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# Negative priming and sequence learning

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Three experiments used a novel sequence learning task, in which participants responded to changes in location of one visual stimulus whilst ignoring another. Experiment 1 demonstrated negative priming effects in this task, in that responses to individual sequence elements were disrupted when the attended stimulus (e.g., red asterisk) appeared at the location taken by the unattended stimulus (e.g., blue asterisk) on the immediately preceding trial. Experiments 2 and 3 found that negative priming effects extended beyond sensitivity to individual items, suggesting that people may be able to learn about sequential features of ignored events as well as about single events in isolation. The results are discussed in relation to current theories of negative priming.

A key aspect of effective perceptual-motor functioning is the ability to select and respond to relevant stimuli in the environment, as well as the ability to ignore (and not respond to) irrelevant stimuli. In order to account for these abilities, a number of models of attention (e.g., Houghton & Tipper, 1994; Neill, 1977, 1989) have been proposed in which visual selection depends on the existence of both excitatory and inhibitory mechanisms. Much of the behavioural evidence for this comes from the phenomenon of Negative Priming (NP). Negative priming is shown when a stimulus that was irrelevant on one trial (known as the prime trial) becomes relevant on a subsequent trial (known as the probe trial). In such situations, responses on the probe trial are typically

impaired compared with responses to a control stimulus that was not previously presented. For example, in a now classic study by Tipper (1985), participants viewed a prime display consisting of a red line drawing superimposed over a green one and were asked to name the red drawing. The subsequent probe display also consisted of a red drawing superimposed over a green one, and participants were again asked to name the red drawing. In the control condition, neither of the drawings in the prime display was related to the subsequent probe, but in the ignored repetition condition, the distractor in the prime display was the same as the target in the probe display. The results showed longer reaction times in the ignored repetition condition compared with the control condition.

Since the initial demonstrations, negative priming has been documented in a large number of studies which have used a variety of stimuli, procedures and subject populations. For example, NP effects have been demonstrated in selective attention tasks that require letter naming (Tipper & Cranston, 1985), word naming (Tipper & Driver, 1988), lexical decision (Yee, 1991), matching of nonsense shapes (DeScheppe & Treisman, 1996), target localisation (Tipper, Brehaut, & Driver, 1990), and reaching (Tipper, Lortie, & Baylis, 1992). Interestingly, effects have been shown to be diminished in certain subject populations; for example, children (Tipper, Bourque, Anderson, & Brehaut, 1989), people with schizophrenia (Beech, Baylis, Smithson, & Claridge, 1989), and Alzheimer's patients (Simone & Baylis, 1997; Sullivan, Faust, & Balota, 1995). It has been argued that these diminished levels of negative priming might stem from a deficiency in the inhibition of irrelevant information.

In terms of theoretical accounts, the prevailing view (most associated with Tipper and colleagues) is that NP is a reflection of inhibitory processes of selective attention. In contrast, the episodic retrieval account (e.g., Neill & Valdes, 1992) suggests that NP is produced by the memory retrieval of an episode in which the current target stimulus was ignored. According to this view, delayed responding on the probe trial is caused by a conflict between the ''do not respond tag'' associated with an ignored distractor on a prime trial and a ''respond'' tag on the same stimulus on the subsequent probe trial. Two other accounts which attempt to explain NP without recourse to inhibitory processes are Park and Kanwisher's (1994) Perceptual Mismatching account and Milliken, Joordens, Merikle, and Seiffert's (1998) Temporal Distinctiveness account. According to the former, NP is caused by a change in the bindings of symbol identities associated with objects which appear in the same location in the prime and probe displays.[1] In contrast, the latter account suggests that slowed responding results from ambiguity as to whether a probe should be responded to by reinstating prior learning or by engaging new learning.

[1] There is now mounting evidence against the Park and Kanwisher account (see, for example, Baylis, Tipper, & Houghton, 1997; Buchner, Steffens, & Berry, 2000; Fuentes, Humphreys, Agis, Camona, & Catena, 1998; Milliken, Tipper, & Weaver, 1994; Tipper, 2001).

Despite the vast amount of research on the topic in the last decade, nearly all NP studies to date have involved participants responding to individual stimulus events; only a small number (e.g., Allport, Tipper, & Chmiel, 1985; Tipper & Cranston, 1985) has been concerned with sequences of events. Tipper and Cranston, for example, demonstrated negative priming in a list reading task in which participants had to read aloud a list of red letters while ignoring simultaneously presented green letters. One reason for the bias towards experiments using individual items is that sequential tasks have typically produced smaller negative priming effects. Despite this, the present study employs a sequential task, as it allows us to address the important (and hitherto neglected) question of how much can be learned about ignored events. Specifically, can people learn about sequential features of ignored events, in addition to learning about single events in isolation? Our study addresses this question using a continuous sequence learning task, in which participants respond to the location of asterisks appearing on the computer screen (following a patterned sequence). The primary question of interest (investigated in Experiments 2 and 3) is whether negative priming effects can extend beyond sensitivity to individual items, that is, to higher levels of learning. However, it is first necessary to establish that negative priming can be observed in a continuous sequence learning task (Experiment 1).

In the standard sequence learning task (e.g., Nissen & Bullemer, 1987), an asterisk appears in one of four locations (arranged horizontally) on a computer monitor. Participants are required to press the one key, out of four keys, that is directly below the position of the asterisk. A second asterisk then appears, and so on. The sequence of the asterisks is either determined randomly, or else appears in a continous repeating sequence. The results typically show a significant decrease in reaction time with training in the repeating sequence condition, but not in the random condition. Futhermore, when participants in the repeating condition are switched to a random sequence, reaction times increase substantially.

In the present study, a novel version of the sequence learning task is employed, in which participants have to attend (and respond) to one stream of information while ignoring another. Colour is used to differentiate between the to-be-attended and to-be-ignored streams. Thus, on each trial, participants are required to respond to the location of a red asterisk, for example, whilst ignoring a simultaneously presented blue asterisk. Experiment 1 investigates whether negative priming of individual stimulus elements occurs in this continuous task. Experiments 2 and 3 examine whether priming effects can extend beyond sensitivity to single elements within the sequence.

## EXPERIMENT 1

This experiment examines whether negative priming effects can be observed in a novel version of the sequence learning task, in which participants have to respond to one sequence of information whilst ignoring another. In this task, the

attended (e.g., red) asterisk appeared in one of six locations on the computer screen and followed a repeating 10-element sequence. The unattended (e.g., blue) asterisk followed a pseudorandom sequence which was modified to include negative priming (NP) trials. Negative priming trials were those on which the attended asterisk appeared in the location taken by the unattended asterisk on the immediately preceding trial. Twenty percent of trials were designated NP trials. It was predicted that RTs (to the attended asterisk) on these trials would be slower than those (to the attended asterisk) on corresponding non-primed trials.

## Method

*Participants.*    The participants were 20 undergraduate students from the University of Reading participant panel, aged between 18 and 45, with normal or corrected vision. They were either paid for their time, or received course credit.

*Apparatus.*    The experiment was run on a 486 IBM-compatible personal computer, with a 34 cm colour monitor and standard keyboard.

*Task and design.*    On each trial, two asterisks (one red and one blue) appeared on the computer screen in two of six horizontal locations.[2] The asterisks were positioned 7 cm above the bottom of the screen. Each asterisk measured $0.5 \times 0.5$ cm. Asterisk locations were marked by underline bars, which stayed on the screen throughout. Each underline bar was separated from its neighbouring bar/s by a gap of 3 cm. Responses were made by pressing one of six keys on the second from bottom row on the computer keyboard (\ x v n , /). On each trial, the two asterisks stayed on the screen until the participant pressed the key corresponding to the current position of the attended asterisk. The next trial began 400 ms later. Participants were instructed to attend to one asterisk (e.g., the red one) and ignore the other. The attended asterisk followed a repeating, 10-element, sequence. Two different (attended) sequences were used, which were counterbalanced across participants, as was asterisk colour (both attended and unattended). The sequences were 2412543651 and 5145216324, where the numbers 1–6 represent the six possible horizontal locations from left to right. The unattended asterisk also used the same locations, but followed a pseudorandom sequence (which matched the patterned sequence in terms of the frequencies with which asterisks could appear at each of six locations) with additional constraints. The unattended asterisk was not allowed to appear in the same location as the attended asterisk on any trial, nor in the location which would be the location of the attended asterisk on the next trial (except for on the

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[2] We used six locations rather than the standard four in order to meet the constraints imposed by the co-incidence of the (10-element) attended and unattended streams.

specified negative priming trials). It was also not allowed to appear in the same location on two successive trials.

There was only one experimental condition, with negative priming being manipulated within participants. A negative priming (NP) trial was defined as one in which the attended asterisk appeared in the location taken by the unattended asterisk on the immediately preceding trial. Twenty percent of trials (approximately two in every 10) were designated NP trials. All elements of the attended sequence were ''negatively primed'' comparably often in each block of 130 trials. None of the first 20 or last 10 trials of each block were designated NP trials. RTs on each NP trial were compared with those on equivalent non-NP trials. For example, for the sequence 2412543651, if the first occurrence of the attended asterisk in location 5 was the designated NP trial (i.e., the unattended asterisk appeared in that location on the immediately preceding trial), the RT on this trial was compared with the average of the RTs to the location 5 (following location 2) on its immediately preceding and immediately following occurrence (i.e., 10 trials before and 10 trials after).

*Procedure*. Participants were tested individually. Requirements were explained to them both orally and in writing. They were told that they should respond to the red (blue) asterisk, and ignore anything else on the screen. They were instructed to respond as quickly as possible, whilst ensuring that errors were kept to a minimum. Responses were made by pressing one of the six designated keys (\ x v n , /). Participants were instructed to use their ring, middle, and index fingers of each hand. It was explained that the asterisk would stay on the screen until they pressed the appropriate key. They were informed that there would be two preliminary practice blocks of trials (as indicated on the screen), followed by the main experiment. Each practice block consisted of 130 trials, on which the attended (and unattended) asterisk followed different pseudorandom sequences. Participants were not told anything about the possible existence of a (patterned) sequence at any stage. The main experiment consisted of nine blocks of 130 trials. At the end of each block, a message appeared on the screen advising participants to take a short break. They were told to press any key to continue the experiment. At the end of the final block, participants were asked a series of graduated questions to assess their awareness of the attended and unattended streams of information, and any relationship between them (see Appendix A). The entire experiment lasted about 50 minutes, after which participants were fully debriefed.

## Results

Participants made relatively few errors; the average across blocks being 7.55% for the NP trials and 6.69% for the non-NP trials. A two-factor (block × priming type) ANOVA showed no significant effect of block, $F(8, 12) = 1.14$, $p > .1$, no

significant effect of priming type, $F(1, 19) = 1.66$, $p > .1$, and no significant interaction, $F(8, 12) < 1$. The following analyses are based on RT data for correct responses. A preliminary analysis of the correct RT data showed no effect of sequence used or asterisk colour; these factors were not entered into the following analyses.

Figure 1 shows mean response latencies for both NP and comparison non-NP trials for the nine blocks of trials. A two factor (block × priming type) within-subjects multivariate analysis of variance showed significant effects of both block, $F(8, 12) = 7.34$, $p < .001$, and priming type, $F(1, 19) = 16.12$, $p < .001$, with participants responding more slowly on the NP trials (mean = 529 ms, SD = 67) than on the non-primed trials (mean = 517 ms, SD = 62). There was no significant interaction, $F(8, 12) = 0.32$, $p > .1$.

As far as the post task questions were concerned, 13 of the 20 participants reported noticing (but only after some time) that the attended asterisk did not move at random. Of these, three could specify the whole sequence and four could report parts of it. None of the participants made any spontaneous com-
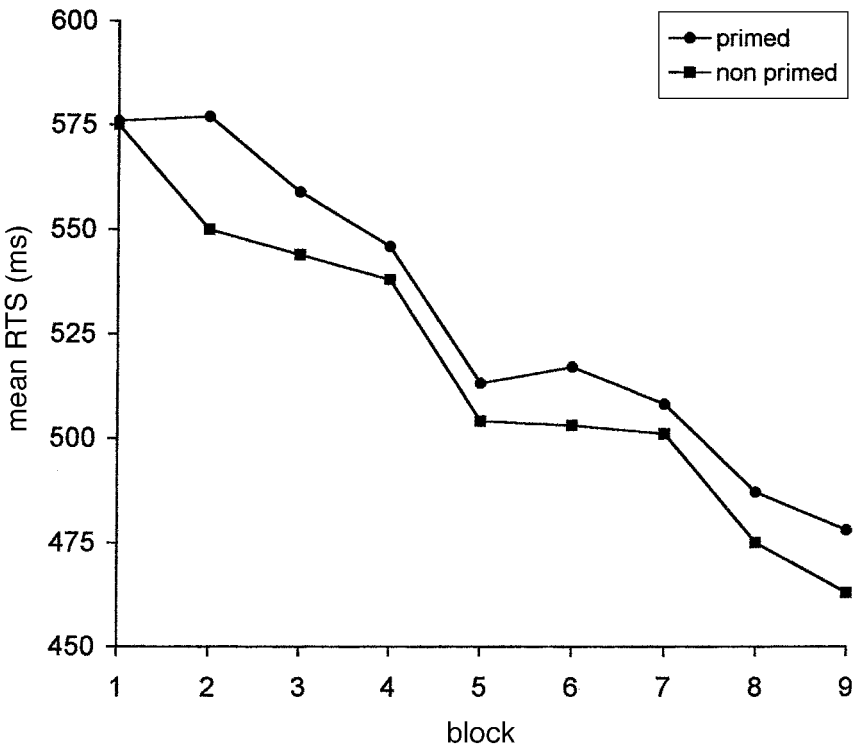


**Figure 1.** Experiment 1: Mean reaction times for the Negative Priming and comparison Non-Negative Priming trials for the nine blocks of trials.

ments about the unattended stream; when prompted, they said they had assumed that it was random. None of the participants reported any relevant information about the relationship between the locations of the attended and unattended asterisks across trials.

Given that so many participants became aware of the systematicity in the attended sequence during the course of the experiment, we felt it important to confirm that the negative priming effect was still present on the final block of trials. A paired $t$ test showed that participants were still responding more slowly on the negatively primed (mean = 478 ms, SD = 92) than on the non-primed (mean = 463 ms, SD = 78) trials on block 9, $t(19) = 1.76$, $p < .05$ (one-tailed).

## Discussion

In line with many other studies in the literature, participants showed significantly faster responding with practice (implying learning of the attended sequence). More interestingly, they responded significantly more slowly on the designated NP trials than on the corresponding unprimed trials. Although the size of the RT difference between negative priming and control trials was relatively small (12 ms), it is not out of line with that reported in many other negative priming studies (see Fox, 1995). Moreover, the sample estimate of the standardised NP effect was very large, $d_z = 0.9$ (cf., Cohen, 1977). Of particular interest is the fact that the NP effect was still very much in evidence on the final (ninth) block of trials. By this stage, participants had learned to anticipate (to some extent) the location of the attended asterisk, yet they were still disrupted when the attended asterisk appeared in the location taken by the immediately preceding unattended asterisk. In other words, we might have expected the NP effect to dissipate as participants came to learn the attended sequence and respond more automatically. As this was not the case, our results confirm and extend those of Tipper, Eissenberg, and Weaver (1992), showing that the negative priming effect is very robust.

The fact that participants responded more slowly on the NP trials shows that they were clearly sensitive to the unattended stream of information. Despite this, they showed no explicit awareness of the nature of the unattended stream, nor its relationship to the attended sequence.

## EXPERIMENT 2

Experiment 1 showed evidence of negative priming of individual stimulus elements in a sequence learning task. The purpose of Experiment 2 was to examine whether negative priming effects can extend beyond the learning of individual items. Specifically, in a sequence learning task, if participants respond to one patterned sequence while ignoring another, do they learn something about the ignored sequence? More specifically, do they learn which event is to be ignored next if the to-be-ignored events exhibit a certain

sequential regularity? If so, then reactions to the next to-be-ignored event may be inhibited so as to reduce interference at the time of responding. As a consequence, one may assume that responses will be slowed in a condition in which participants are required to react to a previously ignored sequence in relation to a condition in which participants have never been exposed to that sequence before.

In order to address this question, one group of participants in Experiment 2 (ignore-pattern condition) attended and responded to a certain patterned sequence for eight blocks of trials, while ignoring a different patterned sequence. A second group (ignore-random condition) attended and responded to the patterned sequence for eight blocks, while ignoring a pseudorandom sequence. Both groups were then required to respond (for four blocks of trials) to the sequence previously ignored by participants in the ignore-pattern condition. On the strength of the results of Experiment 1, we anticipated that participants would be sensitive to the unattended stream. In particular, we predicted that if negative priming effects can operate with other than isolated stimuli, participants in the ignore-pattern condition should be more disrupted at block 9 (when the attended sequence changed) than participants in the ignore-random condition.

There are two other possible outcomes for this experiment. First, if participants are not sensitive to the patterned structure of the unattended stream of information (presented on blocks 1–8) one would predict that both groups would perform at a comparable level on the final four blocks of trials. Second, it was possible that prior exposure to the unattended sequence might actually result in facilitation when participants are required to respond to the previously ignored sequence. Indeed, some experiments using traditional negative priming tasks (e.g., Lowe, 1979; Milliken et al., 1998; Moore, 1994) have found that when participants are not required to ''select'' (i.e., respond to one stimulus while ignoring another) on probe trials, repeated exposure to a previously ignored stimulus leads to positive rather than negative priming. Experiment 2 was designed such that only the attended asterisk was presented during blocks 9–12 (and hence no selection was required on these trials).

## Method

*Participants.*    The participants were 124 undergraduate students from the University of Reading subject panel, aged between 18 and 45. They were either paid for their time, or received course credit. None had participated in Experiment 1. Fifty participants were allocated at random to each of two experimental conditions. A further 24 participants were allocated at random to a control condition (see later).

*Apparatus.*    This was the same as in Experiment 1.

*Task and design.*    On each trial (apart from those in the last four blocks), two asterisks (one coloured red and one blue) appeared on the computer screen in two of four horizontal locations.[3] The asterisks appeared 7 cm above the bottom of the screen. Asterisk size and position (including underline bars) were the same as in Experiment 1. Participants were instructed to attend to one asterisk (e.g., the red one) and ignore the other. Responses were made by pressing one of four keys on the second from bottom row on the keyboard (z c b m), and participants were instructed to use their middle and index fingers of each hand. On each trial, the two asterisks stayed on the screen until the participant had pressed the correct key corresponding to the position of the attended asterisk. The next trial began 400 ms later.

Two different repeating, six-element, sequences were used, which were counterbalanced across participants, as was asterisk colour. The sequences were 123243 and 241321, where the numbers 1–4 represent the four possible horizontal locations from left to right. All participants carried out two blocks of 90 practice trials (with pseudorandom sequences), followed by 12 blocks of 90 experimental trials. On the first eight blocks, participants had to attend to one asterisk whilst ignoring the other. During blocks 9–12, only the attended asterisk appeared on the screen. In one experimental condition (ignore-pattern group), participants attended to a certain patterned sequence during blocks 1–8, whilst ignoring a different patterned sequence. Unbeknown to them, the sequence that they were required to respond to on blocks 9–12 was the same as the one they had ignored on blocks 1–8. In the other experimental condition (ignore-random group), participants attended to the same patterned sequence whilst ignoring a pseudorandom sequence on blocks 1–8. The pseudorandom sequences were matched for location frequency to the structured sequences in the ignore-pattern group (counterbalanced across participants). Participants in the ignore-random group were also switched to the second patterned sequence for blocks 9–12. Finally, a control condition was included, in which participants responded to the same patterned sequence for all 12 blocks of trials. During the first eight blocks they were also presented with the to-be-ignored distractor sequence (in the same way as participants in the ignore-pattern condition). There was only one asterisk present on each trial during the final four blocks. This control condition was included to ensure that any drop in performance at block 9, particularly for participants in the ignore-pattern group, could not simply be attributed to the disappearance of the unattended asterisk.

*Procedure.*    The procedure was very similar to that used in the previous experiment, with the exception that, following practice, participants carried out 12 blocks of 90 trials (rather than 9 blocks of 130 trials). Following the twelfth

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[3] We were able to return to four locations in this experiment as the sequences had only 6 elements, as opposed to 10 in Experiment 1.

block, they were asked a series of graduated questions to assess their awareness of the attended and unattended sequences on both blocks 1–8 and 9–12 (see Appendix B).

## Results

As in Experiment 1, overall mean RTs, together with error rates, were measured for each block. The mean RTs for each different attended element transition (for example, 1–2, 2–3, 3–2, etc.) were also recorded for each block. Preliminary analyses again showed no significant effect of asterisk colour or sequence used (at least, not with regard to within-condition counterbalancing), so these factors were not entered into the subsequent analyses.

### Blocks 1–8

*Error data.*    Error rates were again very low, ranging between 3% and 5%. A multivariate analysis of variance (MANOVA), with group as a between subjects factor and block as a within subjects factor, showed no significant effect of block, $F(7, 115) = 1.21$, $p > .1$, nor group, $F(1, 121) = 1.87$, $p > .1$, and no significant interaction, $F(14, 232) < 1$.

*RT data.*    Figure 2 shows mean response latencies for two experimental and one control group across blocks 1–8. A MANOVA, with group as a between-subjects factor and block as a within-subjects factor, showed a significant effect of block, $F(7, 115) = 30.32$, $p < .001$, but no significant effect of group, $F(1, 121) < 1$, and no significant interaction, $F(14, 232) < 1$. This lack of effect of group and lack of significant interaction was confirmed in a second ANOVA, when performance on only blocks 1 and 8 was considered ($p > .1$ in both cases).

### Blocks 9–12

*Error data.*    Error rates ranged from 4% to 6%. A MANOVA, with group as a between-subjects factor and block as a within-subjects factor, showed no significant effect of block, $F(3, 119) = 2.28$, $p > .05$, nor group, $F(2, 121) = 1.03$, $p > .1$, and no significant interaction, $F(6, 240) < 1$.

*RT data.*    Figure 2 also shows mean response latencies for the three groups, taken separately, across blocks 9–12. A MANOVA, with group as a between-subjects factor and block as a within-subjects factor, showed a significant effect of block, $F(3, 119) = 45.31$, $p < .001$, and a significant effect of group, $F(2, 121) = 4.91$, $p < .01$. The interaction just missed significance, $F(6, 240) = 2.05$, $p = .06$. Post hoc Newman Keuls tests showed that the performance of participants in the control group differed significantly from that of participants in both
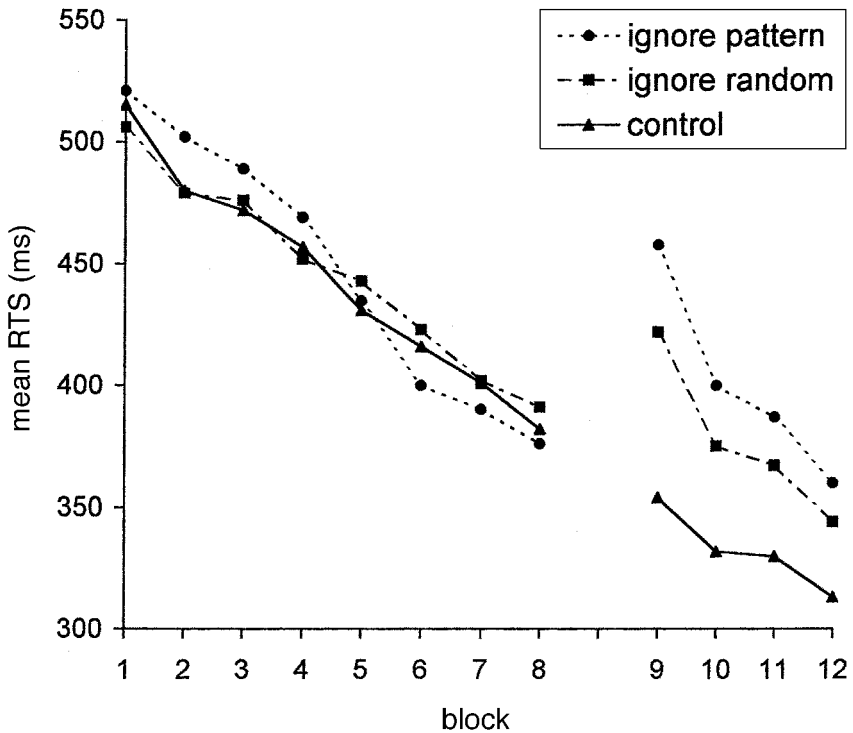
**Figure 2.**   Experiment 2: Mean reaction times for the three groups of participants for the 12 blocks of trials.

experimental groups ($p < .05$), but the latter two groups did not differ significantly from each other.

### Blocks 8 and 9

The most important aspect of the results concerned the performance of the two experimental groups on blocks 8 and 9. A difference score was computed (between mean scores on blocks 8 and 9) for each of the two groups of participants, for error and RT data.

*Error data.*    Mean difference scores were 1.30 and 1.0 for the ignore-pattern and ignore-random groups respectively. An independent $t$ test showed no significant difference between the two groups, $t(98) = 0.57$, $p > .1$.

*RT data.*    Mean difference scores were 81.26 and 30.24 ms for the ignore-pattern and ignore-random groups respectively. An independent $t$ test showed a significant difference between the two groups, $t(98) = 3.10$, $p < .01$.

*Transition analysis*

The preceding analysis showed that participants in the ignore-pattern group were more seriously disrupted at block 9 (relative to block 8) than were participants in the ignore-random group. This could be because participants in the former group learned to ignore, and to inhibit reactions towards, the successive events of the entire unattended sequence during the earlier blocks. Alternatively, participants may have been inhibiting only those transitions that were unique to the unattended sequence (and not those that were common to the attended and the ignored sequence). Specifically, transitions 1–2, 3–2, and 2–4 were common to both patterned sequences. All other transitions were unique to one of the two sequences. We therefore computed (for both experimental groups) the difference between response times at block 9 for element transitions that were common to both the attended and the unattended sequence during blocks 1–8 and those for element transitions that were only present in the unattended sequence. The mean RT differences were 30.93 ms and 40.14 ms for the ignore-pattern and ignore-random groups respectively. An independent $t$ test showed no significant difference between the groups, $t(98) = 0.826$, $p > .1$.

*Post task questions*

The majority of subjects in the control group (19 out of 24) reported that the attended asterisk had followed a pattern, and 13 of them could specify most of the sequence. They were all aware that the unattended asterisk disappeared in the latter part of the experiment. As far as the experimental participants were concerned, the majority (42 out of 50 for the ignore-pattern group and 38 out of 50 for the ignore-random group[4]) were aware that the attended sequence followed a pattern on blocks 1–8, but were unable to recall it precisely (when prompted) due to the delayed questioning. The majority of experimental participants also reported that the attended sequence changed in the latter part of the experiment, and were aware that the sequence on blocks 9–12 was also patterned. Most (45 out of 50 in the ignore-pattern group and 43 out of 50 in the ignore-random group) could report at least some elements of it. In contrast, very few of the participants (8 out of 50 in the ignore-pattern group and 3 out of 50 in the ignore-random group) who ignored a patterned sequence on blocks 1–8 commented (incorrectly in the case of the ignore-pattern group) that the unattended sequence might not have been random and, even when prompted, no participants in the ignore-pattern group reported noticing a relationship between the unattended sequence on blocks 1–8 and the attended sequence on blocks 9–12.

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[4] The difference between the ignore-pattern and ignore-random groups was not significant, Chi-square $(1) = 1.0$, $p > .1$.

## Discussion

Significant learning of the attended sequence was found for all three groups across blocks 1–8. There was no significant difference between groups and no interaction, showing that participants performed at the same level whether they were ignoring a patterned or a random sequence.

Across blocks 9–12, control participants (who responded to the same attended sequence throughout) continued to improve in line with previous performance. Simple disappearance of the unattended asterisk therefore did not cause any serious disruption. In contrast, and as expected, response times of both experimental groups increased significantly at block 9 when the attended sequence changed (falling again across blocks 9–12 as participants started to learn the new attended sequence).

Most importantly, experimental participants who ignored the patterned sequence on blocks 1–8 were significantly more disrupted at block 9 than those who ignored the random sequence on the earlier trials. This suggests that participants inadvertently learned something about the ''unattended'' sequence while responding to the attended sequence during the earlier trials, and that this learning resulted in a detrimental rather than a facilitative effect on subsequent performance. Furthermore, the results of the transition analysis showed that the slowed responding was not restricted to transitions which were unique to the unattended patterned sequence on blocks 1–8. Rather, participants learned to ignore the successive events of the entire unattended sequence during the earlier blocks of trials.

How can we account for the fact that participants in the ignore-pattern group were significantly more disrupted at block 9 than were participants in the ignore-random group? Our preferred explanation is that slowed responding at block 9 to the previously ignored sequence is due to some form of negative priming. Kahneman, Treisman, and Burkell (1983) have shown that giving explicit advance information about target or distractor locations can reduce selection costs. It is thus easy to imagine that it would be an advantage to have a mechanism that could determine in advance the location of an irrelevant stimulus so that responses to this stimulus could be prevented either by an inhibitory device (e.g., Tipper, 1985, 2001) and/or by attaching a ''no response tag'' to the (visually marked) episodic representation of the distractor location (e.g., Neill & Valdes, 1992). This could be accomplished by a sequence learning mechanism that would be powerful enough to pick up contingencies not only between attended but also between to-be-ignored events (that belong together and form a stream of events as a result of their having the same perceptual features, colour in our case).

Recent evidence has suggested that the mechanism underlying sequence learning can indeed be both general and powerful. For instance, Schmidtke and Heuer (1997) concluded from their findings that implicit sequence learning could be characterised as a basic and nonselective learning of all potentially

relevant relations between a person's actions and the stimuli in the environment. Their participants responded to systematic sequences of visual events with manual key presses. They also reacted to systematic sequences of auditory events interspersed between the manual responses and the subsequent visual signals by pressing, or not pressing, a foot pedal, depending on which of two different tones was presented. The data indicated that participants were able to learn the systematicities inherent in the visual and auditory sequences as an integrated visual-auditory sequence.

Frensch and Miner (1995) presented data indicating that participants who respond to sequences of alternating letters and unpronounceable graphical symbols may also learn both kinds of sequence simultaneously. However, in this case, the sequences of letters and of graphical symbols appeared to have been learned independently of each other. The authors assumed that the learning of the sequences of letters and graphical symbols involved a phonological and a visual working memory, respectively, as explicated in the working memory model of Baddeley and Hitch (1974). Along similar lines, Mayr (1996) demonstrated that people can simultaneously learn two independent sequential patterns. One pattern consisted of a regular sequence of objects to which participants reacted with a discriminative response. Successions of locations at which these objects could appear constituted the other pattern. The two sequences were uncorrelated. Nevertheless, even participants classified as unaware of the patterns learned both of them, and the acquisition of one of the sequences did not interfere with the acquisition of the other.

Although the previously mentioned evidence is supportive of the idea that participants in the ignore-pattern group ''learned'' distractor contingencies, it is necessary to consider (and exclude) an alternative account of our findings. Specifically, participants may have benefitted, in terms of stimulus predictability, from having an unattended patterned sequence during blocks 1–8 rather than an unattended random sequence, and so were more disrupted when the ''supportive'' unattended patterned sequence disappeared. Rather than learning the attended and unattended sequences separately, participants in the ignore-pattern group may have been learning a configuration of the two streams of information. There is, however, some evidence against this second account, as participants in the control group who encountered the same learning situation as the ignore-pattern group during blocks 1–8, showed absolutely no sign of disruption when the unattended patterned sequence disappeared at block 9. However, in order to be more confident in our interpretation of the findings in terms of negative priming, we decided to carry out a direct test of the alternative explanation in Experiment 3.

## EXPERIMENT 3

The design of Experiment 3 was very similar to Experiment 2, with one group of participants being a replication of the ignore-pattern condition (ignore-pattern 1 group). The second group of participants was similar to the ignore-random

group, but rather than being required to ignore a pseudo-random sequence on blocks 1–8, they were required to ignore a second patterned sequence (ignore-pattern 2 group). If the detrimental effect at block 9 in Experiment 2 is due to removal of a previously ''supportive'' correlated sequence, both conditions in the present experiment should be disrupted to the same extent. In contrast, if the disruption was due to the learning of the sequence of to-be-ignored events (to which responses were inhibited) of the specific unattended sequence, we would expect the ignore-pattern 1 group to be more disrupted than the ignore-pattern 2 group.

## Method

*Participants.*     The participants were 60 undergraduate students from the University of Reading subject panel, aged between 18 and 45. They were either paid for their time, or received course credit. None had participated in the earlier experiments in this series. Thirty participants were allocated at random to each of two experimental conditions.

*Apparatus.*     This was the same as in Experiments 1 and 2.

*Task and design.*     The basic task and design was very similar to that used for the ignore-pattern condition in Experiment 2. Three sequences were used in the present experiment, these being 123243, 241321, and 312432, where the numbers 1–4 represent the four possible horizontal locations from right to left. Participants in the ignore-pattern 1 condition attended to sequence A and ignored sequence B on blocks 1–8. They then attended to sequence B on blocks 9–12. (This condition is the same as the ignore-pattern condition in Experiment 2.) Participants in the ignore-pattern 2 condition attended to sequence A and ignored sequence C on blocks 1–8. They then attended to sequence B on blocks 9–12. For both conditions, the three different sequences were designated as sequence A, B, and C in a counterbalanced manner (giving six possible combinations for each condition, with equal numbers of participants assigned to each).

*Procedure.*     The procedure was the same as that used in Experiment 2, with the exception that the participants differed with respect to the particular sequences they were attending to and ignoring on blocks 1–8 and 9–12.

## Results

A preliminary analysis again showed no significant effect of asterisk colour or sequence used (at least, not with regard to within-condition counterbalancing), so these factors were not entered into the subsequent analyses.

*Blocks 1–8*

*Error data.*    Error rates were again very low, ranging between 2.5% and 4%. A MANOVA, with group as a between-subjects factor and block as a within-subjects factor, showed no significant effect of block, $F(7, 52) = 1.62, p > .1$, nor group, $F(1, 58) = 3.09, p > .05$, and no significant interaction, $F(7, 52) < 1$.

*RT data.*    Figure 3 shows mean response latencies for the two groups across blocks 1–8. A MANOVA, with group as a between-subjects factor and block as a within-subjects factor, showed a significant effect of block, $F(7, 52) = 48.37$, $p < .0001$, but no significant effect of group, $F(1, 58) = 0.12, p > .1$, and no significant interaction, $F(7, 52) = 0.65, p > .1$.

*Blocks 9–12*

*Error data.*    Error rates ranged from 3% to 5%. A MANOVA, with group as a between-subjects factor and block as a within-subjects factor, showed no significant effect of block, $F(3, 56) = 1.63, p > .1$, nor group, $F(1, 58) = 1.19$, $p > .1$, and no significant interaction, $F(3, 56) < 1$.
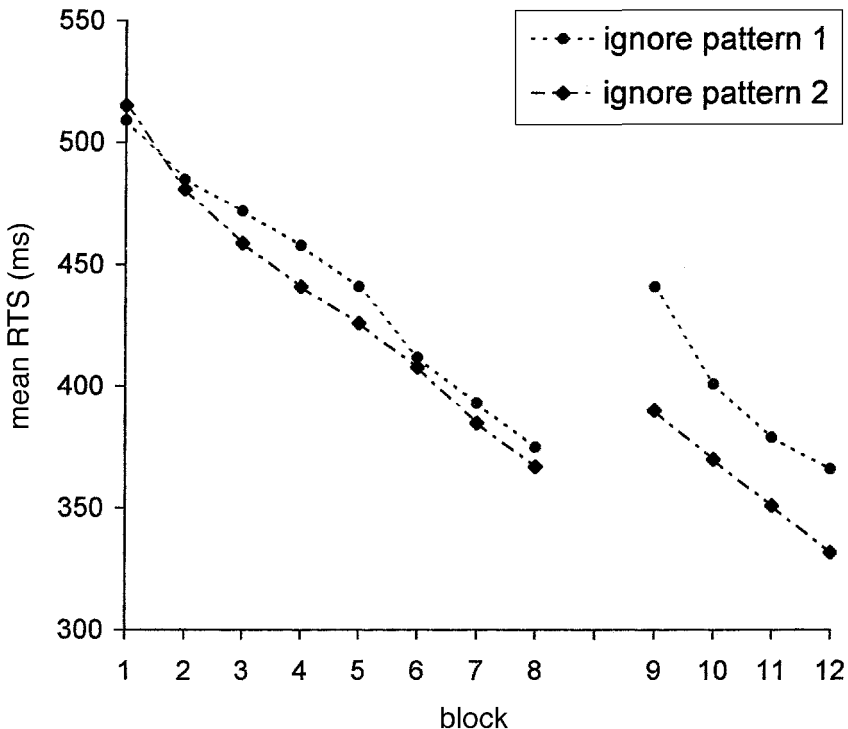


**Figure 3.**    Experiment 3: Mean reaction times for the three groups of participants for the 12 blocks of trials.

*RT data.*    Figure 3 also shows mean response latencies for the two groups, taken separately, across blocks 9–12. A MANOVA, with group as a between-subjects factor and block as a within-subjects factor, showed a significant effect of block, $F(3, 56) = 40.11$, $p < .001$, but no significant effect of group, $F(1, 58) = 3.41$, $p > .05$, and no significant interaction, $F(3, 56) = 1.7$, $p > .1$.

### Blocks 8 and 9

The most important aspect of the results again concerned the performance of the two experimental groups on blocks 8 and 9. Difference scores were again computed for both error and RT data.

*Error data.*    Mean difference scores (between blocks 8 and 9) were 1.27 and 1.17 for the ignore-pattern 1 and ignore-pattern 2 groups respectively. An independent *t* test showed no significant difference between the two groups, $t(58) = 0.18$, $p > .1$.

*RT data.*    Mean difference scores were 65.53 and 22.40 ms for the ignore-pattern 1 and ignore-pattern 2 groups respectively. An independent *t* test showed a significant difference between the two groups, $t(58) = 4.63$, $p < .001$.

### Post task questions

Answers to the post task questions (which were not given until after block 12) revealed that the majority (25 out of 30 for the ignore-pattern 1 group and 23 out of 30 for the ignore-pattern 2 group[5]) were aware that the attended sequence followed a pattern on blocks 1–8, but again were unable to recall it precisely (when prompted) due to the delayed questioning. The majority of participants also reported that the attended sequence changed in the latter part of the experiment, and were aware that the sequence on blocks 9–12 was also patterned. Most (25 out of 30 in the ignore-pattern 1 group and 23 out of 30 in the ignore-pattern 2 group) could report at least some elements of it. In contrast, very few of the participants (4 out of 30 in the ignore-pattern 1 group and 5 out of 30 in the ignore-pattern 2 group) who ignored a patterned sequence on blocks 1–8 commented that the unattended sequence might not have been random and, even when prompted, no participants in either group reported noticing a relationship between the unattended sequence on blocks 1–8 and the attended sequence on blocks 9–12.

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[5] The difference between the ignore-pattern 1 and ignore-pattern 2 groups was not significant, Chi-square $(1) = 0.42$, $p > .1$.

## Discussion

Significant learning of the attended sequence was again found for both experimental groups across blocks 1–8. There was no significant difference between groups and no interaction, showing that participants in the two groups were performing at the same level across the blocks. Importantly, participants who were required to respond to a previously ignored sequence at block 9 were significantly more disrupted than those who had previously ignored an unrelated sequence. This finding suggests that the slowed responding of the ignore-pattern 1 group at block 9 (and also of the ignore-pattern group in Experiment 2) is due to some form of negative priming. Answers to the post task questioning further showed that participants in the ignore-pattern 1 group were not aware of the critical relationship between the previously ignored sequence and the attended sequence on blocks 9–12.

## GENERAL DISCUSSION

The three experiments in this study extend our current conceptualisation of negative priming. Experiment 1 demonstrated clear negative priming effects for individual elements in a continuous sequence learning task. Participants responded significantly more slowly to element locations that they had ignored on the immediately preceding trial, and the effect persisted throughout the nine blocks of trials. The latter finding is quite remarkable considering that the attended sequence was probably well-learned by block 8 so that responding should have been relatively automatic. More importantly, Experiments 2 and 3 provided evidence for some form of higher level negative priming in that participants showed significantly slowed responding to a patterned sequence that they had ignored during earlier blocks of trials. This suggests that people were able to learn about sequential features of ignored events as well as about single events in isolation. Moreover, this learning had a detrimental rather than facilitative effect on subsequent performance. Fox (1995) has argued that the phenomenon of negative priming establishes that the identities (and locations) of ignored items are indeed encoded, and that the analysis of ignored information appears to be ubiquitous in information processing. Our findings suggest that, under certain circumstances, ignored stimuli may be processed to an even higher level than previously acknowledged.

The fact that ''negative priming'' was observed on the transfer trials (block 9) in Experiments 2 and 3 even though there was no distracting sequence present is worthy of note. Earlier reviews of negative priming (e.g., Fox, 1995; May, Kane, & Hasher, 1995; Milliken et al., 1998) reveal that most studies that did not require selection on probe trials, failed to find negative priming, and some even reported facilitation. May et al. suggest that negative priming effects occur only on non-conflict probe trials when the response task (e.g., lexical decision) induces episodic retrieval. Fox (citing a study by Moore, 1994) suggests that

negative priming occurs on non-conflict probe trials only when participants can not anticipate when the probe trial might contain conflicting information. Neither of these two conditions held in the present study. However, Fox (again citing Moore, 1994) also suggests that negative priming might be more likely to occur on non-conflict probe trials when the probe task is especially demanding. Although responding to the location of asterisks is not that demanding in itself, learning the inherent sequence must considerably increase task demands (even when this learning is carried out implicitly).

It is instructive to consider our findings in relation to current theories of negative priming. As outlined in the introduction, the two dominant accounts in the literature are the Inhibition View (e.g., Houghton & Tipper, 1994; Tipper & Cranston, 1985) and the Episodic Retrieval View (e.g., Neill & Valdes, 1992). Although we have interpreted our findings in relation to Tipper and colleagues' inhibition account, they could also be accounted for in terms of episodic retrieval. May et al. (1995) have recently suggested that negative priming can, in fact, be produced by two mechanisms, one inhibitory and one memorial (see also Kane, May, Hasher, Rahhal, & Stoltzfus, 1997; Tipper, 2001). They further propose a set of conditions under which each mechanism is more likely to operate. According to their dual account, episodic retrieval is induced when processing difficulties (e.g., target degradation) occur on test trials, when the experimental context makes such a process advantageous (e.g., repeated target trials are included), or when the response task encourages postlexical processes. Given that none of these conditions held in our experiments, we feel more justified in framing our findings in terms of inhibition.

Finally, although the primary interest of this study has centred on negative priming, the results also have implications for current theories of sequence learning. Participants in Experiments 2 and 3 were able to pick up systematicities in two simultaneously presented patterned sequences. However, learning ''what to ignore next'' did not appear to benefit their performance in terms of responding to the attended sequence. Participants performed at much the same level whether they were ignoring a patterned or random sequence. Learning without observable performance benefits in sequence learning tasks has also recently been shown by Frensch, Lin, and Buchner (1998).

It is not possible to assess, with the current experimental set up, the extent to which acquired knowledge of both the attended and unattended sequences was explicit. Answers to the post task questions certainly suggest that knowledge of the attended sequence was more explicit than knowledge of the unattended. However, given that questioning did not take place until after participants had completed four blocks of trials with the second sequence, we need to be very cautious when interpreting these data. Future experiments in the area of sequence learning could usefully employ our novel sequence learning task, with more sophisticated methods for assessing acquired knowledge (e.g., Buchner,

Steffens, Erdfelder, & Rothkegel, 1997; Jimenez, Mendez, & Cleeremans, 1996), to investigate further the potential power of the implicit (and explicit) learning mechanism.

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# APPENDICES

## Appendix A: Final post task questions asked (orally) in Experiment 1

1. Did you notice anything about the positions of the asterisk you attended?
2. If not, do you think it moved at random?
3. If you think it did not move at random, what do you think was happening?
4. If you noticed a pattern, could you specify it (or at least some of it)?
5. Did you notice any changes to the pattern during the course of the experiment?
6. You were told to ignore the other asterisk, but did you notice anything about it?
7. Do you think there was any relationship between the attended and unattended asterisks?

## Appendix B: Final post task questions asked (orally) in Experiments 2 and 3

1. Did you notice anything about the positions of the asterisk you attended, during the first half of the experiment?
2. Do you think it moved at random?
3. If not, what do you think was happening?
4. If you think the attended asterisk was following a pattern in the first half of the experiment, can you specify what it was?
5. Did you notice any change in the behaviour of the attended asterisk in the second half of the experiment?
6. Do you think it moved at random in the second half of the experiment?
7. If not, what do you think was happening?
8. If you think the attended asterisk was following a pattern in the second half of the experiment, can you specify what it was, or any part of it?
9. Regarding the unattended asterisk, was it present throughout the experiment?
10. Do you think the unattended asterisk moved at random?
11. If not, do you think that the unattended asterisk followed a pattern?
12. Can you specify what this 'unattended' pattern was?
13. Do you think there was any relationship between the asterisk patterns in any part of the experiment?