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*Evidence for a top-down matching mechanism in
visual priming with abstract shapes*

Birgitta Dresp

CNRS, Université de Strasbourg, FRANCE

E-mail:

`birgitta.dresp@icube.unistra.fr`

Abstract Whether physical and structural attributes of visual stimuli engender automatic priming effects is a much debated issue. In this study, we investigated effects of shape and colour of abstract visual shapes (primes) on the identification of subsequently presented target shapes (probes). Two independent groups of observers were tested. One group was explicitly told that the primes preceding the probes could be relevant for identification, the other group was merely instructed to identify the shape of the probes. We find significant interactions between primes and probes in the group of observers who received the explicit instructions. These interactions reveal that probes with the same shape and colour as the prime are processed faster than probes with only the same shape. Probes with the same colour as a prime but different shape yield longer response latencies than probes preceded by primes with the same shape and colour, by non-congruent primes, or by no prime at all. The findings provide evidence for a top-down matching mechanism in shape priming, which explains phenomena such as attentional binding by interaction between neurons sensitive to the shape and the colour of visual stimuli.

Introduction

The present study investigates context effects of shape similarity and color on form recognition in abstract visual configurations.

Priming to probe attentional selection

Visually presented primes preceding a visually presented probe may influence attentional selection and perceptual judgements resulting from such a selection. The effect of a prime on the processing of a probe can be either facilitating or inhibiting (Farah, 1989; Maxfield, 1997) depending on its beneficial or detrimental action on attentional processes activated by the task. It has been suggested (e.g. Ochsner, Chiu, & Schacter, 1994) that priming effects depend on representations that are stored in modality-specific cortical memory systems. In the specific case of visual perception, this memory system may be based on parallel perceptual mechanisms, each devoted to the independent analysis of a single physical stimulus dimension (Magnussen & Greenlee, 1999), and coupled to a global storage system that may be identified in terms of the Tulving-Schacter (Tulving & Schacter, 1990) perceptual representation system (*PRS*). How such a perceptual representation system is activated in priming

strongly depends on the semantic and/or categorical properties of the stimuli under investigation. Moreover, priming effects are sensitive to constraints specific to the task, or instructions given to observers. Recent evidence from priming experiments with visual forms has established that observers can be induced to give attentional priority to a strictly local stimulus dimension and thereby be prevented from processing semantic information (Murray & Jones, 2002). This finding suggests that task specific demands command the attentional selection process involved in priming.

The effect of task context and specific task demands

The possibility that priming effects may depend on task demands, or instructions communicated to observers has, until recently, received little attention. However, Holbrook, Bost & Cave (2003) found that repetition priming in a naming task was elicited by stimuli that were seemingly non-relevant to the task in cases where they had previously been pointed out as relevant in a search task. This observation shows that priming is highly sensitive to the task context, the specific study-task demands, and the overall contextual information communicated to observers. In agreement with Murray & Jones (2002), the authors concluded that attentional selection in priming effects appears to be more dynamic and flexible than had been previously considered. Similar conclusions had been drawn earlier from results of a repetition priming study with pictures (Bruce, Carson, Burton, & Ellis, 2000). Considering this, we wanted to clarify whether visual priming by abstract stimuli carrying no particular semantic « weight » would be elicited spontaneously in naive observers, or whether specific information indicating a possible relevance of the primes to the task under study needs to be provided.

Contextual dynamics of attentional selection

The shape or the colour of visual objects may determine attentional processing in any perceptual task. Evidence from visual search studies has produced a theoretical framework of so-called attentional binding to explain how object properties such as shape and colour are processed in a search task (Treisman, 1991; 1998). According to the classic theory, visual search for an object defined by a conjunction of features, such as a particular colour and a particular shape, would require serial processing and attentional binding of shape and colour. Search for a single object attribute like shape,

for example, would be preattentive and not require attentional binding of features. Attentional binding describes what happens when a certain colour is bound to a certain shape. When the shape changes, the colour needs to be bound to the new shape at a certain cost, and when colour changes, the shape needs to be bound to the new colour at a certain cost. However, this binding postulate is basically a working hypothesis. It does not provide any insight into the mechanisms underlying attentional selection. Clearly, the role of perceptual mechanisms and their implication in priming effects (e.g. Srinivas, 1993; Marsolek, Schacter, & Nicholas 1996; Schacter & Buckner, 1998) is subject to much controversial debate. Moreover, it is important to point out that priming effects are not exclusive to visual search tasks, but have since been shown to occur in a much larger range of experimental paradigms. While search tasks tightly constrain selection by a specific stimulus attribute, or combination of attributes, other experimental tasks, where priming may occur unexpectedly, not necessarily do so. This suggests the need for a rather flexible, dynamic theory of attentional selection (e.g. Holbrook et al., 2003).

The fact that priming can occur unexpectedly after some time in a context defined by a specific succession of trials or tasks, for example, indicates that dynamic mechanisms of perceptual learning are involved in attentional selection. Goolsby & Suzuki (2001) found that visual search for a single, odd-coloured item among homogeneously coloured distractors primed observers' responses in a subsequent search task. In fact, when a given colour combination happened to be a critical attribute for attentional selection in trials of a previous task, items defined by the same colour combination tended to be detected faster in trials of a subsequent experiment with different task requirements. This finding suggests that colour, and possibly any other attribute of a visual stimulus, can produce contextual dynamics in a more intricate and indirect way than previously considered.

Attentional selection by top-down matching

The role of contextual dynamics and basic mechanisms of visual learning, which may produce priming effects in a multitude of experimental paradigms, is emphasized in Grossberg's (e.g. 1999) theory of visual attention. According to this theory, attentional selection may elicit priming whenever an expectation (top-down) signal triggered by a previous visual event can be matched to an incoming (bottom-

up) signal triggered by an ongoing visual event at a given moment in time. This top-down matching mechanism is sensitive to events from previous tasks or trials as well as specific task instructions which determine the general contextual relevance of a visual stimulus in a given situation, as indicated by some of the most recent experimental findings (e.g. Holbrook et al., 2003; Goolsby et al., 2001). The principle of top-down matching is illustrated in Figure 1. In addition to contextual relevance, intrinsic object properties such as figure saliency, filling-in, and figure-ground organization (e.g. Grossberg, 1997; 1999) determine the strength of the expectation signal that an object will trigger in a given context.

Contextual relevance

The contextual relevance of a prime with regard to a probe depends on the instructions that are communicated to observers beforehand (see above). In the present experiments, two different task instructions were given to two different groups of subjects who all had to identify the shape of a probe preceded by a congruent prime, a non-congruent prime, or no prime at all. The potential importance of the primes with regard to the probes was explicitly pointed out to one group of subjects to make them aware of a possible contextual relevance. In the instructions given to the other group, no specific mention concerning the primes was communicated. The possible contextual relevance of the primes in regard to the probes was thus not made explicit to the subjects of that group. We predict that the explicit instructions should be particularly efficient in triggering top-matching of primes and probes and may, therefore, engender stronger priming effects.

Temporal separation of primes and probes

The time interval separating the end of the presentation of a prime and the onset of a probe (prime-probe interval) has been identified as a critical variable in priming studies. Some studies have shown that there seems to be an optimal temporal window in which optimal priming effects occur. Our choice of a duration of about 770 ms as prime-probe interval is based on findings from two of such studies. One is concerned with attentional processes in a visual discrimination task (Tanaka & Sagi, 2000), the other with gender discrimination (Versace & Allain, 2001). The results

from both studies show that prime-probe intervals between 300 and 1000 ms produce optimal priming effects.

Experimental validation

To test these predictions relative to attentional selection by top-down matching of shape and colour signals triggered by primes and probes, we investigated facilitatory/inhibitory priming effects of shape and colour in the identification of abstract visual shapes.

Methods

Subjects

20 observers with normal or corrected-to-normal vision participated in the experiment. All observers were naive as to the purpose of the experiment. 10 of them received the explicit task instructions, 10 received the non-explicit instructions.

Stimuli

The stimuli were generated by a PC equipped with a graphic card (VGA Trident) and consisted of two complex abstract shapes (see Figure 1). One of the shapes was the target that subjects had to identify. The shapes were either empty (outlined) or filled-in, and their colour was either red or green. Red shapes had a luminance of 8.5 cd/m², green shapes a luminance of 25,2 cd/m². Pretesting established that red and green stimuli presented at these luminance levels appeared to have equivalent subjective intensity. The size of a given shape was 1.5 degrees of visual angle. Examples of the stimuli were shown to all observers before the experiment. An example of the shapes they had to discriminate (see Figure 1) was shown to them for as long as they wished.

Procedure

The task of an observer in any given trial was to decide which of the two possible shapes (see again Figure 1) was presented in the second stimulus interval (probe). A response was given by pressing one of two possible keys of the computer keyboard ("1" or "2"). The response time for a given trial and whether a response

corresponded to a correct identification or an incorrect identification were recorded. The experiment was run with two independent groups of observers. One group was made aware, by an explicit message in the instructions, that the shapes presented in the first stimulus interval (prime) could be relevant for identifying the probe. The instructions given to subjects in this condition, the so-called explicit instructions, were to "decide as quickly as possible without making mistakes which shape was presented in the second stimulus interval. Note that the stimulus presented just before could help you make that decision." The other group of subjects received the so-called non-explicit instructions with no message concerning the primes. The instruction given to subjects in this condition was to "decide as quickly as possible without making mistakes which shape was presented in the second stimulus interval."

In trials with prime-probe congruency, primes and probes had either the same colour but different shape (colour congruency), the same shape but different colour (shape congruency), or the same colour and shape (shape-and-colour congruency). In non-congruent trials, primes and probes differed in shape and colour. In some of the trials, henceforth referred to as neutral trials, no prime was presented, and a plain background preceded the probe instead. Congruent, non-congruent, and neutral trials were presented in a random order. In trials other than neutral trials, either of the two abstract shapes shown in Figure 1 was randomly presented as either the prime, or the probe. A trial block consisted of 96 trials for each of the five prime-probe congruency conditions. Filled and outlined shapes were presented in separate trial blocks. The order of presentation of the different trial blocks was counterbalanced for each observer and between observers. Each observer was given 480 trials in a block, and the rest period between blocks was approximately 15 minutes. Each observer completed four trial blocks on the same day, with two blocks of trials with filled shapes and two with outlined shapes.

Subjects were seated in a semi-dark room at a viewing distance of 3 metres from the computer screen. A prime was flashed on the computer screen for 67 milliseconds (ms), succeeded by a probe of exactly the same duration. Each prime/neutral event and each probe was announced by a brief sound of 100 ms, presented 170 ms before. The duration of the interval between the end of a prime or neutral event and the sound announcing a probe was 500 milliseconds. Subjects had to identify the shape of the probe as quickly as possible without making mistakes. The

next sound, announcing the next prime or neutral event, appeared 1200 ms after a response had been given.

Results

Analysis of the number of correct responses and response times in the different experimental conditions revealed no systematic differences in number of correct responses between conditions. The performance of subjects varied between 92% and 100% correct identifications in any of the experimental conditions. Noticeable systematic differences in response times between conditions were found, and ANOVA was performed on mean response times calculated per observer and per experimental condition. Response times for incorrect identifications were not taken into account for the computation of means.

ANOVA for a between-groups design that takes into account all five levels of the factor prime-probe congruency, was performed. This analysis consisted of a 2 x 2 x 5 ANOVA on response times with group (explicit instructions, implicit instructions) as between-subjects factor, and shape structure (filled, outlined) and prime-probe congruency (shape only, shape and colour, colour only, neutral, non-congruent) as within-subjects factors. A significant effect of the type of instructions communicated to observers ($F(1,18) = 6.3, p < .05$) was found. This effect is described by the observation that response times for the group who received non-explicit instructions are fairly levelled, between 400 and 450 ms, with little variability across the five conditions of prime-probe congruency, whereas noticeable variations as a function of prime-probe congruency are found for the group who received explicit instructions (see Figure 2 a). The overall effect of the five levels of prime-probe congruency was statistically significant ($F(4,72) = 3.43, p < .05$). Figure 2 a shows, for example, that the group who received the explicit instructions identified probes with the same colour and the same shape as the prime considerably faster than probes that were not preceded by any prime (neutral trials), or probes that were preceded by a non-congruent prime. Conversely, probes with only the same colour as the prime were identified noticeably slower than probes that were not preceded by any prime, and somewhat slower than probes preceded by a non-congruent prime. The effect of shape structure, which describes the observation that response times for

filled shapes were systematically shorter than response times for outlined shapes (see Figure 2 a), was statistically significant ($F(1,18) = 37.2, p < .001$). Significant interactions were found between the type of instructions communicated to observers and prime-probe congruency ($F(4,72) = 11.87, p < .001$), between the type of instructions and shape structure ($F(1,18) = 4.293, p < .05$), and between prime-probe congruency and shape structure ($F(4,72) = 3.23, p < .01$). The triple interaction between type of instructions, prime-probe congruency, and shape structure was, as expected, statistically significant ($F(4,72) = 2.76, p < .05$).

Discussion

The results of our study show that priming with abstract visual shapes requires subjects to be made aware, by an explicit message in the instructions, of the potential relevance of prime shapes for the identification of probe shapes. This observation lends further support to the idea that task specific demands "dictate" the attentional process that triggers the memory processes involved in priming (e.g. Murray & Jones, 2002). The effects of the explicit instructions on the processing of visual primes and probes reveal how task demands can determine the contextual relevance of a prime in a given situation. They also reveal that physical attributes of a visual prime, whether seemingly relevant or not to the task under study, carry potential contextual weight, which is consistent with the conclusions from Goolsby et al.'s (2001) and Holbrook et al.'s (2003) studies. The impact a certain combination of stimulus attributes will have on a given performance or task depends on instructions given, and on the kind of visual signals that are triggered.

The ways in which primes and probes were processed by the observers of the group who received the explicit instructions reveal that attentional binding (e.g. Treisman, 1993, 1998) of the attributes shape and colour occurred during the task, despite the fact that subjects were required to identify shape only. Although it might be thought that shape was the only relevant stimulus attribute in the task presented here, we find significant interactions between shape and colour in the group of observers who received the explicit instructions. These interactions reveal that probes with the same shape and colour as the prime are processed considerably faster than probes with only the same shape and, more importantly, that colour and shape do not

produce merely additive effects on response latencies. In addition, probes with the same colour as a prime but different shape produced noticeably longer response latencies than probes that were not preceded by any prime. They produced slightly longer latencies than probes that were preceded by a non-congruent prime. While these findings may reveal attentional binding of shape and colour (see introduction), the question as to how they can be interpreted in terms of a mechanism of attentional selection yet remains to be answered.

Grossberg's theory (e.g. Grossberg, 1999) takes into account contextual dynamics of attention and suggests an explanation of how a selection process sensitive to the context of stimuli operates in visual priming and related phenomena. His concept of top-down matching describes a mechanism where top-down expectations activated by a specific context, or prime, are compared or matched to current bottom-up input. Top-down matching was conceived originally as a basic learning mechanism within a neural network model, and is now successfully applied to explain phenomena such as category matching in recognition processes, or the control of attentional processes by volition. This theoretical framework of visual attention and learning proposes that positive matches between top-down expectation signals and bottom-up stimulus signals produce facilitation, whereas negative matches between expectation signals and bottom-up events produce suppression. In the brain, facilitation would generate the progressive reinforcement of specific neural connections via repeated top-down matching; suppression would generate inhibition of connections. The logical behavioural consequence of neural facilitation or suppression would be a faster or a slower reaction to a target stimulus, or probe. Top-down matching provides a plausible model to explain how expectation signals triggered by a congruent or a non-congruent prime generate facilitating or inhibiting matching signals that speed up or slow down a response to a probe. The effects we report in this study can be explained in terms of such a top-down matching mechanism.

On the one hand, we show that primes with both the same colour and the same shape as the probe produce considerably stronger facilitation than primes with only the same shape as the probe. This suggests that a single congruent attribute of a visual prime has less priming power compared with combinations of several congruent attributes. An explanation in terms of a top-down matching mechanism would

suggest that several congruent attributes of a prime generate a comparatively stronger expectation signal and therefore produce stronger response facilitation when a probe is presented, whereas a single congruent attribute of a prime would generate a comparatively weaker expectation signal and therefore produce less facilitation. This is consistent with the idea that visual mechanisms devoted to the independent analysis of a single physical stimulus dimension feed into a global storage system, or perceptual representation system which, when activated by a stimulus that provides sufficient relevant structural information, produces a perceptual priming effect (e.g. Magnussen & Greenlee, 1999; Tulving & Schacter, 1990; Srinivas, 1993).

On the other hand, we show that primes with the same colour as the probe but not the same shape are found to slow down shape identification compared to neutral trials where no primes are presented at all. This suppressive effect of "colour-congruent-only" primes is noticeably stronger than the suppressive effect of primes that are completely non-congruent with respect to the probe. In fact, in the case of "colour-congruency-only", the expectation signal triggered by the colour of the prime is matched when the probe is switched on, whereas the expectation signal triggered by the shape of the prime is not. "Colour-congruent-only" primes therefore generate a conflict between matching signals, one positive, the other negative. In the case of complete non-congruency of prime and probe, neither the expectation signal triggered by the colour of the prime, nor that triggered by the shape of the prime is matched when the probe is switched on. This readily explains why "colour-congruency-only" has a more detrimental effect on the speed of the discrimination process compared with complete non-congruency, which does not generate a conflict between matching signals, but only produces non-ambiguous, negative matching signals.

Finally, in the group with sufficiently explicit instructions, congruent primes with filled shapes had a tendency to produce slightly stronger effects (see Figure 2 a) than primes with outlined shapes. This effect can be explained by the relative figural saliency of the stimuli. Filled visual primes produce more salient figure-ground percepts, possibly because the colour of the filled primes covers a larger area of the visual field than the colour of outlined primes. As a consequence, filled primes are likely to activate a larger proportion of visual neurones. The facilitation they engender on the discrimination of subsequently presented probes could thus be due, at least partly, to spatio-temporal probability summation over neural « channels » activated by

attentional selection (e.g. Tolhurst, 1975). In luminance discrimination tasks, relatively brief stimuli with coloured surfaces have been found to attract visual attention more efficiently than brief stimuli with achromatic surfaces, for example (e.g. Dresch & Grossberg, 1999). As a consequence, it is plausible to assume that filled chromatic primes may benefit more efficiently from attentional selection and thereby trigger stronger top-down expectation signals compared with outlined chromatic primes. When such a stronger expectation signal is positively matched with a bottom-up target signal, it would then generate a matching signal resulting in comparatively stronger response facilitation.

Conclusions

Whether the shape or colour of a prime produces a contextual effect on the identification of the shape of a probe in visual repetition priming depends on the instructions given to observers. These have to be explicit enough for observers to expect a possible relationship between prime and probe, but do not need to constrain observers to use a specific cue. Prime-probe relationships are likely to be processed by a top-down matching mechanism which generates facilitating or inhibiting matching signals when a probe is switched on, and thereby determines the speed of the discrimination process that triggers a response to the probe. This top-down matching mechanism is sensitive to variations in the context in which the stimuli are presented. Such a sensitivity is revealed by our findings, which can be explained by mechanisms of attentional selection such as those proposed in Grossberg's theory of attention and visual learning (e.g. Grossberg, 1999).

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Figure Captions

Figure 1

The stimuli used in the experiment consisted of green and red abstract shapes. Outlined shapes and filled shapes were presented in separate trial blocks. Within a given block, any shape could be either the prime, or the probe that was presented shortly after the prime. Subjects had to decide which shape was presented in the probe interval by pressing key "1" or "2" on the computerkeyboard.

Figure 2 a

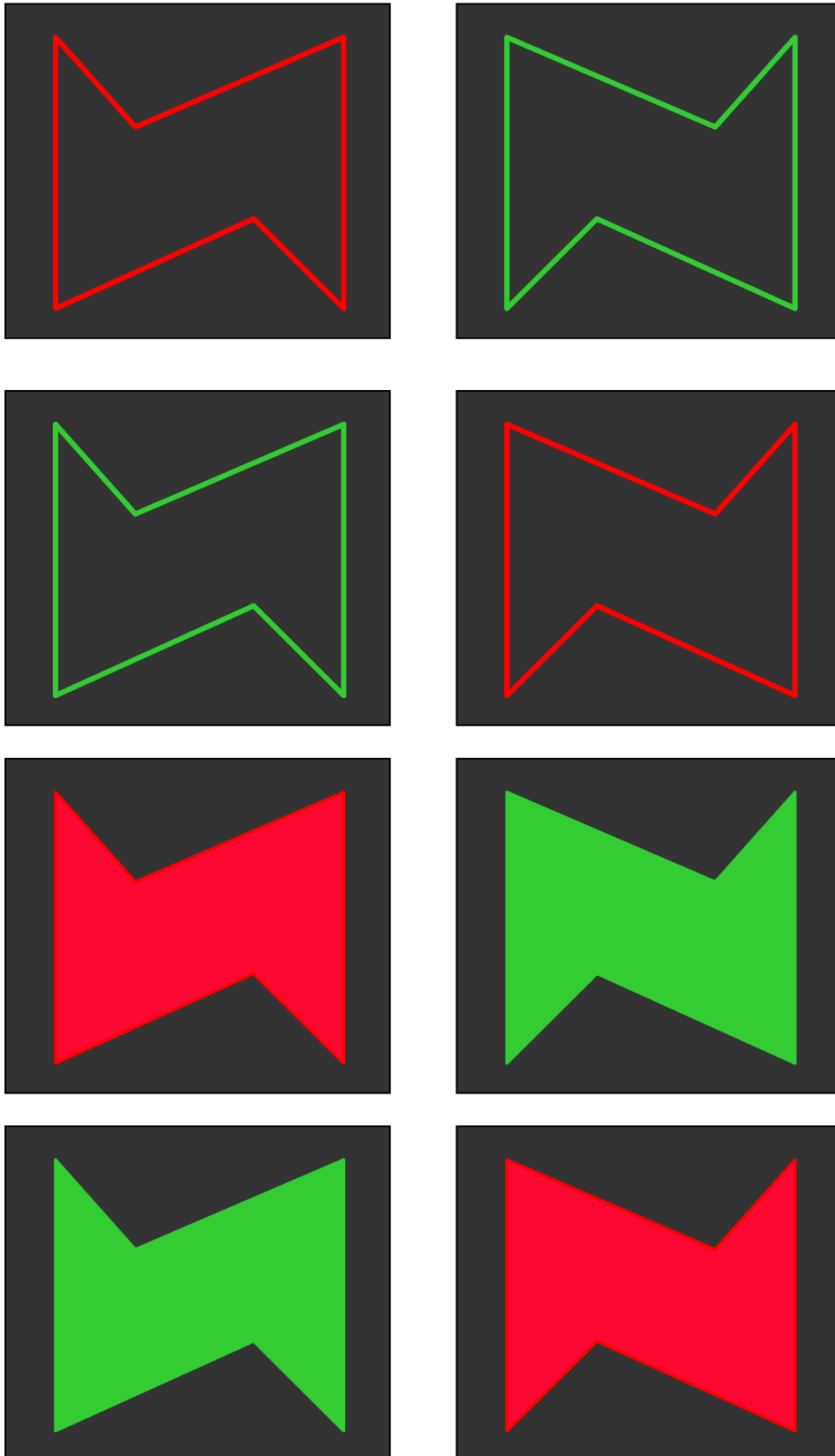
Mean response times as a function of prime-probe congruency obtained with the two groups of observers. One group did not receive any information regarding a possible relevance of the prime for the identification of the probe (non-explicit instructions) the other group was told explicitly that the primes could be relevant to the identification of the probes.

Figure 2 b

Mean response times as a function of prime-probe congruency obtained with the group of observers who received the explicit instructions.

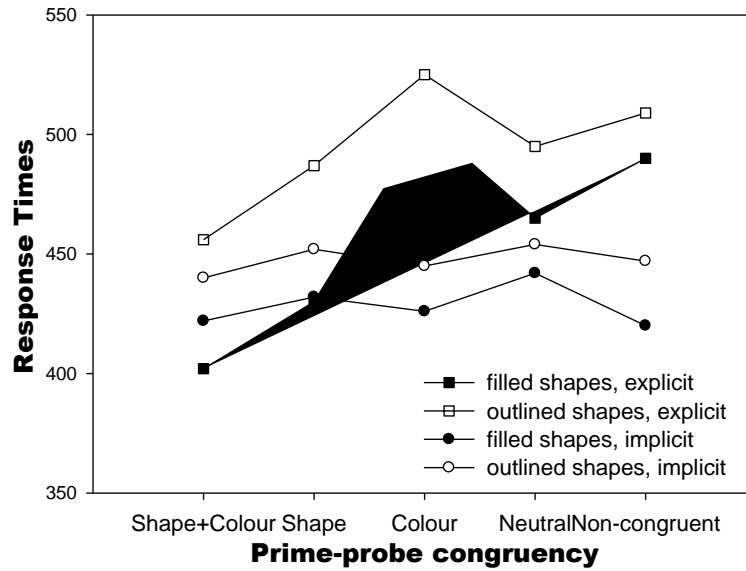
Figure 2 c

Mean response times as a function of prime-probe congruency obtained with the group of observers who received the explicit instructions.

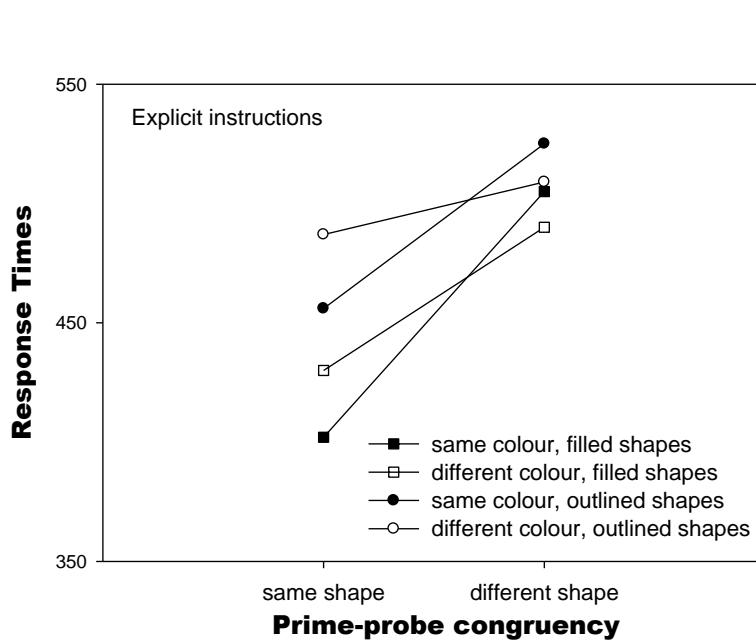


SHAPE "1"

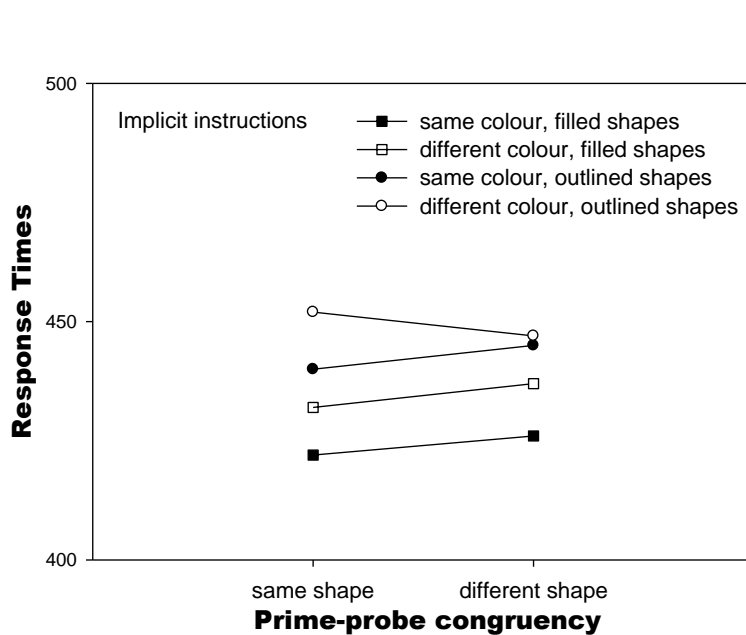
SHAPE "2"



2 a)



2 b)



2 c)