction Time Intercepts, Search Slopes, and Error Rates for H.J.A. in Experiment 4

Target condition	Intercept (ms)	Slope (ms/item)	Errors (%)
Vertical canonical object			
Absent			
Vertical	361	243.3	0.00
Tilted	679	175.8	7.81
Present			
Vertical	980	119.5	18.75
Tilted	644	79.5	10.94
Tilted canonical object			
Absent			
Vertical	756	131.4	3.13
Tilted	649	127.1	1.56
Present			
Vertical	557	159.2	10.94
Tilted	590	67.2	0.00

Table 5
Reaction Time Intercepts, Search Slopes, and Error Rates for the Controls in Experiment 4

Target condition	Intercept (ms)	Slope (ms/item)	Errors (%)
Vertical canonical object			
Absent			
Vertical	405	346.1	0.00
Tilted	409	250.8	1.56
Present			
Vertical	1281	135.4	10.94
Tilted	764	131.6	3.13
Tilted canonical object			
Absent			
Vertical	355	351.6	1.56
Tilted	735	327.0	0.00
Present			
Vertical	754	169.6	3.13
Tilted	872	216.8	9.38

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[4] H.J.A.'s better RT performance than the controls was likely due to his greater familiarity and experience with experimental psychology experiments.

General Discussion

In this study, we investigated the role of canonical orientation in the discrimination of object orientation in visual search. The results of four experiments provide evidence that knowledge of the canonical orientation of objects can affect visual search for orientation, provided that object identity can be accessed. In Experiment 1, participants were better at detecting a target in a noncanonical orientation among distractors in a canonical orientation than vice versa. Degrading the stimulus displays through high-pass and low-pass filtering changed these asymmetries in search performance (Experiment 2): With high-pass-filtered objects, the asymmetry in search as a function of canonical orientation was reduced, whereas with low-pass-filtered objects, search depended on the global physical orientation of the stimuli. When the objects appeared only in unfamiliar, noncanonical orientations (Experiment 3), search asymmetries occurred only as a function of global physical orientation. In Experiments 2 and 3, access to object identity was likely impaired by stimulus degradation (filtering) and rotation, respectively. This in turn affected the effects of canonical orientation.

In a final experiment, we demonstrated that the effect of canonical orientation on object orientation coding in search was dependent on access to object identity. Our visual agnosic patient, H.J.A., who was unable to identify the objects used in the experiment, showed no effect of canonical object orientation despite the fact that he was able to discriminate the physical orientation of the objects (he performed generally at the same level as did the controls). Indeed, in contrast to the controls, whose performance showed an asymmetry in search as a function of canonical orientation, H.J.A. showed an asymmetry as a function of the physical orientation of the search elements. This suggests that despite performing comparably to the controls, H.J.A.'s impaired access to the identity of the objects prevented him from accessing information about an object's typical or canonical orientation. The finding that an impairment in access to object identity can abolish the effect of canonical orientation further supports the notion that the differential asymmetries in search observed in Experiment 1 can be attributed to access to an object's canonical orientation.

There are several aspects of these results that merit discussion: They concern the role of stimulus familiarity, the role of principal axes of objects, the level of processing at which canonical orientation affects performance, and, finally, the generality of the findings. These are briefly discussed in the remainder of the article.

Canonical Orientation and Familiarity

The results corroborate other studies demonstrating higher order influences on visual feature discrimination with familiar objects (e.g., Boucart & Humphreys, 1994, 1997). In particular, the results can be interpreted as showing an effect of stimulus familiarity on search performance, though this study is one of the first systematic explorations of an effect of object orientation familiarity on orientation processing (Wolfe, 2001, provided a demonstration using upright and inverted animals). A number of studies using visual search have described familiarity-based search asymmetries, in which search for an unfamiliar target among familiar distractors is more efficient than the reverse (e.g., Shen & Reingold, 2001; Treisman & Souther, 1985; Wang et al., 1994; Wolfe, 2001). In the context of our experiments, search with familiar (recognizable) objects in different orientations (see Experiment 1) can be conceived of as a search for a target in a familiar orientation among distractors in an unfamiliar orientation, and vice versa. Because an object's canonical orientation is most likely an orientation with which an observer will be most familiar, the canonicalness of an orientation and its familiarity are closely related (see S. Palmer et al., 1981).

The search asymmetries as a function of canonical orientation correspond to the familiarity-based search asymmetries that have been encountered with other familiar stimulus classes, such as faces (Tong & Nakayama, 1999) or alphanumeric characters in different languages (see Shen & Reingold, 2001; Wang et al., 1994). When the targets and distractors appeared in familiar and unfamiliar orientations (Experiment 1), familiarity-based asymmetries in search occurred; however, when the familiarity of the stimuli (Experiment 2) or of their orientations (Experiment 3) was reduced, these effects disappeared or were diminished. Finally, in Experiment 4, our visual agnosic patient, who showed no familiarity with the objects (in that he was unable to recognize them), showed no familiarity-based search asymmetry, whereas the controls did.

What causes the facilitation in search in the canonical orientation condition? Some studies on familiarity effects in visual search (Shen & Reingold, 2001) have suggested that the familiarity of distractors, rather than the familiarity of the target, improves search efficiency. This suggests that search proceeds through a distractor-rejection process whereby familiar distractors are easier to reject than unfamiliar ones. In our experiments, this process may have involved access to object identity (when the search elements were recognizable). Whether the orientation of the target or of the distractors is more important here is an issue for future research—for example, manipulating the orientations of the distractors while keeping that of the target constant, and vice versa.

Principal Axes and the Coding of Canonical Orientation

In our study, we contrasted search for objects that possessed a vertical principal axis when in a canonical orientation with search for objects that possessed a tilted principal axis. We used this manipulation because we expected to observe search asymmetries as a function of the congruency between the orientations of the principal axes of the objects and their canonical orientations. In Experiment 1, search was more efficient for targets whose axis orientation was incongruent with their canonical orientation: This meant that for vertical canonical objects (whose main axis was vertical when in their canonical orientation), a search asymmetry occurred in favor of a physically tilted axis, whereas for tilted canonical objects (whose main axis was tilted when in their canonical orientation), the search asymmetry occurred in favor of a physically vertical axis.

Although these results emphasize the role of canonicalness in orientation coding in the task, they also raise the question of the role of principal axes in the coding of object orientation. To what extent was orientation discrimination based on the extraction of a principal axis from the objects (see Boutsen & Marendaz, 2001)? We suggest that extraction of the orientation of the objects was influenced by salient characteristics of the global shape of the objects, such as elongation, and that these shape characteristics aided in the extraction of an axial orientation from the shape (Found & Müller, 1997). In other words, we suggest that shape processing resulted in the extraction of the type of principal axis that we assumed to be present in our objects (see Figure 1) and that this axis-extraction process played at least a partial role in the search asymmetries observed. When objects appeared in a familiar orientation, this axis-based orientation code was supplemented by additional top-down knowledge of the object's canonical orientation. The observed search asymmetries as a function of canonical orientation indicate that such top-down knowledge had a predominant role in determining orientation discrimination. When objects were shown in unfamiliar orientations only (as was the case in Experiment 3) or when they were degraded to unrecognizable elements (Experiment 2), orientation coding was mainly based on axis-extraction processes, and any top-down influence from object knowledge was reduced or absent. In addition, it should be noted that patient H.J.A. also seemed to resort to an axis-based orientation code when performing the search tasks.

In sum, the coding of the orientation of familiar and unfamiliar objects in our tasks seemed to proceed on the basis of an process of principal-axis extraction, and this determined search asymmetries (in a manner similar to that reported by Found & Müller, 1997, and Boutsen & Marendaz, 2001), at least if such information was not supplemented by top-down information on canonical orientation.

Level of Processing of Canonical Orientation

In this study, we addressed the question of at what level of visual processing canonical orientation coding occurs by measuring the efficiency of target orientation discrimination as a function of the presence of distractors. Efficient search that was relatively unaffected by the presence of distractors—that is, showed relatively shallow search slopes—might suggest that processing of the search display occurred with little attentional demand and was relatively unaffected by sensory factors (e.g., signal-to-noise ratio; J. Palmer, 1995). In contrast to this, the search slopes in most of our experiments were steep, suggesting that search required attentional resources. Only when stimuli were degraded to nonrecognizable elements (see the low-pass-filtered displays in Experiment 2) did search become relatively more efficient. This last result can be attributed to search being slowed when more complex images were used (i.e., images containing both high and low spatial frequencies). In other studies with naturalistic images (e.g., with faces; Tong & Nakayama, 1999), search has generally been slow, and it has been affected by the number of distractors present. This may reflect a general limitation in the capacity of the visual system to process multiple complex images simultaneously. Nevertheless, our data reveal that when objects are attended serially, observers access information about each object's canonical orientation, and this influences judgments that could be made purely on the basis of the physical information present.

The strong set-size effects observed in our experiments indicate that the processes that seemed to underlie object orientation coding (including axis extraction and top-down knowledge of canonical orientation) were relatively late, occurring after any preattentive visual processes. This "late" account of global orientation coding with complex shapes in multielement displays is consistent with Boutsen & Marendaz's (2001) earlier study of global orientation coding.

Generality and Limitations of Results

A final issue to be addressed concerns the generality of our results. To what extent do our search asymmetries generalize to other object classes? Our study used a limited set of objects that were chosen for their particular spatial structures—objects with salient vertical and tilted principal axes. Many objects in the world possess entirely different spatial structures (e.g., cars have horizontal principal axes, and many fruits have reduced or nonsalient axes), and one can argue whether the processes that were observed in our task would play a mandatory role with other object classes. Although this remains an issue to be tested empirically, we suggest that for objects with a distinctive and salient principal axis (e.g., objects with horizontal or otherwise tilted axes), axis-based processing may underlie the processing of object orientation in the same way that it did with our stimulus set. For objects with nonsalient axes, we would not expect that an axis-based strategy would contribute significantly to orientation coding. We should also note that our study leaves open the issue of whether the role of principal axes in object processing extends to object recognition processes. Although other evidence suggests that the extraction of principal axes in objects may play only a limited role in accessing object identity (Large, McMullen, & Hamm, 2003), our study suggests that extraction of the main axis of an object plays a significant role in the coding of object orientation.

Another issue concerns the role of variability in orientation between objects in orientation coding. Our objects were animals that typically appear in a relatively limited range of orientations, especially with regard to their top–bottom orientations: These objects are mono-oriented. In contrast, many other objects are polyoriented (e.g., hand-held tools): They are typically encountered in a larger variety of orientations, and each of these orientations may be "canonical" (e.g., S. Palmer et al., 1981; see also Verfaillie & Boutsen, 1995, for normative evidence on preferential orientations of mono- and polyoriented objects). The narrowness or broadness of the range of canonical orientations of an object may determine its effect on orientation discrimination in the present paradigm. When orientations that are similar in canonicalness need to be discriminated, search may be more reliant on visual characteristics of the search elements than on top-down knowledge, whereas top-down factors may play a greater role for orientations that are more distinct in their canonicalness. Such a hypothesis could be tested by contrasting orientation discrimination performance between mono-oriented objects (e.g., the animals used in the present study) and polyoriented objects (e.g., hand-held tools). In any case, although our study would have benefited from the use of a wider range of object classes, our current attempt to contrast orientation discrimination with objects in familiar and unfamiliar orientations suggests that this paradigm can be extended to a wider range of objects and orientations in a meaningful way.

Conclusion

In conclusion, the present study provides evidence that high-level object knowledge (e.g., information on an object's canonical orientation[s]) can influence performance in a task that involves the mere discrimination of physical orientation. Because access to information about an object's canonical orientation critically depends on object recognition, this result suggests that object identity is processed even in tasks in which recognition is irrelevant. The results of our study are in accord with existing work on high-level influences on stimulus processing (e.g., familiarity effects on visual search), and they provide further support for the role of canonical orientation in object processing.

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If you are interested in reviewing manuscripts for APA journals, the APA Publications and Communications Board would like to invite your participation. Manuscript reviewers are vital to the publications process. As a reviewer, you would gain valuable experience in publishing. The P&C Board is particularly interested in encouraging members of underrepresented groups to participate more in this process.

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