

Does negative priming reflect inhibitory mechanisms? A review and integration of conflicting views

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Negative priming has traditionally been viewed as a reflection of an inhibitory mechanism of attention. However, recent accounts have suggested that negative priming does not reflect inhibitory mechanisms. Rather, slowed reaction times on negative priming trials are either due to retrieval of incompatible response tags or of mismatching perceptual information, or due to extra processes needed to distinguish past from present information. In contrast, it is proposed that there is *no* firm evidence to discount inhibition models. In fact, although retrieval processes can be implicated in negative priming effects, understanding of these requires consideration of the inhibitory processes involved in selecting information for goal-directed behaviour.

There is now abundant evidence that visual processes can flow automatically into actions, such that the latter can be evoked with little or no conscious intention to act (e.g., Bridgeman, Lewis, Heit, & Nagle, 1979; Coles, Gratton, Bashore, Eriksen, & Donchin, 1985; Duncan-Johnson & Koppell, 1981; Eriksen & Eriksen, 1974; Goldberg & Segraves, 1987; Gratton, Coles, Sirevaag, Eriksen, & Donchin, 1988; Lhermitte, 1983; Miller & Hackley, 1992; Navon, 1977; Norman, 1981; Reason, 1979; Simon, 1969; Stroop, 1935; Weiskrantz, 1986). Unrestrained, such efficient perceptual processes would result in chaotic behaviour that is unrelated to behavioural goals. That is, the most dominant perceptual input of the moment will capture action, and this will vary haphazardly over time. Clearly, therefore, to exercise free choice and control it is essential that organisms have the capacity to resist the strongest response of the moment (Diamond, 1990). This inhibitory control, so crucial for coherent behaviour, is difficult to directly measure in normal human subjects. Therefore it has been necessary to develop indirect measures such as priming techniques.

Negative priming refers to the apparent disruption (usually slowing) of the response to an item if it has previously been ignored. These effects have been extensively studied (see, for example, Fox, 1995; May, Kane, & Hasher, 1995; Neill, Valdes, & Terry, 1995, for reviews). It

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was originally proposed (e.g., Neill, 1977; Tipper, 1985) that negative priming reflects an inhibition mechanism of attention. That is, one means by which a response can be directed toward a target stimulus in the presence of a distractor that competes for the control of action, is for inhibition mechanisms to suppress the activation levels of the distractor's internal representations. (See Houghton & Tipper, 1994, for a formal model of such inhibition mechanisms.)

Negative priming is therefore a means of observing an inhibitory process that is assumed to be a normal component of selective attention. Thus, if the distractor's internal representations in a prime display are associated with inhibition, then processing of a subsequent stimulus in a probe display that retrieves the previously inhibited representations will be impaired. The logic underlying these negative, and in fact, all priming procedures is that to recognize an object, internal representations previously created from prior recognition processes of similar objects must be accessed. That is, we recognize a dog because of prior identification of other dogs. Therefore, if a picture of a dog is ignored in a prime display, its internal representations have received inhibitory processing, and so processing of that same picture, should it become a target in a subsequent probe display, will be impaired.

Problems with early inhibition accounts

Early ideas (e.g., Neill & Westberry, 1987; Tipper, 1985) considered that negative priming was caused entirely by residual inhibition of the internal representation. That is, the internal representations of the prime were associated with transient inhibition, and this inhibition was still present during processing of the probe display. However, Tipper, Weaver, Cameron, Brehaut, and Bastedo (1991b) suggested the somewhat radical idea that "it may be the case that attentional processes that act upon the internal representations of an ignored stimulus can have a long term effect" (p. 690).

This notion of long-term priming effects was based on limited information, in that negative priming had been observed to last 7 seconds and to survive an intervening event between prime and probe. Tipper et al. (1991b) went on to say "experimental procedures that utilize small stimulus sets are incapable of demonstrating long term effects. Therefore other research strategies are required that present a unique item and then observe processing of that item some time later" (p. 691). Just this strategy was subsequently reported, in which unique items were presented on each trial. Thus, DeSchepper and Treisman (1996) observed very-long-term negative priming effects with an interval of one month between initial presentation of the prime and subsequent presentation of the probe. It is clearly unreasonable to postulate such a prolonged period of inhibition of an internal representation. Therefore, residual inhibition cannot explain all negative priming results.

Note, however, that long-term effects do not rule out the existence of residual inhibition that may decay in a matter of seconds, and that some data may be better explained by such decaying residual inhibition. For example, negative priming can be observed when the ignored prime (a picture) and subsequent probe (a word) are very different stimuli (Tipper & Driver, 1988). It is unlikely within most theories describing retrieval of specific processing episodes that very-long-term effects would be observed where a word is able to retrieve the processing of an ignored picture a month earlier (see Tipper & Milliken, 1996 for a review of

such issues, and Banks, Roberts, & Ciranni, 1995; Conway, 1999; Malley & Strayer, 1995; Shiu & Kornblum, 1996; Strayer & Grison, in press).

The Houghton–Tipper model

Even if inhibitory processes do not remain active over very long periods, inhibition accounts of negative priming cannot be ruled out, because these (inhibitory) processes could be retrieved later. That is, the probe target could cue the *retrieval of the prior processing episode* in which the same stimulus was ignored. This would reinstate the distractor's internal representations in the form they were in while the mechanisms of selective attention were acting upon them—that is, inhibited. Two main points are made in later discussions: First, inhibition is not necessarily associated with abstract logogen-like representations. Indeed recent work has examined inhibitory processes during selection from networks utilizing population coding (e.g., Houghton & Tipper, in press; Tipper, Howard, & Houghton, in press; Tipper, Howard, & Jackson, 1997). The second main point is that inhibition is not simply a forward-acting process from prime to probe.¹ Rather, the observation of inhibition via negative priming is by necessity a bi-directional process involving initial inhibitory processing in which a target is selected from a distractor, and subsequent retrieval processes activated while interacting with the probe, in which previous prime processing is reinstated/retrieved.

The ideas discussed here are derived from the work of Houghton and Tipper (1994) who have been concerned with attempting to describe what selection mechanisms mediate the remarkable selective attention performance observed as humans interact with their complex environments. They describe a neural network model in which an internal template is created against which perceptual inputs are compared.² The template contains stimulus features that specify which object is the target for action (see also Duncan & Humphreys, 1992 for similar template-matching selection mechanisms). For example, if participants are told to name the red object in each stimulus array, the template would be red (Tipper & Cranston, 1985). Other potential templates include location (Tipper, MacQueen, & Brehaut, 1988), shape (Tipper, Brehaut, & Driver, 1990), size (Tipper, Weaver, & Milliken, 1995), or any other feature, such as location in a temporal sequence (e.g., Milliken, Joordens, Merikle, & Seiffert, 1998), that distinguishes target from distractor. Any inputs matching this template receive excitatory feedback, whereas those of the distractor that mismatch the template receive inhibitory feedback. For example, in the studies of Tipper (1985) subjects were presented with red and green pictures. They were required to name the red picture as fast as possible. Via this instruction an internal model of the selection feature “red” was created and maintained throughout the experiment, and all perceptual inputs were matched against this template.

¹ We refer to forward- and backward-acting processes in line with the terminology used by other authors (e.g., Neill, 1995). This is not meant to imply that time can go backwards. An event that is processed at Time 1 (the prime) can influence an event at Time 2 (the probe) in at least two ways: The process may still be lingering, or the processing episode may be retrieved.

² The core of this model is the template selection mechanism. This mechanism acts on the internal representations of target and distractor stimuli, and these representations are activated nodes in a network. Although some readers may consider that this form of representation is superficially similar to abstract logogens, this form of representation is not crucial, but rather was chosen for ease of implementation.

It should be noted here that the basic properties of the Houghton and Tipper model are influenced by the neurophysiology mediating the processes of selective attention. Thus the template-matching system has been extensively studied via single cell recordings in the monkey brain (e.g., Miller, Eriksen, & Desimone, 1996). In the prefrontal cortex, cells maintain an activation state over long periods and are not disrupted by other inputs. Just such a neural mechanism is necessary to maintain a target property, such as "red", throughout an experiment. The activity of the prefrontal system is also a source of feedback inputs to more posterior areas associated with attention, such as the inferior temporal and parietal cortex. Activity in these locations is biased, too, in favour of behaviourally relevant stimuli, as reflected in the Houghton and Tipper model.

The other main property of the Houghton and Tipper model is suppression of competing distractor inputs. Here also there is substantial evidence for such suppression processes at the single unit level (e.g., Chelazzi, Miller, Duncan, & Desimone, 1993; Moran & Desimone, 1985; Schall & Hanes, 1993) and via evoked potentials (e.g., Chao & Knight, 1997). For example, a cell that is normally driven by a particular perceptual input is suppressed when the stimulus is actively ignored. Thus the perceptual input remains constant, but the act of ignoring dramatically affects the level of neural activity.

Another property of the Houghton and Tipper model is also relevant to the ideas presented in this article; the inhibition that feeds back to the distractor is reactive. That is, the level of inhibition is determined by the activation state of the distractor. Distractors that are more salient and intrude into the control of action receive greater inhibitory feedback than less salient distractors. Evidence to support the notion of reactive inhibition, where greater initial excitation evokes greater inhibitory feedback, has been reported by Houghton, Tipper, Weaver, and Shore (1996), Grison and Strayer (in press), and Tipper, Howard, and Houghton (in press). This reactive inhibition property of the model is very important for our current arguments.

Empirical research has confirmed the notion of template mismatches as the initial source of inhibition. Baylis, Tipper, and Houghton (1997) predicted that in situations in which no internal template existed, negative priming could not be observed because the critical mismatch between distractor perceptual input and template would not take place. In one of their experiments subjects were either informed of the identity of the to-be-selected target prior to presentation of the display, or presented with exactly the same display but told to respond to whichever stimulus they preferred. In the former case an internal template was created against which perceptual inputs were compared. As predicted, negative priming was obtained, due to the mismatch between template and distractor. In contrast, when subjects were not told which object to select no template existed, and hence the model predicted that no negative priming would be observed because the critical template-to-distractor mismatch did not take place. The prediction of no negative priming was confirmed. Other work has supported this contrast between internal and external selection states (e.g., Park, 1996, Experiment 2).

Some comment concerning how selection is achieved when targets are not pre-specified via a template is necessary. During internal selection there is no template to bias processing of the perceptual input. Both inputs are therefore initially processed in parallel, and because neither has any advantage over the other, each will be activated to the same degree, potentially resulting in deadlock. Following other work resolving response conflict (e.g., Hartley & Houghton, 1996), it is proposed that a winner-take-all mechanism exists to prevent such deadlock. In

particular, lateral inhibition between activated representations will select a “winner”. That is, such competitive systems are sensitive to very small differences in initial response strength that become rapidly magnified, via lateral inhibition, such that only one response remains active. Such high sensitivity means that the presence of a small amount of noise in response activation ensures that one response is chosen over another. Of course, in many situations, such as disambiguation of ambiguous words, background semantic context would bias initial activation levels and determine selection. This biasing via context is probably a common means of selection in many encounters with real-world environments.

The Houghton and Tipper model has captured other aspects of behaviour. For example, the complex relationship between the level of interference produced by a distractor and the amount of negative priming associated with the distractor has emerged from model simulations. Thus, positive relationships, in which interference and negative priming both increase; and negative relationships, in which interference increases and negative priming declines, emerge from the model due to independent excitatory and inhibitory feedback selection mechanisms (see Houghton et al., 1996; Tipper & Milliken, 1996, for discussion; and Grison & Strayer, in press).

This highly complex relationship between levels of distractor interference and negative priming constrains theoretical developments. For example, the claim that negative priming cannot reflect mechanisms of selection because of the complex relationship between interference and negative priming (e.g., May et al., 1995) simply does not follow. Consider the following study. Klein and Christie (1995) have shown that when target and distractor are visually similar interference increases, but negative priming remains stable. The conclusion that such a result proves negative priming cannot reflect selection mechanisms may be mistaken. Such a data pattern would be expected from the model because it takes longer for the template match/mismatch to be triggered when stimuli impinging on the template are difficult to discriminate, hence reaction times are increased (see also Duncan & Humphreys, 1989). However, the reactive inhibition, which is determined by the relative perceptual and/or response salience, is not necessarily affected by delays in distinguishing target from distractor. Such apparently paradoxical behaviour is therefore observed in human behaviour and in the model. Only by studying the complex interactions within a model can such counterintuitive results be subsequently explained.

Although many researchers consider that negative priming does reflect an inhibition mechanism (e.g., Engle, Conway, Tuholski, & Shisler, 1995; Fuentes & Tudela, 1992; Grison & Strayer, in press; Malley & Strayer, 1995; May et al., 1995; Neumann & DeSchepper, 1991, 1992; Neumann, McCloskey, & Felio, 1999; Shiu & Kornblum, 1996; Strayer & Grison, 1999), others consider that it does not. The issue of whether or not inhibition is involved in the negative priming phenomenon is important not only theoretically, but also to enable correct interpretation when negative priming tasks are used in clinical groups. Three of these anti-inhibition theories are outlined here.

Theories of negative priming without inhibitory processes

1. Episodic retrieval account

The most influential anti-inhibition account of negative priming has been the episodic retrieval theory. To be clear at the start, notions of episodic retrieval that imply long-term

priming effects do indeed cause problems for the initial notions of transient inhibition accounting for *all* negative priming effects (e.g., Neill, 1977; Tipper, 1985). However, as discussed earlier, evidence for long-term negative priming effects *cannot* discount the existence of short-term transient effects: Transient and long-term context-specific effects simply are not mutually exclusive.

However, the notion that longer term inhibitory traces could be established and retrieved with the appropriate contextual cues was considered by Tipper et al. (1991b), who initially proposed the following:

Long term inhibitory effects may be an advantage in highly constrained interactions with the environment. Behaviors usually take place in particular environmental contexts, and in these contexts particular stimuli are selected for action, while others are typically ignored Therefore, if the prior experience of ignoring a stimulus in that context can be reinstated, the selection processing will be facilitated . . . the act of preventing response to a stimulus, which may be due to active inhibition, actually alters the internal representation of the ignored stimulus: in essence, its status as an attended or ignored object becomes a component of its representation. (p. 691)

Somewhat similar ideas were subsequently proposed by Neill, Valdes, Terry, and Gorfein (1992) who suggested that a target stimulus cues the retrieval of previous processing episodes involving the same stimuli. These processing episodes include information about responses previously made to the stimulus. For example, if the stimulus was ignored, a “do not respond” tag is associated with the internal representation of the stimulus. When the probe is presented, previous information that is similar to the probe target is retrieved to enable recognition. If this retrieved information is the previously ignored distractor, the “do not respond” tag that is retrieved impairs the response to the probe. It is important to note that throughout this article we refer specifically to the episodic retrieval accounts of negative priming proposed by Neill and his colleagues. We are not referring to the range of episodic models discussed by other memory theorists (see Tenpenny, 1995, for review).

Episodic models that do not consider selection mechanisms are ill equipped to predict the results of the experiment by Baylis et al. (1997) described earlier. In the situation where no template exists, in which subjects were free to select the target, the distractor should still have been tagged with the “do not respond” label. Furthermore, subjects were better able to recognize the distractor at a later time when there was no template. Therefore distractors in this condition appeared to have more elaborate and accessible internal representations. Hence episodic retrieval accounts might predict that the probe should more easily access these available representations. The subsequent retrieval of the “do not respond” label should therefore have resulted in greater, rather than less, negative priming.

Furthermore, a major problem for models that apply tags is that they are infinitely flexible and therefore can explain all data in a post hoc fashion by producing a new tag, or label, to suit. For example, Neill’s (personal communication, February 1997) response to the Baylis et al.’s (1997) results was to propose that a new kind of tag be created: “For all we know it [the ignored stimulus] could be encoded as ‘also good for response’, yielding positive priming instead.” Clearly such a theory can never be refuted, because a new tag can be produced for any new set of data.

It should be made clear at this point that consideration of episodic retrieval processes has had a major impact on the original ideas concerning negative priming. First, Neill (1977) and

Tipper (1985) did not debate the nature of the representations accessed. The issue of whether these were specific processing episodes, as suggested by Jacoby and Brooks (1984) for example, or abstract representations, as proposed by Morton (1969, 1979) was not engaged at that time. Clearly these are major issues that cannot be ignored when interpreting negative priming effects.

Comparison of episodic and inhibition accounts. It has been argued that the main contrast between inhibition and retrieval accounts is in the temporal direction of the effect. Kane, May, Hasher, Rahhal, and Stoltzfus (1997; see also Milliken et al., 1998), for example, describe the inhibition mechanism as acting forward in time from the prime to the probe, and the episodic mechanism as one of retrieval working back in time. Neill et al. (1995) states similarly, "Whereas the deactivation and blocking hypotheses view negative priming as inhibition carried forward from the prime to the probe, the episodic retrieval hypothesis views it as a backward retrieval of the priming episode . . ." (p. 252). However, we would argue that any priming effect is by necessity a product of a dual flow of information, in which current neural processes affect future, and gain access to past, states of the organism. Therefore, attentional processing during selection of the target from the distractor in the prime display (e.g., inhibition) influences behaviour in the subsequent selection of the target in the probe display. This is a forward process. However, analysis of the probe, such as object identification, requires retrieval of processing episodes that took place in the past. This is a backward retrieval process.

In light of this analysis, the contrast between the episodic retrieval and inhibition accounts may not be as stark as has been suggested. In fact, in one of the earliest discussions of inhibition in negative priming effects, Tipper (1985) said ". . . the internal representations produced [when ignoring a stimulus] are such that selection of subsequent objects *requiring those representations* is delayed" [emphasis added]. There was therefore an implicit assumption that retrieval processes are involved, based on the idea that object recognition processes require access to the internal representations produced from prior processing of similar objects. Therefore, the logic underlying the inhibition account, just as with the episodic account, requires that the probe access or retrieve the internal representations and, most important, the *processes* that took place in the prime display.

If both episodic retrieval and inhibition accounts are similar, in that prior events are accessed, then how do these accounts differ? We suggest that they differ in terms of what is emphasized in the sequence of processes engaged in the entire prime–probe event. The episodic account thus far has mainly been concerned with demonstrating the properties that determine whether processing of the probe will cue successful retrieval of the prime. Properties such as the temporal discriminability of the prime (Neill & Valdes, 1992; but see Conway, 1999, and Hasher, Zacks, Stoltzfus, Kane, & Connelly, 1996, for failures to replicate), or the contextual overlap between prime and probe (Fox & de Fockert, 1998; Lowe, 1998; Neill, 1997) have been shown to be important. In contrast, the specific highly complex processes that take place in the prime display when attention mechanisms select the target have not been carefully examined in Neill's model. Indeed there is a denial that more specific levels of description are necessary; rather, higher level abstract labels (e.g., "do not respond to me" tags assigned to distractors) are deemed to be sufficient, and new tags can be proposed to explain all observed data (see also Schooler, Neumann, Caplan, & Roberts, 1997). Figure 1A represents the Episodic Retrieval theory, in which encoding processes are represented in a

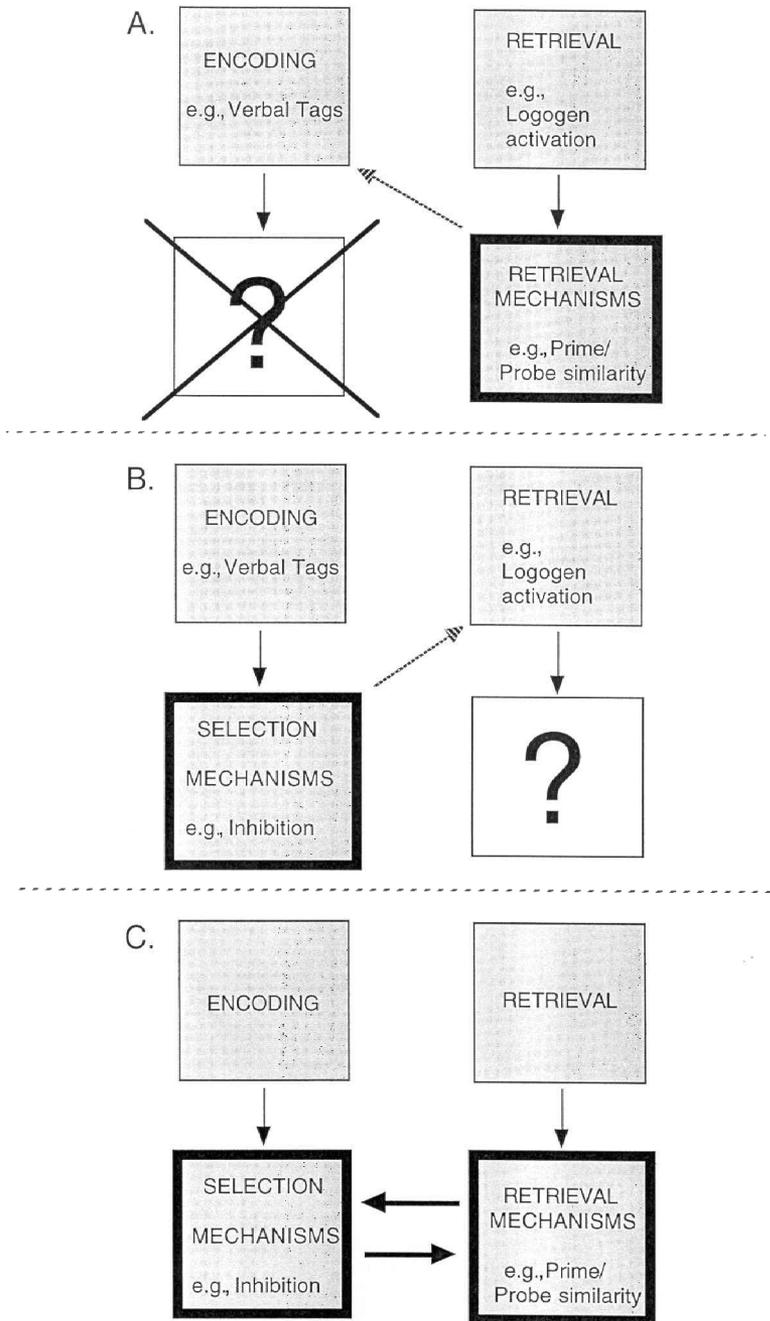


Figure 1. Representation of the interaction between episodic retrieval and inhibitory processing theories of negative priming. The upper two boxes of each panel show the relevant issues at an abstract level, and the lower two boxes show the level at which research is conducted. The boxes considered relevant to the different theoretical approaches are shaded.

relatively abstract way as, for example, verbal tags (e.g., “do not respond to me”). Note that the more specific level of analysis of encoding processes is not considered by these theorists, as represented by the question mark, and is thought quite unnecessary by some, as represented by the cross over this box.

In sharp contrast, inhibition accounts have focused on the mechanisms of selection in the prime, and have not until recently considered the implications of retrieval processes. It has simply been assumed that the probe accesses or retrieves processing that took place in the prime, with little consideration of how this retrieval is achieved and where it might fail (Figure 1B shows the original Inhibition account, in which the selection processes during encoding are explored (e.g., excitatory and inhibitory processes), but little consideration is given to the role of retrieval). For example, on this latter point, completely false conclusions concerning levels of inhibition in particular selection tasks may be drawn from failures to observe a negative priming effect. This lack of negative priming may occur, not because inhibition levels were very low, but rather because the probe failed to cue retrieval of the prime-processing episode. A situation in which this may have taken place was in a study reported by Tipper and Cranston (1985). When a probe stimulus was presented alone, without a competing distractor, no negative priming was observed. Tipper and Cranston suggested that inhibition might have rapidly decayed when selection was not required in the probe. However, an alternative account is that inhibition remained at the same level, but the change in context between prime (select red target from green distractor) and probe (no selection of black target) prevented the probe from cueing retrieval of the prime.

To this point we have been attempting to make clear that the argument about whether episodic retrieval or inhibition explanations of negative priming are correct, is misplaced. It simply does not follow that acceptance of episodic accounts describing retrieval of processing episodes proves that inhibition accounts must be incorrect. Nor does the inhibitory account preclude a role for episodic retrieval, and in fact it requires it. A central thesis of this article is therefore that there is no necessary conflict between inhibition and episodic accounts of negative priming. The difference between the two is analogous to the differences between approaches to memory that emphasize encoding versus retrieval. As Tulving (1983) eloquently argued some years ago, theories of memory must address both encoding and retrieval (see also Bransford, Franks, Morris, & Stein, 1979; Jacoby, 1983; Kolers & Roediger, 1984; Roediger, Weldon, & Challis, 1989). Similarly, conflicting views about attention concerning the level of analysis of to-be-ignored stimuli has been shown to be yet another false dichotomy, where both early and late selection forms of processing are possible in various situations (e.g., Lavie, 1995). As Newel (1973) so cogently argued, psychologists appear to have an enthusiasm for creating such dichotomies at the first opportunity. Such dichotomization is rarely fruitful, and in many cases, an integration of ideas may be more productive.

Negative priming appears to be currently undergoing similar dichotomization, but perhaps integration is more fruitful. Thus negative priming cannot be adequately modelled by an approach that deals only with inhibitory processes at encoding, or by an approach that deals only with the retrieval of episodic information at test. In our view, most previous discussions of inhibition have paid inadequate attention to retrieval processes (Figure 1B), and episodic accounts have paid inadequate attention to processes that operate at encoding (Figure 1A). Therefore, a successful model of negative priming must address both inhibitory processes at encoding and memory retrieval processes at test. This proposal is represented in Figure 1C,

which shows the approach advocated in this paper. Both encoding and retrieval mechanisms play a role in producing negative priming phenomena, and the interpretation of the effect in any experiment needs to incorporate a thorough consideration of what is known to affect both selection and retrieval processes. Thus we do not view inhibitory and episodic accounts as contradictory.

Unfortunately, some of the current research in negative priming is being used to demonstrate the efficacy of the episodic retrieval account and thereby refute the role of inhibitory processes. We suspect that this is partly due to a misunderstanding regarding the nature of the hypothesized inhibitory mechanisms. Specifically, it appears that the concept of inhibition is often assumed to refer to below-baseline reduction of the level of activation of logogen-like representations, because early discussions implied such representations (e.g., Neill, 1977; Tipper, 1985). When evidence is found to oppose the concept of abstract representation, the inhibition account is also dismissed. But, as discussed earlier, inhibitory mechanisms of selective attention are not critically tied to such notions of abstract representations. Inhibitory selection mechanisms can just as easily be instantiated in distributed representations such as the population codes used to represent vision and action in many brain areas (see Houghton & Tipper, *in press*; Howard & Tipper, 1997; Tipper, Howard, & Houghton, *in press*; Tipper et al., 1997). Therefore the notion that episodic retrieval processes can *only* access tags (e.g., “do not respond to me”) or excitation states, but cannot access inhibitory states, does not follow. Reinstating inhibitory states in a neural network is just as feasible.

Advantages of considering encoding and retrieval. The recent work of Neill and colleagues has been extremely important, as it has forced much greater consideration of how retrieval processes influence the interpretation of negative priming effects. For example, analysis of the retrieved information from the prime display has enabled us to appreciate the possibility that negative priming can be caused by the retrieval of more than one process. That is, different kinds of information can be retrieved from the prime display depending upon task demands. This point has been demonstrated in some of our research. For example, Tipper, Weaver, and Houghton (1994) observed negative priming effects associated with both the colour and the location of a distractor. At that time Tipper et al. were not carefully considering the implications of retrieval processes, and hence they interpreted these effects as due to inhibition being associated with both these properties of the distractor object. Subsequent work showed that when this pattern of results was considered via a retrieval process a completely different interpretation emerged, which was confirmed in subsequent experiments (see Milliken, Tipper, & Weaver, 1994).

This retrieval account allowed us to realize that in rather specific circumstances, the retrieval of two completely different kinds of process could cause negative priming. The colour-based negative priming effect was due to the detection of a mismatch between the colour properties of the ignored prime and those of subsequent target probe (see later discussion of Park & Kanwisher, 1994); whereas the location-based negative priming seemed to be caused by inhibition of this stimulus dimension, which competed for the control of action. Simple procedural manipulations were able to dissociate these colour and location-based negative priming effects, confirming that they were caused by retrieval of different forms of prime processing (see Milliken et al., 1994, for details). Importantly, this example shows that it is necessary to carefully consider specific processes that may be retrieved, because simply assigning a

label such as “do not respond” to an ignored stimulus, or arguing for transfer-inappropriate processing between prime and probe, does not identify the specific processes involved.

Other work discussed earlier also highlights the importance of considering the retrieval processes. For example, the long-term effects predicted by Tipper et al. (1991b) and described by DeSchepper and Treisman (1996), and the effects of context described by Neill (1997), reveal fundamental constraints on interpretations of negative priming effects. Our central message is that both encoding and retrieval have to be considered. Thus, the overall pattern of data observed by DeSchepper and Treisman requires that the selection mechanisms acting on the prime display cannot be ignored. They report an individual difference, such that only subjects who produce negative priming at short intervals also produce them at very long intervals. An account based on general labels, such as “do not respond” associated with stimuli that were successfully ignored, does not easily explain these individual differences, as all subjects who successfully select the target should retrieve this label. In contrast, consideration of individual variation in the interaction between excitation and inhibition feedback mechanisms (cf., Houghton & Tipper, 1994; Houghton et al., 1996) enables one to propose that some subjects rely more heavily on inhibitory feedback mechanisms than do others (see Fox, 1995, for a review of individual differences in negative priming effects). Other experimental results that can be explained by the Houghton and Tipper (1994) inhibitory account, and not when only considering retrieval processes, are discussed in Appendix I.

2. *Feature mismatching*

Park and Kanwisher (1994) have argued that negative priming effects in spatial tasks reflect perceptual mismatching, not distractor inhibition. In these tasks (e.g., Tipper et al., 1990) subjects report the location of a target specified by identity (e.g., O) while ignoring a distractor with a different identity (X). When a subsequent probe was presented in the same location as the previous distractor, the response was impaired. It was assumed that inhibition of action towards the competing distractor in the prime display impaired response to the subsequent probe presented in the same location.

In contrast, according to Park and Kanwisher (1994) negative priming in these tasks is caused by a change in the bindings of symbol identities associated with objects that appear in the same location in prime and probe displays. In other words, there is a perceptual mismatch when the probe target (O) appears in the location of the prime distractor (X), as it does in the critical “ignored repetition” condition. Or, as Kahneman, Treisman, and Gibbs (1992) might describe it, the same object file is associated with different identities (O and X). This mismatch does not occur in the baseline (or control) condition.

However, the experimental results reported by Park and Kanwisher (1994) are far from unequivocal. Appendix II contains a discussion of the various experimental techniques adopted by Park and Kanwisher, and it describes how each set of data does not necessarily provide evidence against inhibitory mechanisms. Aside from such critiques of experimental method, their claims have been more forcefully refuted by experimental results that actually demonstrate that negative priming *is* observed when ignored prime and subsequent probe are physically identical objects, and perceptual mismatching is clearly absent (e.g., Milliken et al., 1994; Tipper & Milliken, 1996; Tipper et al., 1994). Furthermore, these studies have shown that where mismatching is present, no increase in negative priming is produced. Hence, in

many procedures there is *no* evidence for mismatching to produce negative priming. Only in one particular condition, in which subjects were provided with prior pre-cueing of stimulus colour, was mismatching detected (Milliken et al., 1994). Hence the mismatching phenomenon exists, but only in very limited experimental conditions that motivate retrieval processes.

Finally, the evidence reported by Baylis et al. (1997) also disproves mismatching accounts (see also Fuentes, Humphreys, Agis, Carmona, & Catena, 1998). Park and Kanwisher (1994) have argued that perceptual mismatching is necessary and sufficient to produce negative priming. However, Baylis et al. report that during internal selection, when subjects are free to select the target from distractor, negative priming is not observed even when the ignored prime and subsequent probe differ in identity (i.e., where perceptual mismatching exists). This same logic was employed in experiments reported by Tipper, Meegan, and Howard (2000). Subjects were required to reach to a red light while ignoring a yellow distractor. The mismatching between ignored prime (yellow) and subsequent probe (red) was held constant, and hence negative priming produced by such colour mismatches should also remain constant. However, negative priming varied dramatically depending on ease of response, as predicted by a reactive inhibition model.

3. *Temporal discrimination*

There is another interpretation of negative priming effects that apparently challenges inhibition accounts. This work places less emphasis on the highly complex selection processes that enable subjects to make fast and accurate responses to a target stimulus when it is in the presence of a distractor, and it instead concentrates on retrospective processes triggered by the probe. Milliken and colleagues (e.g., Milliken et al., 1998) have undertaken an elegant series of experiments examining negative priming effects in a novel context. For example, subjects were presented with a single white word for 200 ms, which they were told to ignore, followed 500 ms later by a to-be-named red target word superimposed over a green distractor. When the ignored prime word and subsequent target probe had the same identity, negative priming effects were obtained, compared with when ignored prime and target probe were different.

Milliken et al. (1998) considered that, as selection was not required in the prime, it was not selected against and hence not inhibited. They therefore explain negative priming as slowed categorization of whether an item is old or new. That is, when a stimulus is processed, there is analysis of whether it is old (recently encountered), which allows automatic retrieval of the stimulus, or new (not recently encountered), which requires further perceptual processing. However, partial activation via the ignored prime leads to ambiguity as to whether the item is old (evoking automatic retrieval from memory) or new (requiring perceptual analysis).

This temporal discrimination of a probe with past events takes different times in various priming conditions. For example, in attended repetition conditions where the same item is attended in the prime and probe, the decision that the probe item is old can be made rapidly, and hence retrieval from memory is initiated quickly. Similarly, in the control condition where items in the prime display are different from those of the probe, the decision that the probe is new/novel can be taken rapidly, and hence the further perceptual analysis necessary for identification is undertaken immediately. However, in ignored repetition conditions where the ignored prime and subsequent probe are identical there is greater ambiguity in temporal discrimination. The low level of activity produced by the ignored prime suggests that the probe is

old, but this is not clear-cut. Therefore the ambiguity as to whether retrieval from memory or further perceptual encoding is necessary slows down processing of the probe. This account has been termed “temporal discrimination”.

Because Milliken et al.’s (1998) new experimental procedures are different from previous studies of negative priming, which required subjects to select a target from a distractor in the prime display, the data were interpreted as challenging inhibition accounts of negative priming. The complex processes that enable subjects to respond to a target rather than to a distractor are not considered by Milliken et al. For example, it is stated that “. . . negative priming can occur without participants having to ‘select against’ a distractor in the prime display” (p. 215). Clearly such statements are not considering how it is that subjects do not attend and respond to a stimulus. There is an implied assumption that processing stimuli to response stages is always an active process, and ignoring is passively achieved (e.g., Neisser, 1967). However, as discussed earlier, substantial evidence now suggests that perception can flow through to action independently of subject’s intentions. Indeed, after brain damage a common problem observed is that patient’s actions are automatically evoked by irrelevant to-be-ignored stimuli. Thus in utilization behaviour (e.g., Lhermitte, 1983) a patient continuously reaches out and grasps objects, even though they are continually informed that the behaviour is inappropriate.

Interestingly, the template mismatch mechanism in the model of Houghton and Tipper (1994) in fact predicts the effects observed in Milliken’s new procedure. Word naming is a rapid and automatic action (e.g., Stroop, 1935), especially in the context of naming probe words: Thus visual processes can flow automatically into actions independent of subjects’ intentions not to respond to the stimulus. Actions evoked by the first stimulus to activate visuomotor pathways would result in chaotic behaviour in tasks where stimuli are presented in temporal sequence. Hence the act of ignoring the prime word probably involves selective inhibition, as it is not possible for the brain to simply fail to process such visual inputs. In other words, the single item in the prime display was processed as a to-be-ignored distractor, only the simultaneous target was missing. It is important to note that negative priming was only obtained when subjects were required to ignore the prime; when told to read the prime word facilitatory priming was obtained. Therefore, it seems that there is a difference in emphasis between what the temporal discrimination and inhibition accounts of negative priming concentrate on: The former does not consider the complex selection mechanisms that guide behaviour.

Let us examine the Milliken task a little more carefully. In this task in particular, familiar stimuli (a smaller set of words presented repeatedly) are processed automatically without subjects’ intentions, or even awareness of the stimulus. Consider that subjects are fixating the locus where the prime is presented while awaiting the arrival of the probe target. The sudden onset of such a stimulus is known to capture processing resources (Yantis, 1993) and interfere with other behaviours (Hillstrom & Yantis, 1994), and the low information load will lead to automatic perceptual analysis of the prime (Lavie, 1995). Furthermore, such perceptual analysis automatically leads to the activation of response systems (e.g., Coles et al., 1985).

The evidence for the continuous fluent processing of familiar stimuli to the stage of response activation was one of the main motivations for our model of selective attention. Given this fluent processing, how is it the case that subjects are so remarkably efficient at responding to the appropriate stimulus in the presence of competing distractors presented

half a second before? Our efficient perceptual-motor systems have necessitated the evolution of inhibitory selection mechanisms to enable coherent goal directed behaviour (see Tipper et al., 1997) Unfortunately, such analysis of the specific mechanisms that mediate selection-for-action in various experimental tasks is not always undertaken.

As described earlier, a central feature of the Houghton and Tipper model is the template match/mismatch process. The model assumes that the template can match on any stimulus dimension that psychophysical research shows humans can use to select a target from distractor. Hence, the template can match on colour, location in space, or location in a temporal sequence, and so on. In the Milliken et al. (1998) experiments the template is colour and/or temporal location in the sequence. That is, any inputs that are red and/or last in a sequence of inputs receive excitatory feedback; any inputs that mismatch the template, such as white and/or an initial perceptual stimulus, receive inhibitory feedback. Therefore, the Houghton and Tipper model predicts, a priori, negative priming in these experiments because the prime will mismatch the template being maintained by the subject. Furthermore, like the Milliken account, the Houghton and Tipper model also fails to produce negative priming when no selection in the probe display is required.

A further very interesting observation made by Milliken et al. (1998) is that these negative priming effects can be observed even when the white prime word is presented for 33 ms and pattern masked. It appears that most subjects are unable to report the identity of these primes. Although in a replication by Neill at least half the subjects could report the prime, so the status of such primes relative to conscious awareness is somewhat ambiguous. As noted by Cheesman and Merikle (1986), the subjective threshold necessary to produce priming effects can vary widely between subjects.

This observation of negative priming produced by pattern-masked primes is an important and surprising result. It does not, however, unequivocally disprove the Houghton and Tipper model for a number of reasons. First, as noted by Milliken et al. (1998) this effect is not observed with pictures (Allport, Tipper, & Chmiel, 1985). One of the hallmarks of negative priming is its generality to a very wide range of stimuli and procedures, so perhaps some caution is required in interpreting this new result. Second, and more important, whether subjects are conscious or unconscious of a distracting stimulus is not explicitly described in the Houghton and Tipper model. Clearly the prime word has been extensively processed (as demonstrated by its priming effects), and the mismatching colour feature of white is visible, so the model predicts that inhibitory feedback can be triggered. Third, it should be noted that the absence of conscious awareness of a prime's identity has been one of the markers of traditional negative priming effects. For example, Tipper (1985) noted that only those subjects who were unaware of the prime distractor's identity produced negative priming effects. Hence, lack of awareness of a prime's identity in no way challenges the Houghton and Tipper model. Finally, Wood and Milliken (1998) have produced other experimental results that apparently challenge the notion of inhibitory selection processes. A critique of this work can be found in Appendix III.

In summary, the contrasts between temporal discrimination and inhibitory accounts of negative priming are in terms of what aspects of prime and probe processing are emphasized. Like us, Milliken et al. (1998) stress that both prospective encoding and retrospective retrieval processes are crucial when they say: "Note that we are not arguing that the direction of priming depends on properties of probe task processing, but that it may depend quite literally on

properties of both prime and probe task processing” (p. 25). Unlike us, however, they place less emphasis on the sophisticated selection mechanism mediating behaviour in their task. At least they make no attempt to consider such selection mechanisms when developing their model. Our point is that such aspects of selection are crucial to the interpretation of negative priming effects.

GENERAL CONCLUSIONS

I have not attempted to make an extensive review of the negative priming literature, which is now very large, and other excellent reviews (Fox, 1995; May et al., 1995; Neill & Valdes, 1996) provide this broader perspective. Rather, this article has focused on a specific and fundamental issue concerning interpretations of negative priming effects: That is, does negative priming reflect an inhibitory selection mechanism? Four main conclusions can be drawn. First, the characterization of inhibition and episodic retrieval accounts of negative priming as forward and backward acting, respectively, does not stand up to careful scrutiny: Both *must* involve forward-acting (encoding) and backward-acting (retrieval) processes if they are to be complete explanations of the phenomenon.

Second, inhibitory accounts of negative priming do not necessitate abstract logogen-like representations. Our current conceptions of inhibition are that these processes are flexibly applied to the relevant characteristics of the event or object that is selected against (e.g., Tipper et al., 1994). It is the retrieval of this processing that is the source of negative priming, and such processing can apply equally well to any form of representation.

Third, the real differences between inhibition and retrieval accounts lie simply in terms of emphasis. Inhibition accounts more completely describe the encoding stage: That is, the selection mechanisms that engage with the prime display. In sharp contrast, the alternative accounts of perceptual mismatching, temporal discrimination and episodic retrieval ignore the selection mechanisms that *must* be engaged in their experimental procedures. Episodic accounts, for example, in their present form simply provide a verbal re-description of prime processing, such as “do not respond to me” or “also good for response” tags, often in a post hoc manner. On the other hand, episodic accounts have been concerned with describing the crucial importance of the retrieval processes triggered by the probe, which inhibition accounts have tended to neglect. As discussed previously, these retrieval processes must also be carefully considered when attempting to infer inhibitory processes via negative priming effects.

Fourth, explicit considerations of retrieval processes, motivated by episodic accounts, have revealed previously hidden issues within the negative priming effect. Such retrieval accounts have shown that negative priming does not just reveal important mechanisms of selective attention. On the contrary, it also reveals fascinating retrieval processes whereby an ignored stimulus that was irrelevant to a subject’s behaviour, and of which they may be unaware, can lay down a long-term trace of the processing it receives during selection of a target, which is automatically retrieved when a similar object is encountered in the future (DeSchepper & Treisman, 1996; but see also Logan, Taylor, & Etherton, 1996 and Strayer & Grison, 1999, for contrary views).

Clearly there is much more to be learned via the experimental vehicle of negative priming, but a careful balance must be struck between considerations of encoding and retrieval. Thus far, there is little clear evidence to unequivocally discount the notion that negative priming

reflects an inhibitory selection mechanism. The assumption that evidence for the existence of episodic retrieval, for example, must discredit inhibition processing accounts does not follow: Inhibition and retrieval accounts of negative priming are not mutually exclusive. A complete understanding of the encoding and retrieval processes that mediate negative priming will have enormous implications for two, often separate, areas in cognitive psychology: attention and memory.

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APPENDIX I

It is worth noting that consideration of the selection mechanisms via a formal neural/computational model is of great value. That is, the Houghton and Tipper model can explain data that appear to be a mystery from other perspectives. For example, Milliken (personal communication, January 1997) noted the following contrast between a single masked word that produced negative priming with masked words in the presence of a supraliminal target, which produced positive priming: “One further report of the effects of masking on negative priming deserves comment. Neill, Valdes, and Terry (1995) report the results of an experiment that employed an Eriksen flanker task (Eriksen & Eriksen, 1974), in which just the flankers in the prime display were pattern masked. When the masking was near threshold for identification of the flanker letters, a non-significant tendency toward positive priming was observed. Pilot studies of our own, using the interleaved words procedure, also revealed an elimination of negative priming when the prime distractor was masked. *Exactly why negative priming is eliminated by masking of the distractor but is present for a single pattern masked item is an issue left to future research.*”

This future research is not necessary because the Houghton and Tipper model already predicts such a data pattern. As described earlier, the level of inhibitory feedback triggered by the mismatch between the distractor and the template is determined by the salience of the distractor. The greater the perceptual excitation, the greater the inhibition feeding back on to the distractor. However, the level of activity of the distractor is determined not only by its perceptual intensity, but also by lateral inhibition between it and other simultaneously present perceptual inputs. So, for example, the model predicts that negative priming will be weaker when two, as compared to one, distractors are present. This is because the lateral inhibition between the two distractors weakens the overall excitation, hence there is less inhibition feeding back to each individual distractor, as compared to when each is presented alone. Neumann and DeSchepper (1992) and Houghton et al. (1996) have confirmed this.

These lateral inhibition mechanisms predict the apparently paradoxical results referred to by Milliken et al. (1998). Consider the following simple example: Lateral inhibition between perceptual inputs is 10% of their overall activation state. A pattern-masked distractor could have a low level of activity, for example 10 units. A simultaneously present supraliminal target could have a higher activation state of, say, 30 units. The lateral inhibition from the target will therefore reduce the activation state of the distractor by 10% of 30, which is 3. Therefore the distractor's activation state feeding into the template mismatch system is a value of 7. Now consider that this same distractor when presented alone will not receive any lateral inhibition. Hence its activation state remains at a value of 10. Therefore this latter lone distractor will receive greater inhibitory feedback, resulting in larger negative priming effects. A further reasonable assumption that can be made is that these masked stimuli are close to the threshold at which template mismatching is triggered. It is feasible that excitation levels of 10 are above this threshold, resulting in negative priming effects, whereas those of 7 may be below the threshold, resulting in small positive priming effects.

In fact similar results have been observed previously by Tipper, Eissenberg, and Weaver (1992), but with supraliminal stimuli. In that study subjects were presented with prime displays containing a target and a distractor, or a lone distractor not requiring a response (a spatial version of the Milliken et al., 1998, procedure). The data predicted by the model were observed here also. That is, negative priming effects were larger for the lone distractor (49 ms) than for one accompanied by a target (33 ms). Therefore these simple neural/computational mechanisms have generality and perhaps should not yet be discounted.

APPENDIX II

The experiments used by Park and Kanwisher (1994) to discount inhibition mechanisms in spatial negative priming tasks need to be analysed carefully. In one of their experiments, Park and Kanwisher changed the procedure such that the prime contained two targets (two Os) rather than the usual target and distractor (O and X). Subjects were free to choose either target and then reported its location via a key press. The ignored repetition condition probe had a target (O) in the location of the unselected prime target (O). Park and Kanwisher predicted no negative priming in this case, because there was no perceptual mismatch between probe target and prime distractor. The results confirmed their prediction.

The selection task investigated by Park and Kanwisher (1994) is qualitatively different from that investigated in all other studies of negative priming. As mentioned earlier, Baylis et al. (1997) pointed out that there are two forms of selection: The form usually studied they termed external selection, in which the target is predetermined (e.g., name the red object or report the location of the O); the form of selection studied by Park and Kanwisher (1994) they termed internal selection, because subjects were free to decide which object would be the target and which the distractor. As discussed, the Houghton and Tipper (1994) model also predicts no negative priming when subjects are free to select either stimulus in a display (internal selection). This is because there is no template against which perceptual inputs can mismatch, and hence no source for inhibitory feedback. Consistent with the notion that there is no inhibitory feedback is the fact that individuals free to choose a target apparently analysed distractors to a much deeper level. Thus they were able to recognize the distractors later, whereas those searching for a pre-specified target via a template match/mismatch process (external selection), could not recognise the distractors later. Therefore, the argument here is that negative priming is abolished when two targets are presented in the prime, not because the prime distractor and probe target are the same object (as Park & Kanwisher argued), but because internal selection is taking place, and such selection does not utilize reactive inhibition mechanisms.

In spatial priming paradigms (e.g., Tipper et al., 1990), it is usual to have one letter (e.g., "O") serve as target at all times, and another letter (e.g., "X") as distractor. In another of their experiments, Park and Kanwisher (1994) altered this such that the target was "X" in the prime, and "O" in the probe. The ignored repetition condition as it is usually defined has the probe target appear in the same location as the prime distractor. Note that in this experiment, the probe target and prime distractor were both "O", and there was no perceptual mismatch. In the "attended repetition" condition, on the other hand, subjects had to report the location of an "X" in the prime, and then of an "O" in the same location in the probe. In this case, there is a perceptual mismatch. Park and Kanwisher predicted negative priming for this attended repetition condition because of the perceptual mismatching, but no negative priming for the usual ignored repetition condition because there was no perceptual mismatching. Again, the results bore out their predictions.

Two difficulties arise in interpreting the results of this "switching" experiment. The first is that the attended repetition condition in spatial localization experiments is notorious for producing a variety of results. In various studies the targets in both the prime and the probe display are the same object (e.g., O). Sometimes the attended repetition condition yields facilitation relative to the baseline control condition (e.g., Neill, Terry, & Valdes, 1994); sometimes it yields no difference from control (e.g., Tipper et al., 1990); and sometimes it yields reaction time (RT) costs relative to control (e.g., Shapiro & Loughlin, 1993). This latter outcome has been frequent enough, in fact, to prompt speculation as to whether the attended repetition effect is the same thing as Posner and Cohen's (1984) "inhibition of return". Therefore, given that the attended repetition condition occasionally produces RT costs even when no perceptual mismatches occur, it is difficult to construe Park and Kanwisher's (1994) finding of negative priming as conclusive evidence concerning the mismatching hypothesis.

The second interpretative difficulty concerns the assumption that selection in Park and Kanwisher's (1994) switching experiment is the same as when target and distractor identities remain constant from prime to probe. We have argued elsewhere that this assumption is probably incorrect (Milliken, Tipper, & Weaver, 1994), but did so in a footnote, because the argument was tangential at the time. That argument is not tangential now and bears repeating. In Park and Kanwisher's switching experiment (see also Tipper & Cranston, 1985) subjects were informed of the different selection cues for prime and probe prior to doing the experiment. Ward (1982) used a similar procedure in a task that required subjects to identify the global level of a hierarchical stimulus in a first display (prime), and then the local level in a second display (probe). In Ward's study, and in both negative priming studies cited previously, RTs were generally much longer in these "switch" tasks than in comparable situations in which the selection criterion was the same for both prime and probe displays.

Ward (1982) suggested that switching the selection criteria may have led subjects to adopt two “shared attention states”, one to be used in responding to the first display (global level), and another to be used in responding to the second display (local level). In either state, some resources were directed towards identifying the global level and some towards identifying the local level. The two states differ in terms of how many resources are dedicated to each of these goals. When identifying the global level in the first display, fewer resources are allocated to identification of the local level; and when identifying the local level, fewer resources are allocated to identification of the global level.

Ward’s (1982) description of processing in the global/local task is relevant to Park and Kanwisher’s (1994) switching experiment. It is entirely possible that subjects in the latter experiment were also splitting their resources between the target and distractor in the prime display. This strategy would lead to the longer RTs that were observed as well as to a state of activation for the prime distractor that is quite atypical of traditional negative priming studies in which the distractor is consistently irrelevant to behavioural goals. Therefore it may not be surprising that facilitatory, rather than inhibitory, priming was observed in the Park and Kanwisher study.

In yet another of the Park and Kanwisher (1994) experiments, some of the primes had two distractors only (two Xs). (Note that such primes do not require selection of a target, or any overt behaviour.) The subsequent target probe (O) could appear in an empty location (control) or in a location previously occupied by one of the prime distractors (Xs). As predicted, Park and Kanwisher observed higher RTs in the mismatch condition, where the prime X and probe O appeared in the same location than in the control.

Park and Kanwisher (1994) concluded that “selection for a target has little to do with negative priming in the spatial selection task used by Tipper et al. (1990)”, and as we will see later, similar claims are made by Milliken et al. (1998). However, note that the template match/mismatch mechanism also predicts negative priming in such studies. The X in the prime display, even though not requiring an overt response, accesses the template. This triggers a mismatch signal that feeds back onto the internal representations of the X prime. This notion is discussed in more detail in a subsequent section.

Finally, Park and Kanwisher (1994) required subjects to passively view the O and X of the prime display in their Experiment 5. When the probe appeared, report of the target O’s location was required. Park and Kanwisher argued that because subjects were passively viewing the prime display, that is, they were not overtly responding, there should be no evidence for negative priming. However, even though no overt behaviour towards the prime display was produced, negative priming was observed. This was taken as further evidence to support the notion that negative priming does not reflect a mechanism of selective attention.

Of course the problem with such an experiment is that there is no way of knowing what kind of information processing subjects activate in such “passive” viewing conditions. In fact we would contend that selective attention processes are engaged during viewing of the prime display. It has been well documented (e.g., Posner & Cohen, 1984) that attention is automatically captured by the sudden onset of a visual stimulus. Such attentional capture takes place even when subjects are told to ignore the stimulus (e.g., Tipper, Driver, & Weaver, 1991a), as was the case in the Park and Kanwisher (1994) experiment. Therefore attention would have been oriented towards one of the objects in the prime display. Furthermore, because the procedure required subjects to select the O and ignore the X in the probe display, and to maintain this selection state throughout the experiment, subjects would have been biased to process the prime display similarly. Thus, even though instructed to passively view the prime display, attention may have been directed towards the O and away from the X due to the maintenance of the template for O. Such selection would result in negative priming effects.

Indeed, recent studies have confirmed automatic selection of stimuli that were recently attended but are not relevant to the current task. For example, Downing (2000) required subjects to remember a picture for later recognition. They then had to do an unrelated task that required them to detect the onset of a briefly presented stimulus to the left or right of fixation. Before onset of this target two irrelevant to-be-ignored pictures were briefly displayed. One of these pictures was the same as that required for later matching-to-sample. Downing showed that detection of the target on the same side as the previously presented picture was facilitated. Hence, even though the pictures were irrelevant to the task, attention was automatically oriented to the stimulus maintained in working memory. This automatic selection is the same process mediating the Park and Kanwisher (1994) results (see also Pashler & Shui, 1999, for even more dramatic effects of automatic orienting to no-longer-relevant stimuli). Such failure to disengage from prior processing is not a new idea. For example, it is discussed by Folk, Remington, and Johnston (1992, 1993) and Yantis (1993) within the contingent involuntary orienting hypothesis; as it is in discussions of the impaired performance when subjects have to switch from one task to another (e.g., Allport & Wylie, 1999).

APPENDIX III

Neill (personal communication, 1998) has argued that “damaging to the Houghton–Tipper model is the result of Wood and Milliken (1998), in which negative priming occurred in nonsense–shape matching (as in DeSchepper & Treisman, 1996) for shapes that had been explicitly attended in a corner–counting task.” It is necessary to consider the Wood and Milliken experiments here, because, on the contrary, a model in which irrelevant information can be inhibited predicts the data. In the Wood and Milliken task subjects are presented with random shapes (e.g., DeSchepper & Treisman, 1996). Subjects were required to undertake two forms of processing during the prime. In the *remind* condition subjects wrote down what each shape reminded them of. In the *corners* condition subjects counted the corners of the shapes. There were two main findings: First, in later explicit recognition, subjects were more accurate after viewing the shapes in the remind than in the corners condition; second, negative priming, when the shape was subsequently presented as a target to be matched with another same or different shape, was only observed in the corners counting condition. Wood and Milliken concluded that “the negative priming effects observed here cannot reasonably be attributed to a process of ignoring” (p. 19).

We find these conclusions somewhat puzzling. Consider the tasks again. In the remind condition subjects attend to the global shape. Thus the standard result is observed in which attended processing does not necessarily produce negative priming, and the shapes are explicitly recognized later. In the corners condition, however, the global shape is now irrelevant to performance and can provide information conflicting with response decisions. That is, two stimuli with different numbers of corners requiring a “no” response can have very similar shapes activating a “yes” response; whereas two stimuli with the same number of corners (“yes” response) can have very different global shapes (“no” response). This task is therefore a variant on the familiar Stroop (1935) or local–global (Navon, 1977) displays in which negative priming is well established (Briand, 1994; Dalrymple–Alford & Budayr, 1966; Neill, 1977): Some properties of an object can be relevant to behavioural goals whereas other properties are irrelevant and can interfere. Thus, the act of selecting corner information from irrelevant global shape could be achieved via inhibition of the global shape, which results in subsequent negative priming in a shape–matching task and relatively impaired explicit recall of the ignored global shape information.

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