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Global/local processing and negative priming: the influence of selection difficulty and stimulus exposure

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Abstract Negative priming is a decrement in performance observed when a previously ignored stimulus is re-presented as a target. The present study examined the relation between selection difficulty and negative priming in five experiments that used hierarchical stimuli (large letters made up by small letters). The results show that negative priming is greater when subjects direct attention to the local level (more difficult selection) than when they direct attention to the global level (less difficult selection). However, that occurs only when exposure of prime and probe is sufficiently long. With shorter presentations, negative priming is still observed but is no longer modulated by selection difficulty. These results suggest that both anticipatory and reactive mechanisms are responsible for the occurrence of negative priming and that instantiation of the reactive mechanism depends on the time available for prime and probe selection.

Introduction

Selective attention theories have proposed that attended and unattended stimuli are processed differently, although the extent and quality of unattended processing is highly debated (Allport, 1989). In selective attention tasks, information that is relevant to the task is presented together with irrelevant information[1]. Because subjects are explicitly asked to ignore irrelevant information – for which no response is required – its processing can only be inferred using indirect measures, such as interference and negative priming.

The Navon task (Navon, 1977; also see Kimchi, 1992) is a paradigm in which asymmetric interference occurs. The stimuli are hierarchical visual patterns that comprise a global and a local level (e.g., large capital letters made up by small capital letters). These stimuli are either consistent, when the local and the global levels share the same identity (e.g., a large H formed by small Hs), or conflicting, when the global and the local levels have different identities (e.g., a large H formed by small Ss). In the Navon task, instructions are manipulated to generate two different attention conditions. In the global attention condition, subjects have to identify the global configuration, regardless of the identity of the local elements, whereas in the local attention condition, subjects have to identify the local elements, regardless of the identity of the global configuration. Two results are typically found. First, responding to the global configuration is faster than responding to the local elements (global advantage). Second, while global information interferes with local information processing, local information has a small or no effect on global information processing (asymmetric interference).

While interference measures the influence of irrelevant information on a simultaneously presented target, negative priming measures the effect of previously presented irrelevant information on the current target. In particular, negative priming is the decrement in performance (i.e., increase in reaction times, RTs, and in error rates) observed when the current target is the same as, or is semantically related to, the previous distracter (Fox,

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[1] Note that there is a difference between the terms "irrelevant" and "unattended". The former stresses the fact that it is not useful to process that information to efficiently perform the task. The term unattended is based on the assumption that subjects do not pay attention to that information.

1995a; May, Kane, & Hasher, 1995; Neill, Valdes, & Terry, 1995). Although different theories have been proposed to account for negative priming, several authors have suggested that it may be associated with attentional selection. In particular, some studies have shown a direct relation between selection difficulty and size of negative priming (Neumann, 1993; Pavese, 1997a,b; Ruthruff & Miller, 1995).

In this study, we examine the relation between interference and negative priming. In particular, we use the Navon paradigm to investigate whether selection difficulty modulates the size of negative priming. The interesting peculiarity of hierarchical stimuli is that one can vary selection difficulty, without changing the stimulus, by manipulating the attentional requirements. Experimental evidence suggests that attention to local elements is more effortful that attention to the global configuration (e.g., Miller, 1981; Stoffer, 1994). If negative priming is modulated by selection difficulty, we should expect a greater negative priming when people are asked to respond to the local level than to the global level.

The second purpose of this study is to investigate the temporal parameters that allow selection difficulty to influence negative priming. Previous data from our laboratory (Pavese, 1997a) suggests that, while negative priming can be found with long and short stimulus exposure, changes in it as a function of selection difficulty are observed only with longer stimulus exposures. That suggests that the presence of negative priming is independent of selection difficulty, but that adjustments may occur if stimuli are physically present for a sufficiently long time.

Interference and negative priming

Interference is affected by variables that manipulate selection difficulty, such as spatial separation (Kahneman & Chajczyk, 1983) or physical discriminability (Duncan & Humphreys, 1989) between relevant and irrelevant dimensions, as well as spatial uncertainty (Fox, 1995b; Paquet & Lortie, 1990; Yantis & Johnston, 1990). Interference usually decreases or even disappears when selection is easier. Therefore, interference can be considered as an index of selection difficulty. Allport (1989) proposed that interference is a measure of "selective cueing", that is, the efficiency of the segregation between relevant and irrelevant information.

Two lines of evidence have suggested that negative priming is also associated with selection efficiency. Some theoretical models proposed that negative priming is a measure of inhibitory processes involved in attentional selection (Houghton & Tipper, 1994; Neill, 1977; Tipper, 1985). This hypothesis has motivated a number of studies investigating individual differences in selective attention and in negative priming. They have strongly supported the hypothesis of a correlation between deficits in selective attention and reduced or absent negative priming in clinical, developmental and aging populations (e.g., Beech, Baylis, Smithson, & Claridge, 1989; Kane, Hasher, Stoltzfus, Zacks, & Connelly, 1994; Tipper, Bourque, Anderson, & Brehaut, 1989). Some other studies found that negative priming can be modulated by manipulating variables that influence selection difficulty such as spatial uncertainty (Neumann, 1993; Ruthruff & Miller, 1995), spatial separation and perceptual discriminability (Pavese, 1997a). For example, Ruthruff and Miller (1995, Experiment 1) found negative priming when target and distracter positions varied from trial to trial (difficult selection), but not when these positions remained fixed (easy selection). Lowe (1979) and Moore (1994) showed that negative priming is observed only when subjects expect response-selection difficulties. These studies further support the hypothesis that negative priming contributes to attentional selection by inhibiting irrelevant information.

The relation between negative priming and interference is quite complex. Several studies failed to find any relation between changes in interference and changes in negative priming (e.g., Driver & Tipper, 1989; Fox, 1995b; Tipper, Weaver, Kirkpatrick & Lewis, 1991; Valdes & Neill, 1993). Driver and Tipper (1989) showed that, when subjects were asked to count red items in the presence of black distracters, the distracters did not produce interference but produced negative priming. That demonstrates that negative priming and interference can be dissociated.

Houghton, Tipper, Weaver, and Shore (1996) manipulated three variables (interval between prime and probe, perceptual salience of the distracter, and number of distracters) and measured changes in negative priming and interference. Results showed that different variables differentially affect negative priming and interference. While making the distracter more salient increased both negative priming and interference (positive correlation), increasing the number of distracters yielded greater interference but reduced negative priming (negative correlation). Finally, eliminating the blank interval between prime and probe produced no change in interference, but abolished negative priming.

It appears that interference is a generic label that defines a particular empirical finding, that is, an increase in RTs and/or error rate due to the presence of irrelevant or unattended information. However, the mechanisms that are responsible for interference can be very different. For example, both increasing the perceptual similarity (Duncan & Humphreys, 1989) and manipulating response congruency between relevant and irrelevant information (Eriksen & Eriksen, 1974) may increase interference. However, changes in interference in the two conditions are mediated by different processes – stimulus selection and response selection (Phaf, Van der Heijden, & Hudson, 1990), and these processes may use distinct mechanisms (Pavese, 1997a). Similarly, both increasing distracter salience and increasing the number of distracters yield greater interference, but the mechanisms that mediate these changes are not equivalent and have opposite effects on negative priming (Houghton et al., 1996).

These considerations suggest that the investigation of the relation between interference and negative priming require a more precise definition of the processes that mediate changes in negative priming and interference and how these processes act. A first step in this direction is the distinction of Neill et al. (1995) between anticipatory and reactive inhibition. The concept of anticipatory inhibition assumes that a constant quantity of inhibition is applied to suppress distracter information before interference is expressed. If the quantity of inhibition is constant, a weakly activated distracter may be completely suppressed, yielding no interference, whereas a strongly activated distracter will still be able to interfere. This hypothesis predicts a result similar to that of Driver and Tipper (1989): a constant amount of negative priming and a varying amount of interference. The concept of reactive inhibition, instead, assumes that inhibition is applied proportionally to the amount of activation (or interfering potential) of the distracter. This hypothesis predicts a direct relation between the two effects: Greater interference should be accompanied by greater negative priming. Results of this kind have been found in studies that manipulated difficulty of selection (e.g., Ruthruff & Miller, 1995).

The proposal of Neill et al. (1995) distinguishes between different ways in which inhibition may be applied to distracter information. The definition of inhibition in terms of anticipatory and reactive mechanisms allows one to observe different relations between interference and negative priming, although it does not distinguish between different types of processes that may mediate interference. Moreover, Neill et al.'s proposal does not specify why evidence sometimes suggests an anticipatory mechanism (e.g., Driver & Tipper, 1989) and sometimes a reactive mechanism (e.g., Ruthruff & Miller, 1995).

A possibility is that other factors, besides selection difficulty, influence relations between negative priming and interference. For example, Pavese (1997a) found that increasing perceptual similarity between relevant and irrelevant dimensions increased both negative priming and interference when the stimulus was presented until response execution. However, when the stimulus was briefly presented, the same manipulation yielded no change in negative priming. That suggests that negative priming is influenced by selection difficulty only when the stimulus is presented long enough. We propose that the mechanism responsible for negative priming may be anticipatory or reactive, depending on the temporal characteristics of the stimulus. Also, we propose that if stimuli are presented for long durations, negative priming may be modulated as a function of selection difficulty (reactive mechanism). If stimuli are only briefly presented, however, the same amount of inhibition is applied, regardless of the interfering potential of the unattended dimension (anticipatory mechanism).

In this study, we examine the effect of duration of both prime and probe stimuli, because it was shown that probe characteristics can also affect negative priming (Lowe, 1979; Moore, 1994; Tipper & Cranston, 1985). Tipper and Cranston (1985), for example, demonstrated that negative priming depends on proprieties of the probe task. When a no-selection probe (i.e., a single letter) followed a selection prime (i.e., two overlapping letters of different color), positive priming rather than negative priming was observed.

Models of negative priming

The first models of negative priming postulated an inhibitory mechanism associated with the internal representation of the to-be-ignored object(s) (the distracter inhibition model; Neill, 1977; Tipper, 1985; see Houghton & Tipper, 1994, for a computational model). When the distracter in one trial becomes the target on the next trial, the inhibition that is still associated with its representation slows down the response to the following target. In this view, negative priming has often been interpreted as reflecting the persistence of inhibition used to aid the selection of relevant prime information.

An alternative version of the inhibitory account (May et al., 1995) proposes that negative priming is caused by inhibition persisting from the prime trial to the probe trial, but the inhibitory mechanism acts only after selection is completed. Inhibition is a flexible, post-selection process operating to prevent recently rejected information from quickly regaining access to effectors.

Neill and colleagues (Neill & Valdes, 1992; Neill, Valdes, Terry, & Gorfein, 1992) have proposed a non-inhibitory account of negative priming, the episodic retrieval theory. Negative priming would be caused by the episodic retrieval of information from the prime trial that conflicts with the current response. A current target stimulus causes retrieval of an instance in which the same stimulus was ignored, and this memory may interfere with selecting an appropriate response. The underlying assumption is that negative priming is specifically caused by probe processing and not necessarily by persisting prime inhibition[2]. Negative priming indexes a mismatch between previous and subsequent information.

The temporal discrimination model (Milliken & Jordens, 1996; Milliken, Joordens, Merikle, & Seiffert, 1998) combines elements of inhibition and episodic retrieval models. According to this, negative priming is associated with a process of attentional modulation of retrieval processes. When a stimulus is presented, a new/old categorization is performed that determines how the

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[2] The strongest evidence for the episodic retrieval account of negative priming comes from decay effects (i.e., negative priming depends on the delay prior to a prime stimulus; Neill et al., 1992) and long-term negative priming from novel shapes (DeSchepper & Treisman, 1996; but see Strayer & Grison, 1999, for a failure to replicate).

stimulus will be further processed. If the stimulus is categorized as old, subjects rely on automatic processing based on previous experience. If the stimulus is categorized as new, the orienting system is activated and subjects engage in a more detailed perceptual analysis and respond on the basis of new learning. The negative priming condition is a unique condition of temporal discrimination ambiguity, because the current target has already been presented in the previous trial, but as irrelevant information. That makes it more difficult to categorize the current stimulus as new or old, and delays the decision process.

All these theories can account for the increase in negative priming when selection is more difficult. The distracter inhibition model proposes that, when attentional selection is more difficult, greater inhibition is needed for an efficient selection and, in turn, greater inhibition results in greater negative priming. The episodic retrieval model explains this effect in terms of depth of processing of the distracter information. When selection is easy, the distracter stimulus is filtered out more rapidly and completely, and thus is processed to a lesser extent. When selection is difficult, the distracter stimulus is processed more extensively before being filtered out. The quality of distracter information that is encoded in the episodic trace depends, therefore, on ease of selection. In turn, quality of distracter information determines the strength of the memory trace retrieval. The temporal discrimination model explains the effect of difficulty of selection on negative priming by assuming that the ease of old/new classification of the current stimulus in the negative priming condition depends on the extent that distracter information was processed. Therefore, the classification of a stimulus as old in this condition is easier when selection is difficult than when it is easy.

Although different theories may be able to explain the relation between negative priming and difficulty of selection, only inhibitory theories propose a functional relation between attentional selection and negative priming. As a consequence, adjustments of negative priming as a function of selection difficulty may be more difficult to account for by theories that propose that the crucial factor is the extent of distracter information processing.

Hierarchical stimuli and difficulty of selection

Navon (1977) proposed that the global dominance found with hierarchical stimuli was a perceptual phenomenon. In this view, perception proceeds from the global form to the local details and this "global precedence" in perception accounts for the global advantage (responding to the global level is faster than responding to the local level) and asymmetric interference (global information interferes with local information processing but not vice versa). The idea is that local information does not interfere with global information because is analyzed later. However, Miller (1981) found that in a global/local visual search task, cumulative distributions of response latencies violated the prediction of a horse-race model based on the principle of perceptual global precedence. He proposed that global dominance was rather due to a bias in attentional processes. In this view, information about both levels is available at the same time, but it is easier to attend to information from the global than from the local level. Miller also suggested that the asymmetry between local and global information might result from difficulty in suppressing information from the level that has more power to evoke a response.

Evidence that global advantage and asymmetric interference are not only perceptual in nature comes from studies showing that non-perceptual manipulations influence these effects. The importance of attentional and strategic factors was supported by Kinchla, Solis-Macias, and Hoffman (1983). They used a search task and manipulated the probability that the target letter would appear at the local or at the global level. Target detection latencies at a given level were influenced by the probability manipulation: A local advantage was found when the target was more likely to appear at the local level. Similar results were found when the target had the same probability to appear at either level, but instructions emphasized the importance of the local or the global level. Similar experiments carried out on left and right lesioned patients (Lamb, Robertson, & Knight, 1990; Robertson, Lamb, & Knight, 1988) indicated that patients with parietal lesions do not show differences in RTs associated to target probability. That is consistent with a deficit in strategically allocating attention to a particular level. Patients with temporal lesions, instead, showed alterations of global advantage, but a normal pattern of RTs as a function of target probability.

These results suggest that global precedence is not merely a perceptual phenomenon, but that attentional factors play a central role in determining a bias toward the global configuration (Miller, 1981; Robertson, Egly, Lamb, & Kerth, 1993; Stoffer, 1994; Ward, 1982). One study clearly showed that the global advantage is produced by the time needed to refocus visual attention intentionally from the global level, which is focused at first unintentionally, to the local level (Stoffer, 1994). The attentional account of global dominance has been elaborated by suggesting that processing of hierarchical stimuli involves at least two different attentional mechanisms, one based on spatial frequency analysis and the other based on spatial attention distribution. Attention can be selectively directed to low or high spatial frequencies (i.e., Lamb & Robertson, 1988). Low frequency channels mediate global processing, whereas high frequency channels mediate local information. Attention can be distributed across the visual field in a diffuse or in a focal mode (Paquet & Merikle, 1988). In the processing of hierarchical stimuli the diffuse attentional mode is easier than the focal attentional mode because there are no cues to locate the local features.

Findings from neuroscience studies (see Robertson & Lamb, 1991) suggest the existence of modular systems responsible for the processing of global and local features. At least four separate subsystems would be involved: Two emphasize the global and local features, one controls the distribution of attentional resources to these subsystems, and one interconnects global and local proprieties (Lamb et al., 1990). The existence of the first two separate subsystems is supported by an ERP study (Heinze & Muente, 1993). Early posterior negative components (denoted as N250) to global and local targets exhibited a different time course and different topographical distribution. Furthermore, neuropsychological data showed a left hemisphere preference for local processing and a right hemisphere preference for global processing (Doyon & Miller, 1991; Lamb et al., 1990; Martin, 1979a; Robertson et al., 1988).

The mechanisms underlying interference between levels of hierarchical stimuli are not yet well understood. Both normal and neuropsychological evidence showed that global advantage and asymmetric interference did not always covary, suggesting that these effects may reflect the operation of separate mechanisms (Lamb & Robertson, 1988, 1989; Lamb, Robertson, & Knight, 1989; Lamb & Yund, 1996; Navon & Norman, 1983). In addition, interference has been observed from global distracters when subjects responded to local targets, but not the reverse, even when there was a large local advantage in RTs (Lamb & Robertson, 1989). Thus, it does not seem that interference depends in any crucial way on specific timing relations between local and global information.

In conclusion, it seems that directing attention to the local level requires a higher degree of selectivity than directing attention to the global level. From this, the prediction originates that negative priming should be greater when the local level is task relevant.

The present study

This study was designed to explore the role of attention condition (global or local) on negative priming and Navon interference, and to examine the effect of stimulus exposure time on the relation between interference and negative priming.

Five experiments were carried out to assess whether distracters that produce asymmetric Navon interference produce asymmetric negative priming. We used a negative priming paradigm in which relevant and irrelevant dimensions corresponded to the local and global levels of hierarchical stimuli.

Navon stimuli have three important features: (a) global and local levels are independent, so that the identity of one level cannot be predicted by the identity of the other level; (b) visual complexity and familiarity are equal for global and local stimuli (i.e., both are letters); (c) the different selection conditions depend on the attention instructions (i.e., whether subjects are asked to attend to the local or to the global level) and not on changes in the physical appearance of the stimuli (as was the case in the study of Driver & Tipper, 1989); (d) asymmetric interference can be observed in the same experiment and using the same alphanumeric recognition task. To our knowledge, there is only one study that used hierarchical stimuli in a negative priming paradigm (Briand, 1994)[3].

In the five experiments, the durations of prime and probe stimuli were manipulated to examine the effect of exposure time on negative priming, interference, and their relation. Our hypothesis was that the mechanism responsible for negative priming could be anticipatory or reactive depending on how long the prime and/or the probe stimuli were physically available.

In Experiment 1, the exposure time was 100 ms for both stimuli, and we expected to find asymmetric interference and asymmetric negative priming. In particular, we expected a greater interference and a greater negative priming in the condition in which selection was more difficult, namely, the local attention condition. These expectations are based on the literature on hierarchical processing and on previous studies (see above), suggesting a relation between selection difficulty and negative priming. In Experiment 2, we reduced the exposure time of both prime and probe stimuli to 16 ms. Our prediction was that we would find asymmetric interference and negative priming, but negative priming would not be modulated by difficulty of selection and, therefore, would be similar in the two attention conditions. As previously mentioned, some data from our laboratory suggest that stimulus duration may be a crucial variable in the relation between negative priming and interference. In Experiments 3 and 4, we tested the hypothesis that the crucial temporal manipulations were exposure times of prime or probe stimuli. In Experiment 3 the prime stimulus was presented for 16 ms and the probe stimulus for 100 ms. In Experiment 4 the prime stimulus was presented for 100 ms and the probe stimulus for 16 ms. If negative priming varies as a function of selection difficulty only when the prime stimulus is physically present for enough time, an asymmetric negative priming should be found only in Experiment 4. If probe duration is the crucial variable, an asymmetric negative priming should be found only in Experiment 3. Finally, in Experiment 5, we tested the hypothesis that the crucial temporal manipulation was the exposure time of both prime and probe stimuli. In this experiment the prime stimulus was presented for 100 ms and the probe stimulus for 250 ms. If negative priming varies as a function of selection difficulty only when the prime and probe stimulus are physically present for enough time, only Experiments 1 and 5 should

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[3] This study examined the level-specific filtering effect: When subjects are asked to report either the global or the local level in a stimulus located inside a relevant object, distracters located within an irrelevant object will interfere only if they are at the same level of structure as that of the target item (Paquet & Merikle, 1988). The issue of level-specific filtering is not directly related with our study.

produce an asymmetric negative priming. We decided to use a longer exposure time for the probe (250 vs 100 ms) to generalize the findings of Experiment 1 with a different temporal parameter.

Furthermore, contrasting the results of the five experiments, it becomes possible to test the effect of prime and probe temporal similarity on the retrieval of irrelevant information. The episodic retrieval theory predicts a prime-probe similarity effect (Fox & De Fockert, 1998; Neill, 1997). It is generally accepted that episodic retrieval is influenced by the similarity of context between encoding and retrieval episodes (Tulving, 1983). The prime-probe similarity hypothesis suggests that greater similarity between prime and probe improves effective retrieval, leading to greater negative priming. Neill (1997) found that negative priming occurred only when the distracter onset matched across prime and probe stimuli. Fox and De Fockert (1998) showed that negative priming was maximal when prime and probe stimuli shared the same intensity contrast. Therefore, greater negative priming should be expected in Experiments 1 and 2, where prime and probe have the same exposure times, rather than in Experiments 3 to 5, where different exposure times were used for prime and probe. Furthermore, if temporal similarity plays any role in negative priming modulation by selection difficulty, we expected an asymmetric negative priming in Experiments 1 and 2, and a symmetric negative priming in Experiments 3 to 5.

General method

Apparatus, material, design and procedure were the same for all five experiments. The only difference was in the exposure times. They were: 100 ms for both prime and probe in Experiment 1; 16 ms for both prime and probe in Experiment 2; 16 ms for the prime and 100 ms for the probe in Experiment 3; 100 ms for the prime and 16 ms for the probe in Experiment 4; 100 ms for the prime and 250 ms for the probe in Experiment 5.

Subjects

The subjects of all five experiments were undergraduate students at the University of Padova. All were right-handed, uninformed as to the specific purpose of the experiment, and had normal or corrected to normal visual acuity. Each subject participated in one experiment only. Twenty-four subjects (12 women and 12 men; age range 20–26 years) participated in Experiment 1; 24 (9 women and 15 men; age range 21–33 years) participated in Experiment 2; 24 (12 women and 12 men; age range 24–33 years) participated in Experiment 3; 24 (12 women and 12 men; age range 22–29 years) participated in Experiment 4; and 18 (9 women and 9 men; age range 20–26 years) participated in Experiment 5.

Apparatus and materials

The experiments took place in a sound-attenuated room. Each subject sat in front of a CRT screen with a fast-decay phosphor (P22), driven by an IBM personal computer. The experiments were implemented using the Micro Experimental Laboratory (MEL) software (Schneider, 1988). The subject's head was positioned in an adjustable head-and-chin rest, so that the distance between the eyes and the screen was approximately 1 m.

The stimuli were large capital letters (E, F, H, S) made up by little capital letters (E, F, H, S) and were white on a black background. When projected on the screen, the large letters were 2.8 ° wide × 3.7° high, whereas the little letters were 0.2° × 0.4°. The global and local features were built on a 5 × 7 matrix [as suggested by Navon (1981) Martin (1979b) had showed that matrixes with lower number of elements favor faster processing of the local level]. The number of local elements for each global letter was 19 for the E, 14 for the F, 17 for the H, and 19 for the S.

The prime stimuli appeared 0.4° left and the probe stimuli appeared 0.4° right from the center of the screen (horizontal distance). The visual angle between the leftmost extreme of the left stimuli and the rightmost extreme of the right stimuli was 5.2°.

Design

Each trial consisted of a sequence of two stimuli, a prime stimulus and a probe stimulus. Interference was measured on prime stimuli. Attended and unattended levels in the prime stimulus could be consistent, when the unattended level was the same as the attended level (e.g., a large H formed by smaller Hs), or conflicting, when the unattended level was different from the attended level (e.g., a large H formed by smaller Ss). Comparison of RTs and error rate in these two types of prime stimuli provided a measure of interference.

Negative priming was measured on probe stimuli, which were always conflicting. The relation between prime and probe stimuli in the same trial defined three conditions: (i) consistent-different, when a consistent prime stimulus was followed by a probe stimulus in which local and global letters were different from the prime letter; (ii) conflicting-different, when a conflicting prime stimulus was followed by a probe stimulus in which local and global letters were different from the prime letters; and (iii) conflicting-same, when a conflicting prime stimulus was followed by a probe stimulus in which the letter(s) at the attended level was/were the same as the letter(s) at the unattended level of the prime stimulus. Only the latter two conditions of probe stimulus were analyzed, and provided a measure of negative priming.

Procedure

Each subject participated in two attention conditions. In the global attention condition, subjects had to decide if the large letter was an E, an F, an H or an S, disregarding the smaller letters. In the local attention condition, they had to decide if the smaller letters were Es, Fs, Hs or Ss, disregarding the large letter. The task required pressing the corresponding keys on a computer keyboard. The stimulus-response key mapping was randomly assigned for each subject. Subjects used the index and middle fingers of each hand to make their responses.

In all experiments, except Experiment 5, the two attention conditions were counterbalanced. Half of the subjects started with the global directed condition, and the other half with the local directed condition. These conditions were carried out on 2 consecutive days. In Experiment 5 all the subjects started with the global attention condition and performed the local attention condition the day after[4].

Before the experimental session, the subjects underwent a training session to learn the association between the 4 keys and the 4 possible responses, followed by a block of 36 stimuli to practice the experimental conditions. The instructions stressed both speed and accuracy. A warning tone was given when an error (1,000 Hz for 200 ms) or an omission (70 Hz for 200 ms) was made. An omission was scored when the subject did not respond or when his or her response latency was longer than 2 s. Error trials were subsequently presented again. RTs were recorded to the nearest millisecond through an electronic counter that was started simul-

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[4] Preliminary analyses conducted for the first four experiments showed that the order of attention conditions (global-to-local or local-to-global) did not affect the pattern of results.

taneously with the onset of the stimulus and was stopped by pressing any of the 4 keys.

For each attention condition (global and local), subjects were presented with three blocks of trials, each of which comprised 36 pairs of stimuli (12 pairs of primes and probes for each of the three conditions, consistent-different, conflicting-different and conflicting-same). Therefore, in total subjects were administered 432 stimuli (216 pairs). The pairs of stimuli were randomly presented.

The sequence of experimental events was as follows: a 100-ms warning tone (4,000 Hz), a blank for 1,000 ms, a prime with different durations (100 ms in Experiments 1, 4 and 5; 16 ms in Experiments 2 and 3), a response-stimulus interval (RSI) of 400 ms, a probe with different durations (100 ms in Experiments 1 and 3; 16 ms in Experiments 2 and 4, 250 ms in Experiment 5), and a blank for 3,500 ms.

Analyses

The analyses were conducted in the same way for all the experiments and the significance level chosen was 0.05. Mean RTs, mean error rates and standard deviations (SDs), as a function of Attention condition, Consistency, and Relatedness, are separately reported for each experiment in Tables 1 to 5.

ANOVAs were carried out on mean correct RTs and on arcsine transformations of error proportions for prime stimuli, with Attention condition (global or local), and Stimulus consistency (consistent or conflicting) as within-subjects factors. RTs and errors from the interference-different and interference-same conditions were pooled, because these conditions were not differentiated until the occurrence of the probe stimulus.

ANOVAs were carried out on the mean correct RTs and on arcsine transformations of error proportions for probe stimuli, with Attention condition (global or local) and Relatedness (same or different condition) as within-subjects factors. Only two of the three experimental conditions were of interest in the probe analysis and were therefore analyzed: conflicting-different and conflicting-same.

Results

Experiment 1: 100 ms prime and 100 ms probe exposure times

Overall, the errors were 4.0% for prime and 3.5% for probe stimuli (Table 1).

Prime data

No effects were significant in the error analysis. In the RT analysis, the main effect of Attention condition was significant [$F(1, 23) = 20.57$, MSe = 4,844.53, $P < 0.0001$]. Subjects were 65 ms faster when they attended to the global rather than to the local level. There was also a significant main effect of Stimulus consistency [$F(1, 23) = 7.23$, MSe = 569.62, $P = 0.013$], indicating 13 ms faster RTs to consistent stimuli than to conflicting stimuli.

The interaction between Attention condition and Stimulus consistency (asymmetric interference) only

Table 1 Experiment 1: Ms and SDs of mean RT (in milliseconds) and percent error rate as a function of Attention condition (Global vs Local), and Consistency (Conflicting vs Consistent) in the prime stimulus, and Attention condition (Global vs Local), and Relatedness (Same vs Different) in the probe stimulus (*M* mean, *SD* standard deviation, *RT* reaction time)

Experiment 1								
	Prime: 100 ms							
	Attention condition							
	RT		Error rate					
	M	SD	M	SD				
Global	681	122	3.4	3.2				
Local	746	149	4.6	5.2				
Global advantage	65	27	1.2	2				
	Consistency							
	Global				Local			
	RT		Error rate		RT		Error rate	
	M	SD	M	SD	M	SD	M	SD
Conflicting	684	122	3.3	3.3	756	146	5.3	7.1
Consistent	679	122	3.5	4.4	735	154	3.9	4.8
Interference	5	0	−0.2	−1.1	21	−8	1.4	2.3
	Probe: 100 ms							
	Attention condition							
	RT		Error rate					
	M	SD	M	SD				
Global	622	95	2.3	2				
Local	698	126	4.7	5.7				
Global advantage	76	31	2.4	3.7				
	Relatedness							
	Global				Local			
	RT		Error rate		RT		Error rate	
	M	SD	M	SD	M	SD	M	SD
Same	628	98	2	2.8	715	129	4.6	5.9
Different	614	95	2.5	2.7	682	126	4.7	6
Negative priming	14	3	−0.5	0.1	33	3	−0.1	−0.1

Table 2 Experiment 2: Ms and SDs of mean RT (in milliseconds) and percent error rate as a function of Attention condition (Global vs Local), and Consistency (Conflicting vs Consistent) in the prime stimulus, and Attention condition (Global vs Local), and Relatedness (Same vs Different) in the probe stimulus

Experiment 2								
	Prime: 16 ms							
	Attention condition							
	RT		Error rate					
	M	SD	M	SD				
Global	734	83	2.1	2.1				
Local	807	132	4.6	4.2				
Global advantage	73	49	2.5	2.1				
	Consistency							
	Global				Local			
	RT		Error rate		RT		Error rate	
	M	SD	M	SD	M	SD	M	SD
Conflicting	732	89	2.5	3	819	130	5.3	4.3
Consistent	735	82	1.7	1.8	795	138	3.8	5.5
Interference	−3	7	0.8	1.2	24	−8	1.5	1.2
	Probe: 16 ms							
	Attention condition							
	RT		Error rate					
	M	SD	M	SD				
Global	684	86	2.6	2.7				
Local	751	114	4.1	4.2				
Global advantage	67	28	1.5	1.5				
	Relatedness							
	Global				Local			
	RT		Error rate		RT		Error rate	
	M	SD	M	SD	M	SD	M	SD
Same	697	86	3	3.4	760	125	3.6	4.4
Different	671	89	2.2	3.3	744	109	4.7	5
Negative priming	26	−3	0.8	0.1	16	16	−1.1	−0.6

approached significance [$F(1, 23) = 3.59$, MSe = 439.71, $P = 0.071$], but was in the expected direction, the difference between consistent and conflicting stimuli being much greater in the local attention condition than in the global attention condition (21 vs 5 ms). Two separate ANOVAs carried out on the two attention conditions showed that Stimulus consistency was significant only for the local attention condition [$F(1, 23) = 7.92$, MSe = 681.6, $P = 0.01$]. Furthermore, 67% of the subjects exhibited asymmetric interference.

Probe data

The main effect of Attention condition was significant in RTs [$F(1, 23) = 36.99$, MSe = 3,804.09, $P < 0.0001$] and in errors [$F(1, 23) = 8.21$, MSe = 0.01, $P = 0.009$]. Subjects were faster (76 ms) and more accurate (2.3% vs 4.7%) when they attended to the global than to the local level. No other effects were significant in the error analysis.

There was also a significant main effect of Relatedness [$F(1, 23) = 17.05$, MSe = 756.56, $P < 0.0001$]. As expected, the same condition was slower than the different condition, revealing a significant negative priming of 23 ms.

The interaction between Attention condition and Relatedness was also significant [$F(1, 23) = 6.20$, MSe = 357.07, $P = 0.02$]. The magnitude of negative priming was significantly greater for the local than for the global attention condition (33 vs 14 ms), although post-hoc *t*-tests showed that negative priming was significant for both the global [$t(23) = -1.99$, $P = 0.029$] and the local attention conditions [$t(23) = -4.83$, $P < 0.0001$]; 79% of the subjects exhibited asymmetric negative priming.

Experiment 2: 16 ms prime and 16 ms probe exposure times

Overall, the errors were 3.3% for both prime and probe stimuli (Table 2).

Prime data

There was a significant main effect of Attention condition on RTs [$F(1, 23) = 16.39$, MSe = 7,922.48, $P < 0.0001$] and errors [$F(1, 23) = 9.50$, MSe = 0.01, $P < 0.005$]. Subjects were faster (73 ms) and more accurate (2.1% vs 4.6%) when they attended to the global than to the local level. The main effect of Stimulus consistency was significant only for the error analysis, [$F(1, 23) = 9.56$, MSe = 0.01, $P < 0.005$], indicating a greater error rate for conflicting than for consistent

Table 3 Experiment 3: Ms and SDs of mean RT (in Milliseconds) and percent error rate as a function of Attention condition (Global vs Local), and Consistency (Conflicting vs Consistent) in the prime stimulus, and Attention condition (Global vs Local), and Relatedness (Same vs Different) in the probe stimulus

Experiment 3								
	Prime: 16 ms							
	Attention condition							
	RT		Error rate					
	M	SD	M	SD				
Global	647	92	4.9	3.5				
Local	706	133	5.4	4.6				
Global advantage	59	41	0.5	1.1				
	Consistency							
	Global				Local			
	RT		Error rate		RT		Error rate	
	M	SD	M	SD	M	SD	M	SD
Conflicting	649	95	5.4	3.7	722	132	6.2	5
Consistent	644	91	4.4	4.4	690	136	4.5	6.1
Interference	5	4	1	0.7	32	−4	1.7	−1.1
	Probe: 100 ms							
	Attention condition							
	RT		Error rate					
	M	SD	M	SD				
Global	604	85	4.5	4				
Local	666	108	3.9	3				
Global advantage	62	23	−0.5	−1				
	Relatedness							
	Global				Local			
	RT		Error rate		RT		Error rate	
	M	SD	M	SD	M	SD	M	SD
Same	611	89	4.5	5.1	674	118	4.1	3.3
Different	598	85	4.4	4.9	657	101	3.7	3.7
Negative priming	13	4	0.1	0.2	17	17	0.4	−0.4

stimuli (3.9% vs 2.7%). No other effects were significant in the error analysis.

In the RT analysis, the interaction between Attention condition and Stimulus consistency was significant [$F(1, 23) = 4.95$, MSe = 871.47, $P = 0.036$]. Interference was significantly greater for the local than for the global attention condition (24 vs 3 ms). Post-hoc t-tests showed that interference was significant only for the local attention condition [$t(23) = -2.84$, $P < 0.005$]; 75% of the subjects exhibited asymmetric interference.

Probe data

The error analysis did not show any significant effects. The RT analysis showed significant main effects of Attention condition [$F(1, 23) = 13.51$, MSe = 8,027.14, $P < 0.001$), and Relatedness [$F(1, 23) = 9.03$, MSe = 1,153.65, $P = 0.006$). RT was 67 ms faster when subjects attended to the global than to the local level. RT for the same condition was slower than RT for the different condition, showing a 21-ms negative priming. The interaction between Attention condition and Relatedness [$F(1, 23) = 0.92$, MSe = 685.7, $P = 0.349$] did not approach significance; 54% of the subjects exhibited asymmetric negative priming.

Experiment 3: 16 ms prime and 100 ms probe exposure times

Overall, the errors were 5.1% for the prime and 4.1% for the probe stimuli (Table 3).

Prime data

There was a significant main effect of Attention condition [$F(1, 23) = 17.6$, MSe = 4,811.29, $P < 0.0001$]. Subjects were 59 ms faster when they attended to the global than to the local level. There was also a significant main effect of Stimulus consistency on RTs [$F(1, 23) = 24.86$, MSe = 327.16, $P < 0.0001$] and errors [$F(1, 23) = 9.76$, MSe = 0.01, $P < 0.005$]. Responses to consistent stimuli were faster (18 ms) and more accurate (4.4% vs 5.8%) than responses to conflicting stimuli. No other effects were significant in the error analysis.

The interaction between Attention condition and Stimulus consistency was significant [$F(1, 23) = 5.32$, MSe = 787.51, $P = 0.030$]. Interference was significantly greater for the local than for the global attention condition (32 vs 5 ms). Post-hoc t-tests showed that interference was significant only for the local attention condition [$t(23) = -4.42$, $P < 0.0001$]; 67% of the subjects exhibited asymmetric interference.

Table 4 Experiment 4: Ms and SDs of mean RT (in milliseconds) and percent error rate as a function of Attention condition (Global vs Local), and Consistency (Conflicting vs Consistent) in the prime stimulus, and Attention condition (Global vs Local), and Relatedness (Same vs Different) in the probe stimulus

Experiment 4								
	Prime: 100 ms							
	Attention condition							
	RT		Error rate					
	M	SD	M	SD				
Global	688	99	3.9	2.3				
Local	745	102	4	3				
Global advantage	57	3	0.1	0.7				
	Consistency							
	Global				Local			
	RT		Error rate		RT		Error rate	
	M	SD	M	SD	M	SD	M	SD
Conflicting	694	99	3.8	2.8	759	103	3.9	2.7
Consistent	681	100	4.1	3	731	105	4.1	4.3
Interference	13	−1	−0.3	−0.2	28	−2	−0.2	−1.6
	Probe: 16 ms							
	Attention condition							
	RT		Error rate					
	M	SD	M	SD				
Global	645	105	3.9	3.6				
Local	695	96	3.8	3.4				
Global advantage	50	−9	−0.1	−0.2				
	Relatedness							
	Global				Local			
	RT		Error rate		RT		Error rate	
	M	SD	M	SD	M	SD	M	SD
Same	651	99	3.4	4.5	702	98	3.9	4.2
Different	640	113	4.4	4.2	688	98	3.7	3.8
Negative priming	11	−14	−1	0.3	14	0	−0.2	0.4

Probe data

The error analysis did not show any significant effects. The analysis on RT showed significant main effects of Attention condition [$F(1, 23) = 16.14$, MSe = 5,571.93, $P < 0.001$], and Relatedness [$F(1, 23) = 5.99$, MSe = 935.38, $P = 0.022$). RT was 62 ms faster when subjects attended to the global than to the local level. RT for the same condition was slower than RT for the different condition, revealing a 15-ms negative priming.

The interaction between Attention condition and Relatedness [$F(1, 23) = 0.15$, MSe = 642.18, $P = 0.701$] did not approach significance; 54% of the subjects exhibited asymmetric negative priming.

Experiment 4: 100 ms prime and 16 ms probe exposure times

Overall, the errors were 3.9% for the prime and 3.8% for the probe stimuli (Table 4).

Prime data

The error analysis did not show any significant effects. In the RT analysis, there was a significant main effect of Attention condition [$F(1, 23) = 19.25$, MSe = 4,083.01, $P < 0.0001$]. Subjects were 57 ms faster when they attended to the global than to the local level. Also, there was a significant main effect of Stimulus consistency [$F(1, 23) = 15.76$, MSe = 646.15, $P < 0.001$]. RTs to consistent stimuli were 20 ms faster than RTs to conflicting stimuli.

The interaction between Attention condition and Stimulus consistency was significant [$F(1, 23) = 4.65$, MSe = 348.08, $P = 0.042$]. Interference was significantly greater for the local than for the global attention condition (28 vs 13 ms). Post-hoc *t*-tests showed that interference was significant only for the local attention condition [$t(23) = -3.72$, $P < 0.001$]; 58% of the subjects exhibited asymmetric interference.

Probe data

The error analysis did not show any significant effects. The analysis on RT showed significant main effects of Attention condition [$F(1, 23) = 13.84$, MSe = 4,325.02, $P < 0.001$], and Relatedness [$F(1, 23) = 4.30$, MSe = 836.10, $P < 0.05$]. RT was 50 ms faster when subjects attended to the global than to the local level. RT for the same condition was slower than RT for

Table 5 Experiment 5: Ms and SDs of mean RT (in milliseconds) and percent error rate as a function of Attention condition (Global vs Local), and Consistency (Conflicting vs Consistent) in the prime stimulus, and Attention condition (Global vs Local), and Relatedness (Same vs Different) in the probe stimulus

Experiment 5								
	Prime: 100 ms							
	Attention condition							
	RT		Error rate					
	M	SD	M	SD				
Global	677	103	5.4	3				
Local	706	119	5.4	5				
Global advantage	29	16	0	2				
	Consistency							
	Global				Local			
	RT		Error rate		RT		Error rate	
	M	SD	M	SD	M	SD	M	SD
Conflicting	680	108	5.8	3.3	723	119	6.3	6.7
Consistent	674	100	4.9	4.5	689	121	4.6	4.3
Interference	6	8	0.9	−1.2	34	−2	1.7	2.4
	Probe: 250 ms							
	Attention condition							
	RT		Error rate					
	M	SD	M	SD				
Global	636	106	4.2	4.2				
Local	662	115	3.4	3.2				
Global advantage	26	9	−0.8	−1				
	Relatedness							
	Global				Local			
	RT		Error rate		RT		Error rate	
	M	SD	M	SD	M	SD	M	SD
Same	634	107	5.4	5.8	675	137	2.8	3.6
Different	638	107	2.9	3.5	649	101	4	4.8
Negative priming	−4	0	2.5	2.3	26	36	−1.2	−1.2

the different condition, revealing a 12-ms negative priming.

The interaction between Attention condition and Relatedness [$F(1, 23) = 0.10$, MSe = 739.97, $P = 0.750$] did not approach significance; 50% of the subjects exhibited asymmetric negative priming.

Experiment 5: 100 ms prime and 250 ms probe exposure times

Overall, the errors were 5.4% for the prime and 3.8% for the probe stimuli (Table 5).

Prime data

The Attention condition main effect was close to significance [$F(1, 17) = 4.32$, MSe = 3,557.90, $P = 0.053$]. Subjects were 29 ms faster when they attended to the global rather than the local level. There was a significant main effect of Stimulus consistency in RTs [$F(1, 17) = 11.13$, MSe = 610.77, $P < 0.003$] and errors [$F(1, 17) = 11.13$, MSe = 0.01, $P < 0.004$]. Responses to consistent stimuli were faster (20 ms) and more accurate (4.7% vs 6%) than responses to conflicting stimuli.

The interaction between Attention condition and Stimulus consistency was significant [$F(1, 17) = 4.92$, MSe = 678.68, $P = 0.04$]. Interference was significantly greater for the local than for the global attention condition (34 vs 6 ms). Post-hoc *t*-tests showed that interference was significant only for the local attention condition [$t(17) = -3.99$, $P < 0.001$]; 61% of the subjects exhibited asymmetric interference.

Probe data

The error analysis did not show any significant effects. The analysis on RT only showed a significant interaction between Attention condition and Relatedness [$F(1, 17) = 4.47$, MSe = 932.97, $P < 0.05$]. When subjects attended to the global level, RT for the same condition was 4 ms faster than RT for the different condition. When subjects attended to the local level, RT for the same condition was 26 ms slower than RT for the different condition. Negative priming was significant only for the local attention condition [$t(17) = +2.11$, $P < 0.05$]; 72% of the subjects exhibited asymmetric negative priming.

Table 6 Experiments 1 to 5: Tau_b Kendall correlation and *P* values for interference and negative priming as a function of Attention condition (Global vs Local)

	N	Global attention condition		Local attention condition	
		Tau_b Kendall	*P*	Tau_b Kendall	*P*
Experiment 1	24	−0.138	0.173	−0.239	0.051
Experiment 2	24	−0.087	0.276	−0.217	0.068
Experiment 3	24	−0.014	0.460	−0.051	0.364
Experiment 4	24	+ 0.036	0.402	−0.326	0.013*
Experiment 5	18	+ 0.85	0.311	−0.007	0.485
Experiments 1–5	114	−0.037	0.282	−0.161	0.005*

* Significant effect

Interference and negative priming across subjects: Experiments 1 to 5

We examined whether distracters that produce asymmetric Navon-like interference (i.e., more interference of global on local than of local on global) produce asymmetric negative priming. This issue can also be addressed correlationally, at the subject level, by examining the correlation between interference and negative priming across subjects. The question is whether subjects with more selection difficulties (as indexed by the amount of interference) show greater negative priming. If one accepts the view that distracters are inhibited during selective attention, then one would expect that negative priming should increase with variables that increase interference (i.e., attention conditions). If subjects differ in their ability to inhibit irrelevant stimuli, then those subjects with weaker inhibition should show increased interference but decreased negative priming. In general, the individual difference studies are consistent with this prediction (an inverse relation), despite some failures to find any relation (e.g., Tipper, 1991). There are no individual difference studies that report a positive correlation. It is possible that some of the inconsistencies found in the literature on the relation between interference and negative priming are attributable to improper generalization from different empirical results.

To tentatively verify this idea, the correlation between interference and negative priming was calculated. For each subject, and separately for each attention condition, the amount of interference (defined as the difference between consistent and conflicting stimuli in the prime stimulus) and the amount of negative priming (defined as the difference between same and different conditions in the probe stimulus) were computed. The reason for examining the correlation across our subjects is the substantial variance in the amount of interference and negative priming (see SDs in Tables 1–5). Whether these students differ in terms of resources, memory, information processing or strategical judgment is unclear. Tau_b Kendall correlations and *P* values as a function of attention condition for Experiments 1–5 are reported in Table 6.

For the global attention condition, the correlation did not reach significance in any experiments. That could be explained by the small (always nonsignificant) interference found in this condition. For the local attention condition, the correlation was always negative. It reached significance in Experiment 4 and in the general analysis with all the experiments. It approached significance in Experiments 1 and 2. These results are in agreement with many individual difference studies. Subjects (children, elderly, patients) with more interference often showed less negative priming (e.g., Beech et al., 1989; Kane et al., 1994; Tipper et al., 1989).

In conclusion, we found a tendency towards a negative relation at the subject level, whereas Experiments 1 and 5 showed a positive relation at the stimulus level (more negative priming for the more difficult selection condition). That suggests that some of the inconsistencies found in the literature on the relation between interference and negative priming may be due to the level of analysis considered.

General discussion

The aim of the present study was to explore the role of attention condition (global or local) and of exposure time in modulating interference and negative priming. Experimental evidence suggests that, in the experimental condition in which global advantage and asymmetric interference occur, selecting the local level is more difficult than selecting the global level. We therefore expected that the level that was more difficult to filter out (i.e., the global configuration) would produce more interference and more negative priming than the level that was easier to filter out (i.e., the local elements). In addition, we were interested in investigating the effect of stimulus exposure time on the pattern of negative priming and interference as a function of attention condition. In particular, we wanted to replicate previous findings suggesting that negative priming can be found at short and long stimulus exposures, but that manipulations of difficulty of selection affect negative priming only at long stimulus exposures. A summary of the results is presented in Table 7.

As expected, in the five experiments we found that responding to the global level was faster than responding to the local level (global advantage) and that interference (the difference between consistent and conflicting stimuli)

Table 7 Experiments 1–5: Summary of the results. Mean RT (in milliseconds) as a function of prime, global advantage, interference, and asymmetric interference in the prime stimulus, and probe, global advantage, negative priming, and asymmetric negative priming in the probe stimulus

Experiments	1	2	3	4	5
	Prime exposure time				
	100	16	16	100	100
Prime	713	770	676	716	691
Global advantage: Global < Local	65*	73*	59*	57*	29
Interference: Consistent < Conflicting	13*	11	18*	20*	20*
Asymmetric interference: Local > Global interference	21 vs 5	24 vs −3*	32 vs 5*	28 vs 13*	34 vs 6*
	Probe exposure time				
	100	16	100	16	250
Probe	660	718	635	670	649
Global advantage: Global < Local	76*	67*	62*	50*	26
Negative priming: Different < Same	23*	21*	15*	12*	11
Asymmetric negative priming: Local > Global negative priming	33 vs 14*	16 vs 26	17 vs 13	14 vs 11	*26 vs −4

* Significant effect

was greater in the local attention condition than in global attention condition (asymmetric interference)[5].

In Experiments 1 and 5 attention condition also modulated the amount of negative priming. The magnitude of negative priming was significantly greater for the local attention condition than for the global attention condition. Therefore, Experiments 1 and 5 replicated the results of other studies that manipulated difficulty of selection (Fox, 1994; Lowe, 1979; Neill, 1977; Neumann, 1993; Pavese, 1997a,b; Ruthruff & Miller, 1995): Negative priming was greater when selection of the relevant stimulus dimension was harder. As previously discussed, there is evidence to support the hypothesis that selecting the global configuration is easier than selecting the local elements: The segregation of the global configuration is faster (Navon, 1977, 1981) or is a dominant way of selection (Ward, 1982). The results of Experiments 1 and 5 show that not only responding to the local elements is slower and is subject to greater interference, but also that it is associated with greater negative priming. However, that does not necessarily support a direct relation between increase in negative priming and increase in interference. It is possible that a greater difficulty of selection is a necessary but not sufficient condition for producing an increase in negative priming.

An alternative explanation of the present results might be found in the absence of interference on probe trials in the global-attention condition. Presence or absence of interference on probe stimuli may be critical to negative priming (Lowe, 1979; Moore, 1994; Tipper & Cranston, 1985). This possible interpretation is ruled out by the fact that in Experiments 2, 3, and 4 symmetrical negative priming was found: Negative priming was equivalent for global and local attention conditions.

The asymmetric negative priming was not replicated in either Experiments 2 and 3, in which prime duration was only 16 ms or, surprisingly, Experiment 4, in which prime duration was 100 ms (as in Experiments 1 and 5). Therefore, it seems that a longer prime duration is not sufficient for modulating negative priming. Moreover, Experiments 2 and 3 have different probe durations (16 ms for Experiment 2 and 100 ms for Experiment 3). Therefore, it seems plausible to conclude that an increase in probe duration is not sufficient for modulating negative priming by attention. Experiments 2 to 4 showed asymmetric interference and symmetric negative priming. These results were similar to other results showing no relation between interference and negative priming (Allport, Tipper, & Chmiel, 1985; Driver & Tipper, 1989; Fox, 1995b). Because the experiments reported here were identical in every detail except prime and probe exposure times, our results suggest that changes in difficulty of selection are a necessary but not sufficient condition for a change in negative priming. Asymmetric negative priming was found in Experiments 1 and 5, in which prime and probe were presented for longer durations. Taken together, our results show that both prime and probe exposure times are crucial parameters in determining negative priming modulation by selection difficulty. At relatively long prime exposure times (100 ms, Experiments 1 and 5) and probe (100 ms, Experiment 1; 250 ms, Experiment 5), we found a significant modulation of negative priming as a function of attention condition. At shorter prime and probe exposure times

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[5] In Experiment 1, the interaction between Attention condition and Stimulus consistency was not significant, but was in the expected direction, and post-hoc comparisons indicated that interference was significant in the local attention condition but not in the global attention condition. Moreover, the results of Experiment 4, with a prime exposure duration of 100 ms, as in Experiment 1, suggested that the nonsignificant asymmetric interference of Experiment 1 was probably due to a type II error.

(Experiments 2–4) negative priming was significant but was not modulated by attention condition, that is, by the difficulty of discriminating the target dimension. These results provide further evidence against the view that negative priming occurs during prime selection and is simply measured during response to the probe.

Interestingly, the present study provides further support for the notion that the absence of interference (such as in our global attention condition) cannot be taken as a predictor of the absence of higher-level processing of distracters (see Driver & Tipper, 1989; Fox, 1994, 1995b, for similar results). This is particularly important because too often the absence of interference from distracters has been assumed to be equivalent to the absence of identification and semantic processing. As discussed by Driver and Tipper (1989), to assume that the absence of interference is equivalent to the absence of processing is not only a logical fallacy but is also contradicted by empirical evidence. We found significant negative priming in both attentional conditions in four out of five experiments. Our results suggest that in the global attention condition some processing of the local level always occurs, and that this is sufficient to affect the processing of a successive target. This adds additional evidence against the "global precedence" model of visual perception: The absence of interference in the global attention condition is not evidence of insufficient local processing. As suggested by Lamb et al. (1990) asymmetric interference with hierarchical stimuli is more plausibly due to an asymmetric bias in binding global and local features.

Taken together, our results demonstrated not only that distracters that do not yield interference may nonetheless be processed, but also that negative priming and interference can be dissociated. Another piece of evidence in favor of the dissociation between negative priming and interference comes from the observation that our exposure manipulation modulates negative priming, whereas it does not produce any change in the asymmetric interference (see Table 7). An ANOVA was carried out on prime RTs of Experiments 1–5. The between-subjects factor was Prime duration (100 ms in Experiments 1, 4 and 5 versus 16 ms in Experiments 2 and 3), whereas the within-subjects factors were Attention condition (global or local), and Stimulus consistency (consistent or conflicting). The crucial Prime duration x Attention condition x Stimulus consistency interaction did not reach significance [$F(1, 112) = 0.61$, MSe = 608.96, $P = 0.436$], indicating that asymmetric interference was equivalent across experiments (see Table 7).

The fact that interference and negative priming could be dissociated has important implications for the studies investigating individual differences in selective attention and in negative priming. Many studies showing greater interference and reduced or absent negative priming in clinical, developmental and aging populations discussed this result as evidence of a causal relation between the two phenomena. However, our results suggest that the relation between interference and negative priming is far more complex than previously thought (see Houghton et al., 1996, for similar conclusions).

As we discussed in the introduction, all the theories that have been proposed so far to account for negative priming can explain why negative priming is sometimes greater when attentional selection is more difficult. However, whereas the inhibitory account suggests a functional relation between increase in negative priming and difficulty of selection, other accounts of negative priming explain this relation as an indirect consequence of a greater distracter processing in the difficult selection condition. Can those theories explain the present results?

As we mentioned earlier, according to the episodic retrieval theory (Neill & Valdes, 1992; Neill et al., 1992), the size of negative priming is partly determined by the quality of distracter encoding in the prime stimulus. This theory proposes that negative priming is the result of a mismatch between the current stimulus and memory traces of previous stimuli. The episodic retrieval process is cued by the current target and allows one to respond to the current stimulus on the basis of previous responses. If the distracter of the prime trial is not sufficiently encoded, however, the probability that the probe target will cue the retrieval of the prime episode is very low. Therefore, variables that prevent distracter encoding (i.e., shorter prime duration) should be associated with a smaller negative priming. Our results do not support this prediction. An ANOVA was carried out on probe RTs of Experiments 1 and 3 (the only difference between the experiments is that prime exposure time was shorter in Experiment 3). The between-subjects factor was Prime duration (100 ms in Experiment 1 vs 16 ms in Experiment 3), and within-subjects factors were Attention condition (global or local) and Relatedness (same or different condition). The crucial Prime duration × Relatedness interaction did not reach significance [$F(1, 46) = 0.89$, MSe = 845.97, $P = 0.351$]. Negative priming was equivalent in Experiment 1, in which prime stimuli were presented for 100 ms, and in Experiment 3, in which prime stimuli were presented for 16 ms (23 vs 15 ms, respectively). The prime stimulus-exposure time by itself did not modulate negative priming. According to the episodic retrieval theory, both prime exposure and difficulty of selection can influence the encoding of the distracter dimension. Therefore, at short stimulus exposure, and especially when the distracter dimension is more difficult to discriminate or select (such as in the global attention condition), negative priming should be minimal. However, this is not what we found. Negative priming was equivalent in global and local attention conditions in Experiment 3 (17 vs 13 ms).

The episodic retrieval theory also would have predicted an effect of similarity between prime and probe on negative priming, because prime-probe similarity increases the probability of episodic recall of the prime during probe processing. In particular, this theory would have predicted greater negative priming in Experiments 1 and 2, in which prime and probe durations were the same, than in Experiments 3, 4 and 5, in which prime and probe durations were different. The results were in the predicted direction (see Table 7) but the effect did not reach significance. The between-subjects factor was Prime-Probe temporal similarity (same in Experiments 1 and 2 vs different in Experiments 3–5), and within-subjects factors were Attention condition (global or local) and Relatedness (same or different condition). The crucial Prime-Probe temporal similarity × Relatedness interaction did not reach significance [$F(1, 112) = 2.18$, $MSe = 1{,}044.31$, $P = 0.143$]. Negative priming was 22 ms in Experiments 1 and 2, which used the same Prime and Probe durations (100 ms in Experiment 1 and 16 ms in Experiment 2) and 13 ms in Experiments 3–5, which have different Prime and Probe durations (16/100 ms in Experiment 3, 100/16 ms in Experiment 4, and 100/250 ms in Experiment 5). Furthermore, temporal similarity did not play any role in negative priming modulation by selection difficulty. Experiments 1 and 5 showed an asymmetric negative priming, even though prime and probe durations were the same in Experiment 1 and different in Experiment 5.

The temporal discrimination theory (Milliken & Jordens, 1996; Milliken et al., 1998), which accounts for the difficulty of selection effect in the same way as the episodic retrieval theory, would have the same problems in explaining our results.

The inhibitory theories proposed so far (Neill, 1977; Tipper, 1985; Houghton & Tipper, 1994) do not provide a simple explanation of our results. In particular, the presence of a single inhibitory mechanism cannot account for the dissociation found in our experiments. Our findings show that – within the parameters tested in this study – the presence of negative priming is not influenced by prime exposure time alone. A critical feature of distracter inhibition models is that negative priming is seen as occurring in a forward direction from the prime to the probe. Therefore, according to these models, prime duration (i.e., the time allowed for prime selection) should play a crucial role in modulating negative priming. It should be remembered, however, that Houghton and Tipper's (1994) computational model predicts also some effects of probe duration. The model claims that for brief probe exposures, negative priming involves both increased interference from the probe distracter, while the stimulus is on and in addition a more rapidly fading internal representation of the previous ignored target. Given longer exposures, this "weaker" representation is eventually overcome. Thus, the model predicts a decrease of negative priming with longer probe durations.

Prime and probe exposures determined whether the magnitude of negative priming is influenced by attention conditions. This suggests that two different mechanisms underlie negative priming. The first mechanism seems to behave as the anticipatory mechanism proposed by Neill et al. (1995). This mechanism acts rapidly and is associated with a small, constant, and reliable negative priming. The second mechanism behaves as the reactive mechanism proposed by Neill et al. It is slower, can act only when the stimulus is physically present for a certain minimum time, and can modulate negative priming depending on the difficulty of target selection.

It is interesting to note that other results have suggested dissociations between different mechanisms that may underlie negative priming. For example, Milliken, Tipper, and Weaver (1994) showed that negative priming occurs both when there is a feature mismatch in the absence of distracter-target repetition (Park & Kanwisher, 1994) and when the ignored distracter and subsequent target are identical in the absence of mismatch. Milliken et al. proposed that distracter inhibition and implicit retrieval of previously presented items together provided a better account of their results than did either process alone. Tipper and Milliken (1996), after reviewing a large body of evidence, concluded that both episodic and inhibitory processes play a role in negative priming.

In conclusion, the relation between interference and negative priming appears to be very complex. First, different variables that influence interference have a different effect on negative priming (Houghton et al., 1996). Second, even the same variables may have different effects on negative priming and interference depending on other parameters, such as stimulus exposure time. In the present experiments we manipulated attentional instructions (global and local) without varying the physical aspect of the stimulus and the task. Our results suggest that the effects of attention instruction on negative priming and interference are at least in part independent. Under certain conditions (e.g., short stimulus exposures), changes in interference are not accompanied by corresponding changes in negative priming. This independence can be attributed to an "anticipatory" component of negative priming. However, under other circumstances (e.g., long stimulus exposures), variables that influence interference, such as difficulty of selection, also influence negative priming. This relation of interference and negative priming can be attributed to a "reactive" component of negative priming.

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