Dynamic Prototypicality Effects in Visual Search

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In recent studies, researchers have discovered a larger neural activation for stimuli that are more extreme exemplars of their stimulus class, compared with stimuli that are more prototypical. This has been shown for faces as well as for familiar and novel shape classes. We used a visual search task to look for a behavioral correlate of these findings regarding both simple geometrical shapes and more complex, novel shape classes. The latter stimulus set enabled us to control for the physical properties of the shapes, establishing that the effects are solely due to the positions of the particular stimuli in a particular shape space (i.e., more extreme versus more central in shape space) and not to specific shape features. The results indicate that finding an atypical instance of a shape class among more prototypical ones is easier and faster than the other way around. The prototypical status of a shape in our experiment could change very quickly, that is, within minutes, depending on the subset of shapes that was shown to the participants. Manipulating the degree of familiarity toward the shapes by selectively increasing familiarity for the extreme shapes did not influence our results. In general, we show that the prototypical status of a stimulus in visual search is a highly dynamic property, depending on the distribution of stimuli within a shape space but not on familiarity with the prototype.

Keywords: typicality effects, visual search, asymmetries, object representation, prototype
Human fMRI studies confirmed the results regarding average neural activation. Loffler et al. (2005) showed that the signal in the fusiform face area increases with increasing distance from the prototypical face. An fMRI study with shape spaces also confirmed an increase in activation toward the extremes (Panis et al., 2011). These increased activations were restricted to the highest level of the ventral visual system, in the fusiform gyrus. This study also ruled out the possibility that the effect is caused by short-term adaptation from the preceding trial (see Davidenko, Remus, & Grill-Spector, 2008, for the original criticism on the previous studies). In addition, by using a custom-created, artificial stimulus set, this study could disentangle the prototypical status of a stimulus from its shape properties. Thus, a stimulus that is a prototype in one condition would be an extreme in the other condition and vice versa. This shows that the effect of typicality on neural activation is related to the structure of a presented shape space and not to the specific properties of a fixed set of prototypes.

On a psychophysical level, there is an advantage of less typical shapes in recognition tasks. This has mostly been studied in faces. Less typical faces are perceived as more distinctive and are recognized more easily (e.g., Valentine, 1991). The easier recognition of distinctive faces has been attributed to a lower density of face representations in those parts of the face space that lie further away from the prototype, resulting in less competition between those representations (e.g., Lee, Byatt, & Rhodes, 2000). The advantage of atypicality in face recognition extends to caricatures, that is, faces that lie on the identity trajectory between a face and the average but beyond the face itself. These retain the identity of the original face but are perceived as more distinctive and recognized more accurately than the veridical faces (e.g., Lee et al., 2000). The caricature effect is not limited to the retrieval part of object recognition but extends to object encoding. Specifically, in a matching task with unfamiliar faces, there is a clear advantage of using a caricature as the sample stimulus, even when the matching stimulus is a veridical face (Deffenbacher, Johanson, Vetter, & O’Toole, 2000).

The results of these studies have been used to infer models on how the visual system represents and encodes objects and faces. They have especially been incorporated in so-called norm-based models, in which faces and objects are represented as a function of how and how much they deviate from the prototype (e.g., Leopold, O’Toole, Vetter, & Blanz, 2001; Panis et al., 2011; Rhodes & Jeffery, 2006). These models are supported by the neurophysiological findings that the optimum of the tuning of individual neurons is not divided evenly across face or shape space but is always situated either on the prototype or on the edge of the object space. These individual neurons are thus tuned along dimensions radiating from the prototype toward the edges of the object space and can therefore be used to represent the way and the amount in which particular stimuli deviate from the prototype. Within the face recognition literature, there is additional support for norm-based models through the caricature effect and through adaptation aftereffects. The latter is the finding that adaptation to a certain face enhances the perception and recognition of its “antiface,” that is, the face that deviates from the prototype in exactly the opposite way. This enhancement of the recognition of the antiface is stronger than the enhancement of another equally dissimilar face (Rhodes & Jeffery, 2006) and suggests that adaptation to a face is actually adaptation to the way in which this face differs from the prototype.

Given all this evidence on the differential role of prototypical and less typical exemplars in face and object representations, we wanted to investigate the influence of this representational difference on perceptual performance. We set up a series of studies in

Figure 1. The stimuli that were used by Kayaert, Biederman, Op de Beeck, and Vogels (2005). The stimulus set consists of variations of a triangle (left) and rectangle (right) on, respectively, three and four dimensions. The dimensions are (from top to bottom) taper (for rectangle-variations only), axis curvature, and positive and negative curvature of the sides. The horizontal distances between the stimuli correspond to the physical magnitudes of the difference between them (within the dimensions).
which we used a visual search paradigm to find a behavioral correlate of the neurophysiological findings regarding typicality in shape spaces. A general increase in activation for one type of stimulus could affect visual search for this stimulus by boosting its saliency and, thus, enhancing the way this stimulus stands out from its environment. We measured the saliency of our shapes by assessing how fast they can be detected in a visual search task. If an extreme shape is perceived as more salient than a prototypical shape, it should be easier to find extreme shapes among prototypical shapes than the other way around.

A visual search asymmetry for the prototype compared with its deviations has already been established for very simple stimuli by Treisman and Gormican (1988). They discovered that it was more difficult to find a straight line between curved or tilted lines than it is to find a curved or tilted line between straight ones. They integrated this effect in their general theoretical framework of visual search asymmetries by assuming that the straight line is encoded by the visual system as some kind of standard or reference value. The curved or tilted line would then be encoded as a combination of the standard and the deviation of the standard on the dimension of curvature and tilt, respectively. This deviation of the standard can be seen as the distinctive property that would allow a curved or a tilted line to pop out from a field of straight lines. The straight lines, however, would have no distinctive property compared with the curved or tilted lines, since the representation of the straight lines would also be included in the representation of the curved lines.

Treisman and Gormican (1988) tested the idea that these search asymmetries reflect visual coding of at least some qualitative properties as deviations from a standard by conducting two more experiments, explicitly testing search for a prototypical stimulus among deviations and the reverse. They tested the combination of a prototypical shape (a circle) with shapes that deviated from it (ellipses) and the combination of prototypical colors (red, blue, and green) with deviating colors (magenta, turquoise, and lime). In both these experiments, they found that it easier to find a deviation among prototypes than the reverse. In examining the meaning of these findings, they hypothesized that the representation that is maximally sensitive to the prototype must be more strongly activated by the deviation than the representation of the deviation is activated by the prototype. They put this forward as a constraint for any underlying model trying to explain this effect. We return to this proposal in the General Discussion, in which we use it as a general framework to understand our findings, as well as related ones from the literature.

The stimuli that Treisman and Gormican (1988) used were very simple, designed to probe the early visual system. We were interested in phenomena occurring in higher level object recognition areas, so we used more complex shapes in our series of experiments. Because we were looking for a behavioral correlate of the neurophysiological findings regarding typicality, we used the same shape spaces used by Kayaert, Biederman, Op de Beeck, and Vogels (2005) and Panis et al. (2011).

**General Method**

A total of 130 students from the undergraduate program of psychology at the University of Leuven participated in this study for course credits. All participants had to perform a visual search task, in which they had to indicate whether all shapes on the display were identical or whether there was an odd one out. They had to do this by pushing either the ctrl or the enter key on the keyboard (marked as absent and present). The key that was associated with each response was varied across participants.

The participants were seated in front of a CTX PR700 16 in. (40.6 cm) display, with a refresh frequency of 120 Hz, in a darkened room, at a distance of 57 cm. The resolution of the screen was 1,024 pixels horizontally and 768 pixels vertically. The experiment was run using E-prime (Version 1.1, Service pack 3, PST Inc.).

After the task was explained to the participants, they had the opportunity to do six practice trials with feedback, using stimuli unrelated to the experiment. The practice trials would be repeated until the participants responded correctly on five out of the six trials. However, most participants always responded correctly during the first round. After this, the participants were informed that new trials would be presented without feedback and instructed to respond as accurately and swiftly as possible, with the emphasis on accuracy.

Each trial started with the presentation of a white fixation point in the middle of a black screen, presented for 1,700 ms. After this, the visual search display was presented for as long as the participants needed to give a response. For each trial, all of the shapes (5, 10, or 15) were randomly placed in a 10 × 10 grid, with the restriction that no two shapes should be directly adjacent to each other. They were presented on a black background. The shapes subtended a visual angle of up to 2.5° × 2.5°.

We assessed the effect of typicality on detection rate in the target present trials by doing a dependent-samples t test on the Z scores of the participants1 as a function of the target being either more typical or extreme. For the target absent trials, we assessed the effect of typicality of the background shapes using a Wilcoxon matched pairs test on the proportions correct as a function of the background being either typical or extreme.2 Analysis on detection speed was confined to the reaction times of the correctly answered trials and performed on the logarithm of the reaction times.

**Experiment 1**

We wanted to find out whether typicality effects in visual search could be obtained using the same stimulus spaces as in the neural experiments on the typicality effect. In Experiment 1, we used the

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1 The Z scores were calculated as a means of transforming the distribution of the proportions correct into a normal distribution. To that end, the proportions correct are conceived as the results of the cumulative distribution function of a hypothetical normal distribution with an average of 0 and a standard deviation of 1. Thus, a proportion correct of .30 would be matched to the value in that normal distribution for which the probability of occurrence of either itself or its lesser values is .30, that is, the Z score of .3 is −0.52.

2 A considerable number of the participants responded at a rate of 100% correct on the target absent trials, making it impossible to reliably calculate Z scores for these trials. This is also why we tested for the main effect rather than doing a complete ANOVA on accuracy measurements; the division of the data in all possible conditions results in too many conditions in which accuracy of at least part of the subjects was either 0% or 100%, making it impossible to reliably calculate Z scores.
same stimuli as those used by Kayaert, Biederman, Op de Beeck, and Vogels (2005), that is, variations on a triangle and a rectangle along simple shape dimensions created (shown in Figure 1). As in the original study, the triangle was modified on three dimensions: axis curvature, positive curvature of the sides, and negative curvature of the sides. For the rectangle, a fourth dimension, taper, was added.

We used only a subset of the original stimuli (presented in Figure 2). For each shape dimension, we selected the shape that was two “steps” away from the original triangle or rectangle and the most extreme shape on the dimension. Thus, in this study, we measured the effect of having a low versus high value on a shape dimension rather than typicality itself. This was motivated by the fact that in the original stimulus set the prototype differs from the modified shapes in important aspects of its constituent features (e.g., having only straight lines compared with the curves in six of the seven modifying shape dimensions; see Figure 1). In all of the dimensions of Kayaert, Biederman, Op de Beeck, and Vogels (2005), the transition from the prototype (i.e., triangle or rectangle) to the other shapes in the dimension consisted of a change in a nonaccidental property as defined by the recognition by components theory of Biederman (1987). These properties are hypothesized to be important in object recognition, especially in viewpoint-independent object recognition (Biederman & Bar, 1999), and a change in a nonaccidental property is more salient to the visual system than a change in metric property, as was psychophysically established in several studies (e.g., Biederman, Yue, & Davidoff, 2009; Kukkonen, Foster, Wood, Wagemans, & Van Gool, 1996; Wagemans, Van Gool, Lamote, & Foster, 2000). We recently showed that this distinction also affects looking times of infants and toddlers (Kayaert & Wagemans, 2010) as well as firing rates of single cells in monkey inferotemporal cortex (Kayaert, Biederman, & Vogels, 2003, 2005; Kayaert, Biederman, Op de Beeck, & Vogels, 2005). In the design as it is presented here, the more prototypical and extreme shapes share the same kind of shape features, thus increasing the likelihood that a possible effect is indeed due to the position of the shapes in the global shape space rather than to the presence or absence of specific shape features. It also differentiates this experiment from the experiments by Treisman and Gormican (1988) that showed asymmetrical search for straight versus either tilted or curved lines.

Method

Participants. Sixteen students from the undergraduate program of psychology at the University of Leuven participated in this study for course credits.

Stimuli. The stimuli are a subset of the stimuli used by Kayaert, Biederman, Op de Beeck, and Vogels (2005). The stimuli are shown in Figure 2, whereas the full set of stimuli of Kayaert, Biederman, Op de Beeck, and Vogels (2005) is shown in Figure 1.

The shapes were rendered by 3D Studio MAX (Release 2.5; Autodesk, Kinetix), and the edges were extracted by the “find edges” filler of Adobe Photoshop (Release 5.5; Adobe Systems), after which the image was inverted (replacing dark parts by light parts and vice versa) to produce white shape outlines on a black background.

The shapes were made by creating a triangle and a rectangle in 3D Studio Max (or actually, the front side of a pyramid and a box) and modifying these along different dimensions (see Figure 1). For the rectangle, the dimensions were axis curvature (the bend function in 3D Studio), positive and negative curvature of the sides (using the curve subfunction of the taper function in 3D Studio)
and taper (i.e., the upper side of the rectangle became wider). For the triangle, the dimensions were axis curvature and positive and negative curvature of the sides. For each dimension, we retained a shape that was slightly modified along that dimension (i.e., remaining closer to the prototype) and a shape that was considerably modified along that dimension (i.e., the more extreme shape).

Procedure. There was one session per participant, lasting approximately 50 min. The session consisted of two blocks of 336 trials, with a break between them. The participants could freely choose the length of the break. A block consisted of four cycles of 84 unique trials. The trials were shown in random order, after which the cycle was repeated. Thus, each individual trial was shown eight times. Four factors were crossed within each cycle: shape dimension (i.e., the seven rows in Figure 2), display size (5, 10, or 15), target presence (present or absent) and whether the target was relatively close to the prototype (i.e., left column in Figure 2) or not (i.e., right column in Figure 2). All stimuli were shown an equal number of times, both as a target and as a distractor. There were as many target absent as target present trials, and the three display sizes appeared equally often.

Analysis. We did a within-subject analysis of variance (ANOVA) on the reaction times on the target present trials, using as independent factors typicality of the target, display size, and shape dimension (i.e., the seven rows in Figure 2). For this analysis, we included only the participants who had answered correctly on at least one trial for each of the conditions, which were 10 participants. We did a supplementary analysis to assess whether the effect evolves over the time course of the experiment. For this, we performed a within-subject ANOVA on the reaction times on the target present trials, using as independent factors typicality of the target and experimental cycle. The reaction times of the target absent trials were analyzed with dependent samples \( t \) tests.

Results

It proved easier to find an extreme shape among a more prototypical shape than the other way around (i.e., the shapes of the second column of Figure 2 were more often detected between shapes of the first column than vice versa). Participants detected the extreme shape in 70% of the cases, \( t(15) = 8.40, p < .0001 \). Figure 3A shows the detection rate as a function of the typicality of the target and the display size. The effect of typicality on detection rate did not increase with display size. The typicality effect was present for all but one of the seven shape dimensions, as is shown in Table 1 (first two columns).

The effects of detection rate were mirrored by the reaction times on the correctly answered target present trials. The more extreme shape was found in on average 1,296 ms, whereas the more prototypical shape needed 1,404 ms to be found. Figure 3B shows the detection speed as a function of display size. We did a within-subject ANOVA on the logarithm of the reaction times with typicality of the target, display size, and series as factors. There were significant effects of display size, \( F(2, 18) = 17.13, p < .0001 \), shape dimension, \( F(6, 54) = 17.71, p < .0001 \), and typicality, \( F(1, 9) = 20.83, p < .005 \). There was a significant interaction between typicality and shape dimension, \( F(6, 54) = 5.02, p < .0005 \). Table 1 (last two columns) shows the reaction times as a function of typicality of the target and shape dimension.

Figure 4 shows that the effect of typicality on detection rate remains stable throughout the course of the experiment. There was also no evolution of the effect of typicality on the reaction times. A within-subject ANOVA yielded significant main effects of typicality, \( F(1, 15) = 14.57, p < .002 \), and experimental cycle, \( F(7, 105) = 9.99, p < .0001 \), but no interaction, \( F(7, 105) < 1 \). Thus, we found no interaction between familiarity with the stimuli and the typicality effect on either detection rate or speed.

The average accuracy on the target absent trials was 94\% (i.e., 94\% correct with a background of prototypical shapes, and 93\% correct with a background of extreme shapes), and the average reaction time on the correctly answered target absent trials was 1,653 ms for both kind of background shapes. There was thus no effect of the typicality of the background shapes on the accuracy and reaction times in the target absent trials.

Discussion

We have shown that searching for the extreme shapes of a shape space in a display containing prototypical distractors is easier than the reverse. We demonstrated this effect using a shape space consisting of relatively familiar stimuli, that is, variations on a
rectangle and a triangle, which has also been used to observe a higher average neural activation for the atypical versus prototypical stimuli (Kayaert, Biederman, Op de Beeck, & Vogels, 2005). Experiment 1 demonstrates that effects of typicality in visual search need not be confined to a comparison between the prototype and an extreme shape. There is also a clear effect of typicality when comparing an extreme shape with a more typical shape (which is not necessarily the actual prototype).

It should be noted that typicality is interwoven with the values of the stimuli on certain dimensions within the stimulus space that has the prototype as “origin”; the atypical stimulus, by definition, will have a higher value. Previous studies have demonstrated other instances of asymmetric visual search where stimuli with a higher value on a certain dimension pop out amidst stimuli with a lower value but not vice versa. For example, fast oscillation amid slow oscillation pops out, whereas slow oscillation amid fast oscillation does not (Ivry & Cohen, 1992). Also, when targets and distractors were the same hue, high saturation targets amid low saturation distractors were found more easily than low saturation targets amid high saturation distractors (Nagy & Cohen, 1996).

This makes it different to ascertain whether the effects in Experiment 1 are really due to typicality as induced by the position of the shapes within the general shape space or whether they are the result of the extreme shapes having “more” of a certain shape feature (like curvature or asymmetry). We address this possible confound in Experiment 2, in which we manipulate typicality independent of the shape features of the stimuli.

**Experiment 2**

For Experiment 2, we used the shapes of Panis et al. (2011) to manipulate typicality independent of shape features. These shapes are shown in Figure 5. The allocation of the prototype and the extreme was dependent on the subset of the shape class that was presented to each participant and was counterbalanced between participants (see Method, below). Because we employed stimuli that were previously unfamiliar to the participants, we could also use them to map the time course of the effect. Because the prototypical status of a shape in this experiment only emerges as soon as the participant becomes familiar with the shape space, the possible effect of typicality cannot be there from the first trial but emerges gradually as the participant becomes more familiar with the shape class. Thus, we were able to measure how much experience with a shape class is needed to induce typicality effects.

In Experiment 2B, we measured how stable typicality effects are by introducing a second phase in the experiment in which we showed only the extreme and the prototypical shape of the stimulus class. In isolation, these two shapes represented a new distribution of exemplars in the shape class, in which the new prototype would now be in between both shapes. The question is whether this change in stimulus distribution would change the way the shape class is represented, thereby removing any typicality effects within this experiment, or whether the originally built representation will prevail, no matter how imbalanced the frequency with which its individual members are encountered.

**Method**

**Participants.** Experiment 2A was conducted with 58 undergraduate students. Experiment 2B was conducted with 24 undergraduate students.

**Stimuli.** The stimuli were constructed using a parameterization in terms of radial frequency components as described before (Op de Beeck, Wagemans, & Vogels, 2001, 2003a). The total stimulus set included four classes of seven object exemplars (see Figure 5). The seven exemplars from each class were located on a

<table>
<thead>
<tr>
<th>Shape dimension</th>
<th>% Detection rate</th>
<th>Detection speed (ms)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prototypical</td>
<td>Extreme</td>
<td>Prototypical</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
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<tr>
<td>◯</td>
<td>65</td>
<td>80</td>
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<td>◯</td>
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<td>49</td>
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<tr>
<td>◯</td>
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<td>76</td>
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<tr>
<td>◯</td>
<td>79</td>
<td>85</td>
</tr>
<tr>
<td>Average</td>
<td>70</td>
<td>78</td>
</tr>
</tbody>
</table>

3 Rosenholtz (2001) has criticized the designs of these studies, as well as Treisman and Gormican’s study (1988). It should be noted that her remarks do not apply to our experiments, which in a sense makes them more important as “not yet criticized” instances of asymmetric visual search.
The four novel stimulus classes used by Panis et al. (2011) and in Experiments 2 and 3. Each row represents a stimulus class. The participants in Condition 1 were shown the first five objects (underlined in gray), and the participants in Condition 2 were shown the last five objects (underlined in black). For participants in Condition 1, Object 3 is the prototype, and Object 5 is the extreme shape. For participants in Condition 2, Object 3 is the extreme shape, and Object 5 is the prototype.

Procedure.

Experiment 2A. The experiment involved one session of 450 trials, lasting approximately 40 min. The session consisted of 10 cycles of 45 unique trials. The trials were shown in random order, after which the cycle was repeated. All five objects were used equally often as target and as distractor. Fifteen trials per cycle (33%) were target absent trials. The five objects were crossed with the three display sizes (5, 10, or 15). Thirty trials were target present trials. Because we wanted to expose the participants to all the objects in the stimulus class for an equal number of times, we did show not only trials with combinations of the prototype and the paired extreme shape (the trials used in the analysis) but also trials containing combinations with the other objects. For the participants in Condition 1, the object pairs used in the target present trials were 1–3, 3–5, 2–4, 1–4, and 2–5. The stimuli within each pair were used both as a distractor and as a target, in an equal amount. For the participants in Condition 2, the object pairs used in the target present trials became 3–5, 5–7, 4–6, 3–6 and 4–7 (see Figure 5). Three factors were crossed to obtain the 30 target present trials: Object Pair (5) × Target-Distractor Assignment Within the Pair (2) × Display Size (3).

Experiment 2B. Experiment 2B consisted of two phases, together lasting approximately 45 min. The first phase was identical to Experiment 2A: The 45 unique trials of Experiment 2A were shown in 7 cycles (three less than in Experiment 2A itself, but without a break). The first phase was immediately followed (without a break) by a second phase in which only the prototypical and extreme shape were shown, without the other shapes. The second phase consisted of 12 cycles of 12 unique trials each. The trials included six “target absent” trials in which the two shapes were crossed with the three display sizes (5, 10, or 15) and six “target present” trials in which target-distractor assignment was crossed with display size.

Analysis. We confined the analyses to the target-distractor pairs consisting of a prototypical stimulus and an extreme stimulus that were counterbalanced across conditions, that is, the combinations three (target) among five (distractor) and five (target) among three (distractor).

Reaction times higher than 7 s were discarded, which resulted in the removal of 2% of the data. This did not affect the pattern of results, in the sense that including all reaction times resulted in different averages but did not reduce significant effects to nonsignificant ones or vice versa. To assess the effects of typicality on detection speed during the target present trials, we did a dependent samples t test over subjects as a function of the target being either prototypical or extreme. Over the three experiments in the second series of experiments (Experiments 2A, 2B, and 3), we excluded three out of 82 participants for not having answered correctly within the 7 s time limit on at least one trial in one of the conditions.4

The reaction times of the target absent trials were analyzed with dependent samples t tests. We excluded 20 participants from Experiment 2A and the first phase of Experiment 2B for not having answered correctly within the 7 s time limit on at least one trial in one of the conditions.

The results of Experiment 2A and the first phase of Experiment 2B were analyzed together because these experiments were identical and could therefore easily be pooled. The pattern of results was also similar for both experiments. We analyzed only the data starting from the second presentation cycle, using the first presentation cycle as a means to familiarize the participants with the class structure of the shapes (but we do show the data from the first cycle in Figure 7 for comparison).

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4 This is the reason why we performed a t test rather than a full ANOVA. Dividing the data in more conditions would have resulted in the loss of many more subjects.
Results

Experiment 2A and the first phase of Experiment 2B. It proved easier to find an extreme shape among prototypical ones than to find a prototypical shape among extreme ones. Participants detected the extreme shape in 62% of the cases and the prototypical shape in 53% of the cases, \( t(82) = 4.75, p < .0001 \). Figure 6 shows the effect as a function of display size. Table 2 shows that the effect was present in all but one of the combinations of stimulus classes and conditions. Figure 7 shows the effects of typicality as a function of the representation cycle within the experiment (see Experiment 2, Method section), for the first five cycles (i.e., the part before the break of the subjects in Experiment 2A). The accuracy on the target absent trials was higher when the background shapes were extreme (94%), compared with when the background shapes were prototypical (89%; Wilcoxon matched pairs test, \( n = 82, p < .0005 \)).

The high error rates make interpretation of the reaction times very difficult. We nevertheless present them, but we do not speculate about their meaning. There was no effect of typicality of the target on detection speed. We measured the reaction times (RT) on the correctly answered trials and found no difference between trials in which the target was an extreme shape (RT = 2,646 ms) and trials in which the target was a prototypical shape (RT = 2,692 ms), \( t(79) = 1 \). During the target absent trials, however, the responses were faster when the background shapes were extreme shapes (2,858 ms), compared with when the background trials were prototypical shapes (3,220 ms); \( t(62) = 5.83, p < .0001 \). This effect was present in all but one of the combinations of stimulus class and condition.

We did a further analysis on the relation between accuracy, detection speed, and typicality. This showed that the effect of typicality on accuracy was limited to the responses that occurred within the first 2,500 ms of the trial (see Figure 8). There was a linear increase in detection rate of the prototype as a function of the amount of time the subjects spend examining the display (linear regression analysis, \( r^2 = .93, p < .05, n = 4 \)), whereas there was no linear relationship between the length of the trial and the detection rate of the extreme shape (\( r^2 = .13, ns \)). The effect of typicality remained (and was even slightly enhanced) when one only takes into account those trials that were preceded by an identical trial (detection rate extreme: 69%; detection rate prototype: 52%, \( N \) trials: 77/56; \( p < .05 \) for the difference between the extreme and the prototype, using a proportion test).

Experiment 2B. This experiment shows that the effect of typicality can quickly disappear when the participants are presented only the extreme and the prototypical shape, without the other shapes of the stimulus classes presented in Figure 5. Figure 9 shows that effects of typicality on detection rate were clearly maintained during the first phase of the experiment but disappeared as soon as the second phase started. The main detection rate for the extreme shape during the first phase of the experiment was 72%, compared with 60% for the prototypical shape, \( t(23) = 3.51, \)

Table 2
The Effect of the Typicality of the Target on Detection Rate as a Function of Stimulus Class in Experiment 2

<table>
<thead>
<tr>
<th>Stimulus class</th>
<th>% Detection rate</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>Prototypical</td>
</tr>
<tr>
<td>Class 1 Condition 1</td>
<td>59</td>
</tr>
<tr>
<td>Class 1 Condition 2</td>
<td>64</td>
</tr>
<tr>
<td>Class 2 Condition 1</td>
<td>48</td>
</tr>
<tr>
<td>Class 2 Condition 2</td>
<td>72</td>
</tr>
<tr>
<td>Class 3 Condition 1</td>
<td>31</td>
</tr>
<tr>
<td>Class 3 Condition 2</td>
<td>58</td>
</tr>
<tr>
<td>Class 4 Condition 1</td>
<td>49</td>
</tr>
<tr>
<td>Class 4 Condition 2</td>
<td>42</td>
</tr>
<tr>
<td>Average</td>
<td>53</td>
</tr>
</tbody>
</table>

Note. Presented in Figure 5.
During the second phase, the main detection rates were 71% and 69%, respectively. There was no significant effect of typicality on target detection time within either the first phase or the second phase of Experiment 2B. The accuracy on the target absent trials during the first phase of the experiment was higher when the background shapes were extreme (93%), compared with when the background shapes were prototypical (88%; Wilcoxon matched pairs test, $N = 24$, $p < .005$). This effect was gone in the second phase, where the accuracies were 92% and 93%, respectively. The participants also responded more quickly when the background shapes were extreme (2,818 ms), compared with when the background shapes were prototypical (3,152 ms), $t(23) = 3.24$, $p < .005$, during the first phase. This latter effect was still present, though slightly less pronounced, throughout the second phase. The average response time to a background with extreme shapes was 2,689 ms and to a background with prototypical shapes was 2,814 ms, $t(23) = 2.32$, $p < .05$.

Discussion

We have shown that searching for the extreme shapes of a shape space in a display containing prototypical distractors is easier than the reverse. We demonstrated this effect using a shape space consisting of previously unfamiliar, complex, and very similar shapes, which has also been used to observe a higher average neural activation for the atypical versus the prototypical stimuli (Panis et al., 2011).

This effect of typicality on visual search is quite dynamic. It appears very early during the course of the experiments and disappears as soon as we stop presenting the entire shape space and show only the prototype and the extreme. Thus, we do learn something not only about typicality but also about asymmetric visual search. We have shown that asymmetric visual search can be malleable: It is not the case that certain stimuli will always be easier to find than others will be. Also, asymmetric visual search is not limited to specific kinds of stimuli but can possibly be induced with any kind of stimuli.

It has been suggested that some of the effects of typicality could be due to the prototype being perceived as more familiar (e.g., Op de Beeck, Wagemans, & Vogels, 2003b). Experiment 3 is a replication of Experiment 2, but in such a way that a possible result cannot be attributed to a higher familiarity with the prototype.

Experiment 3

It has been suggested that some of the effects of typicality, asymmetry in similarity judgments, for instance, could be due to the prototype being perceived as more familiar (e.g., Op de Beeck et al., 2003b). The familiarity of a stimulus generally increases through the observation of this stimulus, but it is possible that encountering very similar stimuli also induces familiarity. Because the instances of a stimulus class are on average more similar to the prototype than to one of the extremes of that stimulus class, it is possible that a prototype becomes relatively more familiar through the perception of relatively more similar shapes. This could have been the case in our experiments, in which the stimuli were on average more similar to the prototype than to the extremes. We
investigated whether controlling for familiarity alters the results of our experiments. If this were the case, then it would relate the findings of typicality effects in visual search to the effect of familiarity in visual search, that is, the finding that visual search is conducted faster when the distractors are more familiar (e.g., Mruczek & Sheinberg, 2005; Shen & Reingold, 2001; Wang, Cavanagh, & Green, 1994).

Previous research has shown that the repeated presentation of instances of a shape class without presenting the prototype increases the perceived familiarity of the presented instances while reducing the perceived familiarity of the prototype and the other nonpresented instances of the class. In the same experiment, classification of the prototype as a category member increased even though the prototype itself was not presented (Homa, Goldhardt, Burrel-Homa, & Carson, 1993). Thus, showing different instances of a shape class without showing the prototype is a good way of dissociating the effect of typicality on familiarity from other prototype effects.

In Experiment 3, we induced familiarity to the extreme shapes by extensively showing the extreme shapes to the subjects before the start of the data acquisition trials. In this first phase of the experiment, the participants performed visual search using only the extreme shapes of the dimension (see Experiment 3, Method section). This gave the extreme shapes an exposure advantage over the prototypical shape that could not be compensated for during the second phase of the experiment and that would undo or even reverse the effect of typicality if this effect could be mimicked by or coincides with the effect of familiarity.

An increase in familiarity with the extreme shapes directly leads to a decrease in neural activity for these shapes. Familiarization to a previously novel stimulus leads to a long-lasting suppression of activation in object-selective cortex (Desimone, 1996; Freedman, Riesenhuber, Poggio, & Miller, 2006; Li, Miller, & Desimone, 1993). This makes the results of Experiment 3 important to the way we relate our findings to the effect of typicality on the level of neural activity. If the manipulation in Experiment 3 neutralizes or reverses the main effect, then one could infer that the effect is mediated through a higher neural activity for the extremes. No effect of the manipulation, however, leaves room for the hypothesis that there are other factors producing both the effect of typicality on visual search and the other typicality effects, including the effect on the general level of neural activity.

Method

Participants. Thirty-two undergraduate students participated in Experiment 3.

Stimuli. In Experiment 3, we used the same stimulus space as Experiment 2.

Procedure. Experiment 3 consisted of two phases, together lasting approximately 40 min. In the first phase, only the extreme shapes of the classes are shown (i.e., Shapes 1 and 5 for the participants in Condition 1 and Shapes 3 and 7 for the participants in Condition 2; see Figure 5). This phase consisted of 11 cycles of 12 unique trials each. The trials included six “target absent” trials in which the two shapes were crossed with the three display sizes (5, 10, or 15) and 6 “target present” trials in which target-distractor assignment was crossed with display size. During this phase, the extreme shape that was compared with the prototypical shape was shown as a background shape in 66 displays and as a target shape in 66 displays as well. In total, the participants saw this particular extreme shape 660 times, without having any experience with the prototype.

The second part of Experiment 3 was identical to the first part of Experiment 2B and thus consisted of 7 cycles of the 45 trials also used in Experiment 2A. During one cycle in the second phase of the experiment, a particular shape is shown 90 times. Even under the very conservative assumption that the surplus neighbor of the prototypical shape familiarizes the prototype as much as a representation of the shape itself, it would still take the prototype all seven cycles simply to catch up.

Analysis. The analyses were identical to the corresponding analyses of Experiment 2. Regarding the dependent samples t test used to assess the effect of typicality on detection speed during the target present trials, we had to exclude one participant for not having answered correctly within the 7 s time limit on at least one trial in one of the conditions.

Results

This experiment shows that the effects of typicality can also be found after intensive presentation of only the border stimuli of the classes presented in Figure 5. During the first phase, the extreme shape was coupled with the other border shape of the class (see Experiment 3, Method section) and shown in total 660 times, while the prototypical shape was not yet seen by the participants.

Nevertheless, when the participants were shown the entire stimulus class during the second phase (see Experiment 3, Method section), the typicality effect emerged right from the second cycle of presentation (see Figure 10). During the target present trials, the extreme shape was found in 52% of the cases, and the prototypical shape was found in 42% of the cases, t(31) = 3.12, p < .005. During the correctly answered target present trials, it took the participants on average 2,542 ms to find the extreme shape and

![Figure 10](image-url)
2,435 ms to find the prototypical shape, a difference that was not significant, \( t(30) < 1 \). During the target absent trials in Phase 2, the participants responded correctly to a background of extreme shapes in 95% of the cases and to a background of prototypical shapes in 90% of the cases (Wilcoxon matched pairs test, \( N = 32, p < .001 \)). The response took on average 2.323 ms for the background of extreme shapes and 2.618 ms for the background of prototypical shapes, \( t(31) = 4.39, p < .005 \).

Discussion

We have shown that searching for the extreme shapes of a shape space in a display containing prototypical distractors is easier than the reverse. In Experiment 3, we show that the prototype effect remains equally strong after the participants have been extensively familiarized with the extremes of the shape space, thereby making it unlikely that a higher familiarity for the shape features of the prototype would be a strong determinant of the effect.

General Discussion

General Implications From a Cognitive Psychology Perspective

Influence of a difference in saliency. We have shown that searching for the extreme shapes of a shape space in a display containing prototypical distractors is easier than the reverse. The general effect is consistent with our initial hypothesis of a higher saliency of the extreme shapes, possibly linked to the higher average neural activation to these shapes. In Experiment 1, we observed the predicted effect of typicality both regarding reaction times and regarding accuracy but in Experiment 2 and 3, there was no effect on reaction times. The latter is in contradiction with a possible higher saliency for the extreme shapes, which would have led to a faster detection of these shapes.

However, an effect on reaction times in Experiment 2 and 3 could have been masked by cautious responding of the participants, which is not unlikely, given the difficulty of the task and the generally very slow reaction times. The finding that there is a speed/accuracy trade-off when the prototype is the target but not when the extreme is the target (see Figure 8) is also consistent with a higher saliency for the less typical shapes. It could be that detecting the prototypical shapes requires a more serial scan of the display, whereas the detection of the extreme shapes is in part mediated by a pop-out mechanism. In any case, we need to be very careful with the interpretation of the reaction times, given the high error rates, especially in Experiments 2 and 3.

Underlying stimulus representations. In general, the visual search task was very difficult for the participants, especially when using the shapes in Experiments 2 and 3. The differences between these shapes are relatively easy to see if one is presented with the entire dimension, like in Figure 5. But, there are subtle differences in complex and unfamiliar shapes, and if one sees only one shape at the time, without knowledge of how the target is going to differ from the background, then the target is very easy to miss. The difficulty of the task is reflected by the low accuracy and the long reaction times of the participants. Thus, differentiating between the target and the distractors is an important and challenging part of this task. This makes it likely that the substantial effect of typicality on accuracy in the search task is due to an asymmetry in differentiating between the target and the distractor. Specifically, it is easier to differentiate an extreme shape from a background of more typical shapes than the other way around. This part of the effect calls for a different explanation from the initial hypothesis of this study, in which we looked for stimulus saliency (i.e., the general efficiency in attracting attention, irrespective of context) as a direct behavioral correlate of the higher average neural firing rate for the extremes.

In their seminal article on visual search asymmetries (including the asymmetry between a prototypical and nonprototypical simple feature), Treisman and Gormican (1988) attempted to explain their effects as a function of the properties of the neural representations of both prototype and deviation (i.e., the nonprototypical feature). They argued that in order for search asymmetries to be possible, the representation that is maximally sensitive to the prototype must be more strongly activated by the deviation than the representation of the deviation is activated by the prototype. Thus, the search for a prototype among extremes is mediated by the representation that signals the presence of the prototype, and it is the extent to which this representation distinguishes between prototypes and extremes that determines whether the prototype is detected as an odd one out. The same applies for the search for an extreme among prototypes.

The idea that the neural representation that is used to signal the prototype could be less sensitive than the neural representation that is used to signal the extremes is congruent with neurophysiological and psychophysical evidence. A supplementary analysis on the data of Kayaert, Biederman, Op de Beeck, and Vogels (2005) has shown that neurons tuned toward the prototype of their shape space are indeed less selective than neurons tuned toward the extreme of this shape space.\(^5\) It is furthermore in line with the finding in face literature that the sensitivity with which we can distinguish very similar faces (created using morph lines) from one another is lower around the prototype (Dakin & Omigie, 2009; Rhodes, Maloney, Turner, & Ewings, 2007).

A broader representation of the prototype in our experiments could be a result from the collapsing of the representation of the prototype and the representation of its neighbors into one broader representation. Collapsing of neighboring presentations is predicted by an attractor dynamics model of Preminger, Sagi, and Tsodyks (2007), who also collected psychophysical evidence for their theory (Preminger, Blumenfeld, Sagi, & Tsodyks, 2009). They repeatedly and gradually exposed participants to very similar morphs between a known and an unknown face, which resulted in

\(^5\) We performed a repeated-measures ANOVA on the neuronal responses for the shape dimensions in Kayaert, Biederman, Op de Beeck, and Vogels (2005), with location of the optimal response as a between-neurons variable (on the prototype vs. on the extreme shape) and stimulus rank (the value of the stimulus on the dimension) as within-neurons variable. The analysis was combined over the seven shape dimensions employed in Kayaert, Biederman, Op de Beeck, and Vogels (2005), and only the neurons that responded significantly to a particular dimension were included for that dimension. If a neuron responded significantly to more than one dimension, then it could be included more than once in the analyses. In addition to the main effects, there was a significant interaction that revealed less selectivity for the neurons tuned toward the global prototype of the shape space, \( F(5, 1620) = 9.8706, p < .0001 \).
the gradual broadening and shifting of the representation of the known face, up to the point where it included the unknown face. Within such a framework, the representations of the extreme stimuli in a shape or face space would be less susceptible for broadening because they are situated around the edges of the space (or sometimes maybe even beyond those edges).

The concept of a less sensitive representation of the prototype through interactions with neighboring representations can be related to the currently dominant interpretation of typicality effects in face recognition (i.e., atypical faces get more easily recognized); The objects at the edge of the relevant object space are considered more distinctive due to less interference from neighbors within this space (e.g., Lee et al., 2000).

Integration With Neural Findings

The dynamics of the effect in Experiment 2 set out the conditions that must be fulfilled by any neural mechanism hypothesized to underlie these effects. It has to be quite dynamic, building up in a matter of minutes. It should not be too dynamic, though; it should take at least a couple of minutes to build up and, unlike most adaptation effects, it should last longer than a few seconds to bridge the intertrial intervals. It also has to be reversible: When the distribution of the shapes within the shape changes in Experiment 2B, so changes the effect. Thus, the mechanism really has to be driven by the current structure of the shape space rather than the total amount of exposure to any one stimulus (like in familiarity-related effects). And, the mechanism has to occur unsupervised, that is, unrelated to any feedback about the correctness of the response.

There is one reported instance of neural plasticity that fulfills these conditions. De Baene et al. (2007) have found evidence for the sharpening of the tuning of macaque inferior temporal neurons toward the extremes of a shape dimension, under the influence of the representation of a denser shape space. The shape space consisted of one dimension of very similar stimuli, much alike our shape classes in Experiments 2 and 3, and they manipulated the density and extent of the presented shape space around the prototype. Thus, in the narrow range condition they added four shapes around the prototype in the middle of the dimension while removing four shapes at the extreme ends of the dimensions. The tuning of the neurons that responded optimally to either one of the extremes of the dimension was steeper during the presentation of the narrow shape space, compared with the tuning during the presentation of the broader shape space.

The change in tuning width of the neurons of De Baene et al. (2007) took about 70 stimulus representations (each lasting 100 or 300 ms) to develop, which is well within the time range of the dynamic changes in Experiment 2, and their effects went in two directions, that is, selectivity could both increase or decrease depending on the condition. Moreover, the effect on neural selectivity was accompanied by an effect on average firing rate: Because all selective neurons were tuned toward either one or the other extreme of the dimension, the increase in selectivity in the neurons in the denser shape space was accompanied by a relative decrease in average neural activation to the prototype (i.e., the phenomenon that triggered this research).

In general, these results show that the selectivity of inferotemporal tuning curves to shapes can be influenced using a paradigm much like ours. Unlike the psychophysical evidence on broadening of representations, this neurophysiological evidence is about representations becoming more sensitive under repeated representation of a dense shape space. Those two phenomena might, however, be complementary. The same Hebbian mechanisms that are used to model the merging of initially already substantially overlapping representations could also underlie competition between representations “on a safe distance” from each other. Consistent inhibition from the optimal representation for a stimulus toward those representations that were initially only marginally active to that stimulus would reduce the responsiveness of the latter representations even further. Thus, while one representation broadens, others could shrink. This is in agreement with findings regarding sensitivity to subtle differences between faces as a function of their position in face space. Although sensitivity is comparatively low both for the prototype and morphed faces very similar to the prototype (Dakin & Omigie, 2009; Rhodes et al., 2007), it is on the other hand relatively higher for those faces situated close to the prototype (but still clearly dissimilar from it) compared with more atypical faces (Wilson, Loffler, & Wilkinson, 2002; Dakin & Omigie, 2009). This is consistent both with neural dynamics that broaden the representation around the prototype and dynamics that increase selectivity through competition between neighboring but not too overlapping representations.

Target absent trials. There was also an effect of typicality on accuracy in the target absent trials in Experiment 2 and Experiment 3, that is, there was a higher rate of false alarms in the target absent trials with the prototypical shapes as a background. This could be linked to the development of a response bias: During the target present trials, people perform better in displays with prototypes as a background, start to therefore expect a target more strongly, and develop a corresponding response bias. Alternatively, this could also be attributed to a more efficient encoding of the extreme shape in its role as a background shape. The efficiency with which background shapes can be encoded has been hypothesized to be a major factor in search asymmetries, with more complex (and hence more difficult to encode) shapes hindering visual search on those trials where they constitute the background (Rauschenberger & Yantis, 2006). Less efficient search has also been found when the background stimuli are unfamiliar (compared with more familiar; Mruczek & Sheinberg, 2005; Shen & Reingold, 2001; Wang, Cavanagh, & Green, 1994). We cannot assume that our extreme shapes are more familiar than the prototype (if anything, the hypothesis would be the other way around), but if the presentation of a dense shape space results in sharper tunings for inferotemporal neurons responsive to the extreme shapes (as indicated by De Baene et al., 2007), then they would have this in common with familiar shapes. Inferotemporal neurons also have sharper tunings to familiar stimuli, 

\[\text{In this experiment, a cycle consisted of 45 displays that each could be seen as resulting in maximally 15 stimulus representations, depending on the display size and the degree to which the subjects scan the entire display.}\]
which are hypothesized to result in a more efficient processing of these familiar stimuli (Freedman et al., 2006).

**Search task with a predefined target.** The results of our odd-one-out search task might not be generalizable to search tasks with a predefined target. Looking for a predefined target might put different demands on the underlying representations of target and distractors, which could alter the way in which the participants are influenced by the shape space. Evidence from this comes from a guided search task in which the search is neither faster nor more accurate when the targets are pictures of objects that are less typical within their basic level category (Castelhano, Pollatsek, & Cave, 2008). It should be noted that this study also differs from our study in a number of other ways, for example, their stimuli are highly dissimilar to one another, compared with ours and compared with the stimuli in face studies.

**Conclusion**

In general, we have shown that the prototypical status of a stimulus in visual search is a highly dynamic property, depending on the distribution of the shapes within a shape space, but not on familiarity. These findings emphasize the central role of the prototype in a dynamic representation of shape spaces containing highly similar stimuli.

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