The role of prior exposure on the capture of attention by items in working memory

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Abstract

The Biased Competition Model (BCM) suggests both top-down and bottom-up biases operate on selective attention (e.g. Desimone & Duncan, 1995). It has been suggested that top-down control signals may arise from working memory. In support, Downing (2000) found faster responses to probes presented in the location of stimuli held vs. not held in working memory. Soto, Heinke, Humphreys, and Blanco (2005) showed the involuntary nature of this effect and that shared features between stimuli were sufficient to attract attention. Here we show that stimuli held in working memory had an influence on the deployment of attentional resources even when: (i) it was detrimental to the task, (ii) there was equal prior exposure, (iii) there was no bottom-up priming. These results provide further support for involuntary top-down guidance of attention from working memory and the basic tenets of the BCM, but further discredit the notion that bottom-up priming is necessary for the effect to occur.

Introduction

A generally accepted function of selective attention is that it governs the information that enters memory stores. More recently, it has been suggested that information held in memory may also influence the deployment of selective attention (i.e. a link in the opposite direction; see Desimone and Duncan, 1995; Awh, Vogel and Oh, 2006). The Biased Competition Model (BCM) suggests that both top-down and bottom-up biases operate on selective attention (e.g. Desimone & Duncan, 1995) and it has been suggested that top-down control signals may arise from working memory.

de Fockert, Rees, Frith and Lavie (2001) found that a heavy working memory load in a famous-name classification task resulted in less selective modes of attention, so that distractor stimuli (faces presented in the background) were more likely to be processed. Further evidence for working memory influencing attention comes from Awh, Jonides, and Reuter-Lorenz (1998), who found increased visual processing efficiency for spatial *locations* held in working memory. Participants made forced-choice classification judgements to stimuli presented in a remembered vs. a non-remembered location. Reaction times (RT) were quicker for stimuli presented in the remembered location. In addition, Pashler and Shiu (1999) had participants observe a rapid stream of visual stimuli, in order to detect a digit. They found that participants suffered from an attentional blink effect (and therefore missed the digit) following the appearance of a previously visualised object in the stream of visual stimuli. These results imply that information held in working memory influences the deployment of attentional resources.

More recently, Soto, Heinke, Humphreys, and Blanco (2005) showed that an item in a visual display that shared features (e.g. colour) with an item held in working memory could also attract attention in multiple item displays. This was the case even if doing so was detrimental to search performance because the memorised item in the display never contained the search target. Priming the item alone (with no memory requirement) did not have the same effect. Soto, Humphreys and Heinke (2006) showed that such effects of working memory persisted even in the presence of pop-out search targets. Further work by Soto and Humphreys (2006) investigated the working memory effect in patients with visual extinction. They found that extinction of contralesional targets was reduced when they matched the object held in working memory. Bottom-up priming from the presentation of the object cue was not enough to improve awareness, even when the cue was processed until the level of identification. Together, these studies show that attention can be inadvertently and involuntarily allocated to task performance based on both the representational characteristics of objects and spatial locations stored in working memory.

Downing (2000) performed a series of studies in order to investigate the relationship between working memory and attention. He reasoned that if the biased competition model is correct, stimuli in working memory should bias the competition amongst visual stimuli in a scene *even if there is no visual search task* (cf. Soto et al, 2005 who used a visual search task). He presented a cue stimulus to remember, followed by two further prime stimuli to the left and right of fixation (for which no action on behalf of the participant was required) and then a probe in the location of one of the previous prime stimuli to which participants made a speeded orientation decision. Participants were then presented with a memory test stimulus and they had to indicate whether or not it was the same as the cue stimulus. The crucial manipulation was that one of the prime stimuli presented matched the initial cue stimulus, whereas the other was a novel stimulus. Downing found that when the probe stimulus was presented in the location of the matching prime stimulus, it was responded to significantly faster than when it was presented in the location of the neutral (mismatching) stimulus.

Downing (2000) dismissed the possibility of his effect being one of strategy (attending to the matching stimulus to aid with the memory task) on the basis of: (i) time being too short; and (ii) the minimal demands actually required by the task. He also investigated one possible role of strategy in his fourth experiment. He reasoned that in his previous experiments, participants may have inadvertently been performing the memory task (final task) on the prime stimuli, thereby drawing their attention towards matching stimuli. By removing the matching judgement from the final task, he found no evidence to suggest that this was the case. However, there is an alternative strategy based explanation that Downing (2000) did not consider. Chapman (1967) demonstrated the phenomenon called illusory correlation (overestimating the degree of correlation, or seeing one where none exists), by showing that students overestimated the occurrence of meaningful vs. non-meaningful pairs of words. It can therefore be speculated that Downing's participants perceived an illusory correlation between the matching prime stimulus and the number of times the probe was presented on it and (albeit inadvertently) directed their attention accordingly (but see also Soto et al, 2005). Within Downing's paradigm, such illusory correlations would tend to be perpetuated since attention would be further directed to them, thereby enabling participants to see the probe in the location of the matching prime stimulus within the 147ms before it disappeared. In other words, if people had the perception that a cue would most often appear on a stimulus also held in working memory, then they might direct their attention towards that stimulus and *actually* see the cue on that stimulus more often than on the other stimulus.

In his third experiment, Downing (2000) investigated the possibility of the effect essentially being one of feed-forward priming, rather than top-down priming from the active maintenance of information in working memory *per se*. In this experiment, half the participants performed the memory task at the end of each trial as before, whereas the other half were presented with the same stimuli but were asked to make only an immediate size judgement on the cue stimulus (therefore requiring no memory). Whereas the memory task produced results equivalent to those already discussed, the size task actually produced the opposite pattern of results. Responses to probes placed in the position of matching stimuli were responded to more *slowly* than those placed on mismatching stimuli. This result was interpreted as evidence that mere exposure to the cue shape is not enough to direct attention toward matching objects and it was proposed that the reverse pattern may have been found due to weaker neuronal responses to repetitions of stimuli (Miller and Desimone, 1994).

The argument that feed-forward priming of stimuli can attract attention to them is clearly in contrast to that of Downing's (2000) proposals of weaker responses (and rejection of attention) to repetitions of stimuli unless they are held in working memory. The experiments presented here therefore aimed to further investigate: (i) the role of strategy in the attraction of attention by items in working memory, (ii) whether bottom-up visual priming is sufficient to attract attention *without* a stimulus being in working memory or whether instead attention is actually more likely to be directed to the neutral stimulus in these circumstances (iii) whether holding an item in working memory is sufficient to attract attention *without* a stimulus being bottom-up primed beforehand by a visual representation of it.

Experiment 1: A probability manipulation

Experiment 1 investigated the potential role of strategy in paying attention to the stimulus matching the cue using an adaptation of Downing's (2000) paradigm. In order to avoid participants perceiving a positive relationship (illusory correlation) between the matching stimulus and the location of the probe, in this experiment the probability of the cue being in the location of the matching stimulus was reduced from 50% to 20%, thus actively discouraging any strategy to attend to it (see also Soto et al, 2005).

Participants

18 participants (2 males) volunteered from the 1st year undergraduate psychology students at Aston University in order to earn research credits as part of a course requirement. The mean age of participants was 20.78 (range:18-36). Participants were naïve as to the purpose of the experiment.

Design and Procedure

The experiment was programmed using E prime v1.0 and was similar to Downing's (2000) first experiment. An example of the procedure is illustrated in Figure 1. On each trial, a stimulus to be remembered (a photo of an everyday object) was presented (the "cue" stimulus: 1506ms), followed by a fixation point (1506ms) and a display containing two "prime" stimuli to the left and to the right of the fixation point (187ms). One of the two prime stimuli presented in the array was a "matching" stimulus; the other was a novel stimulus. Matching stimuli would appear on the left or the right side randomly. Participants were instructed that the two pictures presented as primes had nothing to do with their task The same display was then re-displayed containing a "u" or "n" shaped probe (randomly determined with equal frequency) in the centre of one of the stimuli (146ms) and then a further fixation point until response. Participants were asked to respond as quickly and accurately as possible to the probe, using the k (for u) and m (for n) keys with their right hand. Although the probability of the probe appearing on either side of the display was 50%, the probability of it appearing on the matched item was decreased to 20%. Participants were then presented with a further "memory" stimulus and asked to make a judgment, about whether or not it was the same as the cue stimulus (v for yes, c for no), with their left hand. The memory stimulus presented as the final memory task either matched the cue stimulus or was novel (with equal probability). The independent variable in this experiment was therefore the match condition (match or mismatch). 10 trials were run as a practice and then 12 blocks of 10 trials for the experiment.

FIGURE 1 ABOUT HERE

Results and Discussion

One-factor repeated measures ANOVAs were performed on (i) median RTs to probes in the two match conditions, (ii) accuracy of probe identification in the two match conditions, and (iii) accuracy of the memory task in the two match conditions. For RTs, only correct trials were included in the analysis (correct in terms of both probe identification and memory recall – see Downing, 2000). Probe stimulus identification was significantly more accurate in the match vs. the mismatch condition (88% vs. 84%; $F_{1,17}$=24.53, MSE= 0.001, $p<0.001$), but median RTs were not significantly different (890ms vs. 905ms, $F_{1,17}$=0.683, MSE= 3063.32). Importantly, this trend persisted even in the final block (93% vs. 84% accuracy, $F_{1,17}$=3.51, MSE=0.023, p=0.07). It should be noted that 14 of the 18 participants achieved 100% accuracy in the final block for the match condition; only six participants achieved 100% accuracy in the final block in the mismatch condition. This observation suggests limited statistical power that may account for the marginal level of significance. Mean accuracy in the memory task was 96% in both match and mismatch conditions ($F_{1,17}<1$, MSE=0.001).

It was concluded that despite the probability manipulation, to ensure that it was not beneficial to pay attention to the item matching that in working memory, people paid more attention to the memorised stimulus, relative to the novel stimulus. The effect reported in Downing (2000) was, therefore, unlikely to be a consciously controllable phenomenon; otherwise participants in the present experiment would have learnt that it was beneficial to divert their attention away from the matching prime stimulus and toward the mismatching prime stimulus. Thus, our results are concordant with those of Soto et al (2005) and confirm the involuntary nature of the effect. The results also argue against an illusory correlation effect because the probe stimulus was actually correlation in the opposite direction (i.e. with the mismatching stimulus).

Experiment 2 –Previous exposure vs. working memory affecting responses?

A second possibility for Downing's (2000) results is that mere exposure to a cue stimulus is sufficient to make it attract attention when later presented in a display; no memory component is required. Both Downing (2000) and Soto et al (2005) suggested that such a bottom-up priming effect could not account for the bias in the allocation of attention to remembered stimuli because no bias for previously presented stimuli was found when participants were not required to remember cue stimuli. However, in Soto et al (2005) participants had no task to perform on the cue stimulus so may have ignored it, but Downing (2000) found a statistically significant bias in the opposite direction - attention was guided away from previously presented stimuli, suggesting that it was not ignored totally (i.e. was involved in the suppression of responses in some way). It is important to note that in the above studies the neutral stimuli in the displays were not given the same amount of prior exposure (i.e. they were not previously presented) relative to the memorised object. It could be that the effects of memory guidance are enhanced due to this factor. In this experiment, we investigated (i) whether the effects of working memory guidance vary depending on whether the neutral and memorised stimuli in the prime display had been given equal prior exposure or not, and (ii) whether there are weaker responses (i.e. inhibition) to a previously presented neutral stimulus not held in working memory, as suggested by Downing (2000). In other words, we wanted to preclude the possibility that differences in bottom-up visual priming of the different objects presented could account for the bias. In one condition, we ensured that the two stimuli in the prime display had received equal prior exposure, but only one had to be remembered, in the other condition, only one of the stimuli was presented and had to be remembered.

A number of (not necessarily mutually exclusive) possibilities arose from our design: (i) If the differences in prior exposure between memory and probe displays (and not just the active maintenance in working memory) are important to bias attention, we would expect the bias to be enhanced under single cue vs. dual cue presentation conditions, because in dual cue presentation conditions both items in the prime display had received equal prior exposure; (ii) If responses to previously presented (but “ignored”) stimuli are weakened in this paradigm, slower responses to mismatching probes in the dual vs. single presentation condition would be expected; (iii) If holding a stimulus in working memory alone causes attentional bias one would expect a significant and similar effect of probe match in both conditions (the fact that in the dual presentation condition both stimuli have previously been presented will not make a difference).

Participants

22 participants (1 male) volunteered from the 1st year undergraduate psychology students at Aston University in order to earn research credits as part of a course requirement as detailed in Experiment 1. The mean age of participants was 18.89 (range:18-23). Participants were naïve to the purpose of the experiment.

Design and Procedure

The experiment was the same as Experiment 1, except that (i) participants were instructed to remember only the stimulus presented within a black border (from up to two possible stimuli presented – see example in Table 2) and (ii) the probability of the probe appearing on a matching or a non-matching stimulus was 50%, as in Downing’s (2000) original experiment. On half the trials, a single cue stimulus in a black box was presented towards the top of the display, on the other half of the trials, an additional neutral stimulus was presented in the centre of the screen (in an attempt to encourage equality of attention across the two stimuli). When two stimuli were presented in the cue display, the stimuli in the subsequent prime display were the same two stimuli, so that in theory each prime stimulus had received comparable prior exposure. In addition, the memory stimulus presented at the end of each trial could either be completely novel (25% of time), the distractor stimulus from the cue and prime displays (25% of time), or the cue stimulus (50% of time). Participants practiced for 10 trials and then completed 12 blocks of 10 experimental trials.

Results and Discussion

One participant was removed from the analyses due to mean probe identification accuracy of only 56% (chance performance = 50%). Median RTs were included only for those trials in which both the probe and the memory test were both accurately identified (as above). Mean median RTs and percentage accuracy in the different conditions are presented in Table 1.

TABLE 1 ABOUT HERE

A two factor ANOVA examining the effects of procedure (single or dual cue stimulus display presented) and probe match condition was conducted on median RTs to the probe. There was a significant effect of probe match ($F_{1,20}$=6.96, MSE= 4079.08, $p<0.05$), but no main effect of procedure ($F_{1,20}$=2.88, MSE= 4658.68, p=0.11). The interaction between these two variables did not reach significance ($F_{1,20}$=1.25, MSE= 6252.95).

For the accuracy data, there was a highly significant effect of match ($F_{1,20}$=19.82, MSE= 0.008, $p<0.001$), but no main effect of procedure ($F_{1,20}$=0.35, MSE= 0.007). The interaction between these two variables did not reach significance ($F_{1,20}$=1.14, MSE= 0.005).

For the memory test, accuracy to match vs. mismatch conditions were compared, but there was no significant effect ($F_{1,21}$=1.03, MSE=0.002). Results of post-hoc t tests investigating differences between all of the possible conditions are shown in Table 1. It can be seen that there were significant effects of probe match in both single and dual presentation conditions for accuracy, but that probe match only had a significant effect on reaction time in single presentation conditions. There were no significant differences in reaction time or accuracy between single vs. dual presentation conditions.

When both stimuli were presented in the cue display as well as in the prime and prime-probe displays, our results suggested that attention was still more likely to be directed to the stimulus in working memory. However, this was only significant for accuracy (and not RT) in dual presentation conditions. The lack of a significant interaction between procedure and probe match for either RT or accuracy suggested that neither bottom-up priming nor response weakening effects were adequate explanations of the effect and that the best explanation of the effect was working memory alone.

There was no evidence that previously presented objects received weaker responses. The only clear result was that stimuli in working memory attracted attention over stimuli that were not, even if they had been given equal prior exposure. However, one problem with the interpretation of these results is the difficulty of obtaining adequate control over possible bottom-up priming effects. Thus, although a response weakening explanation has been satisfactorily ruled out, the possibility that different amounts of priming were crucial for the effect has not been ruled out. For example, in the dual presentation condition, it remains a possibility that the two stimuli were differentially primed because more attention was given to the stimulus that had to be remembered. Thus, Experiment 3 attempted to address the difficulty of dissociating working memory and bottom-up priming effects under conditions where the memory and non-memory stimuli have initially been given equal attentional allocation and under conditions where memorised stimuli have not always been primed in a bottom-up manner. In order to do this, we required observers to hold in working memory a conceptual representation of a number in working memory without actually presenting it, and conversely by encouraging attention to pictorial stimuli, without actually requiring participants to remember them.

Experiment 3 – Dissociating effects of bottom-up priming and memory

Experiment 3 attempted to dissociate the two processes of working memory and bottom-up priming by asking people to pay *attention* to particular stimuli in the cue array by counting them (thereby priming the stimuli), but to *remember* only the number of stimuli presented rather than their identity. Either a competing (neutral) or a concordant numeral was also presented in the array. It was ensured that participants paid attention to (and therefore primed) both the numeral presented and the stimuli in the array by asking them to indicate whether they were in agreement with each other. Thus, particular pictorial stimuli were visually primed, but not held in memory, whereas numerical stimuli were either visually primed *and* held in memory, or simply held in memory (if a competing number was presented).

In order to investigate the effects of working memory vs. bottom-up priming on the guidance of attention, we then presented various combinations of numerical and pictorial prime stimuli. These included contrasting the remembered number with a novel number, the remembered number with the neutral (incorrect) number presented in the initial array, and a novel number with the neutral number. The possibility of negative priming (e.g. Tipper, 1985) should also be noted in this experiment, since competing numerals may have to be rejected or suppressed.

In order to further investigate whether bottom-up priming of a stimulus could be *sufficient* to affect the deployment of attention under certain circumstances, we also investigated whether the picture that had been presented would still attract attention compared to a novel picture under two conditions: when the numeral presented and the number to be remembered agreed vs. disagreed.

We reasoned that:

i) If bottom-up visual priming was sufficient (memory not necessary) for a remembered stimulus to attract attention, probes on previously presented numbers *and* pictures would be responded to faster regardless of whether they were remembered or not.

ii) If bottom-up visual priming was necessary but not sufficient to attract attention, probes on previously presented numbers and pictures would only be responded to faster if they also had to be remembered and, conversely, remembered numbers would only be responded to faster if they had also been presented previously.

iii) If memory alone is sufficient for a stimulus to attract attention (bottom-up visual priming is not necessary), remembered numerals would attract attention regardless of whether they had been presented previously. Whether or not previously presented pictures attract attention would depend on whether or not bottom-up visual priming was also sufficient on its own to attract attention (see option i).

Participants

36 first year undergraduate psychology students (3 males) at Aston University volunteered to participate in this experiment in return for research credits. The ages ranged from 18-38 years, but the majority of participants were either 18 or 19 years old. The mean age was 19.51 years. Participants were naïve as to the purpose of the experiment.

Design and Procedure

The experiment was programmed using E prime v1.1. On each trial, a display was presented (until response) that contained a numeral between one and six, and between one and six identical photos (see Figure 2). Participants had to decide whether or not the numeral agreed with the number of pictures in the array by pressing the ‘c’ and ‘v’ keys marked ‘yes’ and ‘no’ respectively; no time limit was imposed. Half of the time the numbers agreed (PRIMED condition), half of the time they did not; i.e. the number was ‘neutral’ (NON-PRIMED condition). From this display, participants were also asked to remember the number of pictures in the array (analogous to the cue stimulus in Experiments 1 and 2). A fixation point was then presented (700 ms) before a display containing two prime stimuli to the left and to the right of the fixation point (187 ms). The two prime stimuli presented in the array could be either pictures or numerals (the STIMULUS TYPE factor), but a mixture of pictures and numerals was never presented. This was because pilot work had suggested that responses to probes could not satisfactorily be compared across pictures and numerals due to differences in both RT and accuracy for these stimuli. The same display was then re-displayed containing a “u” or “n” shaped probe (50:50 ratio) superimposed on the centre of one of the stimuli (50:50 ratio) until response. Participants had to respond as quickly and as accurately as possible whether the probe was a “u” or an “n” by pressing the “k” and “m” keys, respectively. Which stimulus the probe fell on constituted the factor of MATCH (match/mismatch; see results section for further details). Following response to the probe, a final screen displayed a memory stimulus in the form of a single numeral. Half the time this numeral was the number that the participant should have been remembering, the other half of the time it was not. Participants indicated which by pressing the yes or no keys as above; no time limit was imposed for this decision.

FIGURE 2 ABOUT HERE

The various experimental conditions are illustrated with examples in Table 2, which also shows results of post hoc t-tests. If the initial numeral had agreed with the number of objects presented in the display (PRIMED NUMBER: 50% of time), pictures occurred 50% of the time with the primed picture on one side and a novel picture on the other side. The other 50% of the time the numeral presented (and to be remembered) was presented on one side of the display, with a novel numeral on the other side of the display. If the numeral presented and the number of pictures had not agreed (NON-PRIMED NUMBER: 50% of time), the pictures (one primed and one novel) occurred only 25% of the time. The other three equally weighted conditions (25% of the time each) contained (i) a novel numeral and the neutral numeral that had been presented in the first display, (ii) a novel numeral (neither previously presented or to be remembered) and the number to be remembered (i.e. the numeral corresponding to the number of pictures in the array) – as shown in Figure 2 - and (iii) the numeral to be remembered and the neutral numeral as presented in the first display.

Results and Discussion

As before, for RT analyses only RTs of trials in which responses to both the probe and the memory test were correct were analysed. Firstly, a three factor ANOVA was conducted investigating the effects on median RTs to probes. The effects of interest were whether or not the number to be remembered had also been previously presented (PRIMED/NON-PRIMED NUMBER), whether pictures or numerals were presented in the display (STIMULUS TYPE) and whether the probe fell on the "matching" item or not (MATCH). Matching was defined when the probe was on either the number to be remembered, or the pictures that had been displayed, as opposed to either the neutral or novel numerals and the neutral pictures This analysis did not, therefore, encompass all of the conditions in the experiment, but was suitable for an initial analysis in order to preclude problems of multiple comparisons with limited cell membership (observations) and allow for investigations of main effects[1].

The main effect of PRIMED/NON-PRIMED NUMBER was not significant ($F_{1,35}$=1.96, MSE=4389.50), suggesting that the format of the initial display had no significant main effect on reaction times to subsequent probes. Effects of both STIMULUS TYPE and MATCH were significant ($F_{1,35}$= 18.26, MSE= 10332.14,

[1] The 'number vs. novel' conditions were used to represent the numerical stimuli in this analysis since these data were available for both levels of the PRIMED/NON-PRIMED NUMBER factor (e.g. no observations in the PRIMED number vs. neutral number condition cell).

$p<0.001$ and $F_{1,35}=6.59$, MSE=9943.33, $p<0.05$) showing that, overall, probes on numerals were responded to faster than probes on pictures and that, as expected, probes on matching stimuli were responded to faster than probes on non-matching stimuli. There was also a significant PRIMED/NON-PRIMED NUMBER x STIMULUS TYPE interaction ($F_{1,35}=4.74$, MSE= 1732.66, $p<0.05$), showing that whereas for responses to probes on the pictures it did not make a difference whether or not the remembered number had been presented in the first display, for the numbers, probes were responded to faster if they had been presented. However, there was also a significant three way interaction ($F_{1,35}=6.76$, MSE= 2892.94, $p<0.05$), suggesting that when remembered numbers had not been presented the effect of MATCH was similar for both stimulus types, whereas when the remembered number had been presented, the effect of MATCH was greatest for the numerals.

In order to simplify the analyses, and due to the three way interaction found, a series of t-tests was conducted to examine the effects of MATCH across various pairings of stimuli. The results of these tests are detailed below, but also illustrated more succinctly in Table 2.

TABLE 2 ABOUT HERE

Firstly, in the conditions in which the remembered number was presented, the effect of MATCH was significant for the comparison between the numeral presented (and remembered) and a novel numeral (874 vs. 909ms, $t(35)=3.54$, $p<0.005$). This replicates the basic effect that stimuli in working memory attract attention, at least when bottom-up priming is present. However, there was also a strong trend towards an effect of MATCH for the comparison between the picture presented and a novel picture (928 vs. 979ms, $t(35)=2.01$, $p=0.052$). This suggests that bottom-up priming effects *are sufficient* to affect the deployment of attention.

In the conditions in which the remembered numeral was not presented, the effect of MATCH was again significant for the comparison between the numeral to be remembered and a novel numeral (892 vs. 934ms, $t(35)= 2.46$, $p<0.05$) and the neutral numeral (939 vs. 873ms, $t(35)= 3.92$, $p<0.001$). Faster responses to probes were given on the number to be remembered, even though it had not previously been visually presented, showing that bottom up visual priming is *not necessary* for the effect reported by Downing (2000) to occur and that working memory alone is sufficient. Interestingly, the differences in latency between number vs. neutral was greater than that between number vs. novel, suggesting that bottom-up priming effects are at the very least 'over-ridden' by working memory effects[2].

In terms of the accuracy data, there were no significant differences between any of the conditions, although in the equivalent 3 factor ANOVA to that performed for the RTs, there was a trend towards significance ($F_{1,35}$ = 3.49, MSE= 0.00, p=0.07). This suggested that the effect of MATCH was larger for pictures than numbers when the number to be remembered had been presented, whereas the opposite was true when the number to be remembered had not been presented. None of the post-hoc comparisons reached significance.

Overall, the data from this experiment suggested that bottom-up visual priming (i) may be sufficient to attract attention, but (ii) is not necessary - memory alone is sufficient. The first conclusion, however, needs to be qualified. Although a trend towards an effect of MATCH (p=0.052) was found in the condition where the number was primed, no such pattern was observed in the condition where the number was not primed. A two factor ANOVA investigating the effects of PRIMED/ NON-PRIMED NUMBER and MATCH on median RTs to probes on pictures found no main effect of MATCH ($F_{1,35}$ = 0.001, MSE= 3689.41), no main effect of PRIMED/ NON-PRIMED ($F_{1,35}$ =1.66, MSE=10667.86), but a significant interaction between the two factors ($F_{1,35}$ = 6.50, MSE=4748.51, p<0.05). The disappearance of any effect of probe match to the picture stimuli in the condition in which there was no agreement between the number of pictures in the array and the numeral presented suggests that the previous presentation of the pictures was *not* enough to attract attention in the subsequent array under these conditions. However, equally, the fact that there was a strong trend towards an effect of probe match in the condition in which there *was* agreement between the number of pictures and the numeral presented, suggests that priming *can*

[2] Negative priming of the novel numeral is one possibility of the increased effect, but the explanation seems unlikely since neither the neutral vs. novel condition (899 vs. 908ms, t(35)=-0.685, n.s.) nor the picture vs. novel picture conditions (957 vs. 950ms, t(35)= -0.50, n.s.) showed a significant difference in either direction. However, both differences were in the expected direction for a *negative* priming effect.

result in such effects. We speculate that attention may be directed away from the number in the display when it is not the correct one to remember. This would lead to the presence of inhibitory processes which could well reduce any effects of bottom-up priming. In contrast, when the number of pictures and the number match, the display does not have to be inhibited in any way and a bottom-up priming effect may emerge in this case. Further research will be required to fully elucidate why these difference have occurred.

For now, we may conclude that stimuli held in working memory *do* seem to attract attention and that priming is not necessary (but may be sufficient) for this process to occur. It is interesting to note, that the effects of holding a stimulus in working memory and of bottom-up visual priming do not appear to be additive. Although this experiment was not specifically designed to test this hypothesis, post-hoc analyses suggested no significant differences between the speeds of responses to probes on remembered numerals in any of the three relevant conditions.

Experiments 4 and 5 – Controlling for strategy effects

Experiments 1 and 2 were close adaptations of Downing's (2000) methodology in that the probe appeared for 146ms before disappearing. However, in Experiment 3, pilot studies suggested that participants needed longer to detect the probe accurately, and so the probe was presented until a response was made. Downing (2000) reported effects for both reaction time and accuracy. In Experiments 1 and 2 we found effects mainly on accuracy, whereas in Experiment 3 our effects were only on reaction time. The inconsistency in methodology between the experiments seems a likely cause of the discrepant locus of effects. However, an alternative view is that it could indicate differential strategies by the participants (i.e. speed – accuracy trade-off). Downing (2000) emphasised effects of reaction rather than accuracy. In Experiments 4 and 5 we investigated whether we could replicate the results of Experiments 1 and 2, but, by altering the presentation time of the probe, shift the effects to reaction time rather than accuracy.

Design

The design and procedure of Experiments 4 and 5 were identical to those of Experiments 1 and 2 respectively, with the following caveats. In both experiments the probe was presented until a response was made. In Experiment 5, the cue stimulus could be presented either towards to top (50% probability) or the bottom (50% probability) of the display. The latter was a further attempt to ensure that both cue objects were viewed.

Participants

14 first year undergraduate psychology students (all female) at Aston University volunteered to participate in Experiment 4 in return for research credits. The ages ranged from 18-47 years, but the majority of participants were either 18 or 19 years old. The mean age was 21.93 years. 16 first year undergraduate psychology students (1 male) at Aston University volunteered to participate in Experiment 5 in return for research credits. The ages ranged from 18-33 years, but the majority of participants were either 18 or 19 years old. The mean age was 19.75 years. Participants were naïve as to the purpose of the experiment.

Results and Discussion

The results of Experiment 4 were analysed as in Experiment 1. One-factor repeated measures ANOVAs were performed on (i) median RTs to probes in the two match conditions (ii) accuracy to probes in the two match conditions and (iii) accuracy to the memory task in the two match conditions. For RTs, only correct trials were included in the analysis (accurate identification of probe and memory performance – see Downing, 2000). Despite extremely high accuracy levels, accuracy was significantly higher in the match vs. the mismatch condition (100% vs. 99%, $F_{1,13}=7.58$, $MSE<0.01$, $p<0.05$). Median RTs were also significantly different (756ms vs. 806ms, $F_{1,13}=27.25$, $MSE= 636.80$) with faster performance in match conditions. In the final block, all participants' accuracy was 100%, but there remained a significant effect on reaction time ($F_{1,13}=5.41$, $MSE=7254.74$, $p<0.05$) with faster performance in match conditions. Mean accuracy in the memory task was 98% in both match and mismatch conditions ($F<1$).

The results of Experiment 5 were analysed as in Experiment 2. One participant was excluded on the grounds of poor performance in the memory task (62% correct). A two factor ANOVA examining the effects of procedure (single or dual objects presented) and probe match condition was conducted on median RTs to the probe.

There was a significant effect of probe match ($F_{1,14}$=27.82, MSE= 4891.10, $p<0.0001$), but no main effect of procedure ($F_{1,14}$=1.34, MSE= 2727.32). The interaction between these two variables did not reach significance ($F<1$). For the accuracy data, there were no significant effects or interactions (all F's<1). For the memory test, accuracy to match vs. mismatch conditions were compared, but there was no significant effect ($F_{1,14}$=3.41, MSE=0.001, p=0.098), but a trend towards a higher performance in match conditions (96% vs. 94%).

TABLE 3 ABOUT HERE

Results of post-hoc t tests investigating differences between all of the possible conditions are shown in Table 3. It can be seen that there were significant effects of probe match in both single and dual presentation conditions for reaction time, but that there were no significant effects on accuracy. There were no significant differences in reaction time or accuracy between single vs. dual presentation conditions.

Together, the results of Experiments 4 and 5 provide reassurance that the original inconsistency between Experiments 1 and 2, and Experiment 3 is unlikely to be due to strategy effects. Rather, whether the effects are exhibited in terms of reaction time or accuracy is more likely related to the presentation method of the stimuli, which was initially different across the experiments.

General Discussion

The results from the experiments presented here therefore show that attention is drawn towards stimuli held in working memory, even when they have not previously been presented (Experiment 3) and when there is no strategic benefit in doing so (Experiments 2 and 4). Thus, we offer further support for the biased competition model of attention (Desimone and Duncan, 1995), which has suggested that top-down control signals arising from working memory can guide attention. In Experiment 3 we showed that working memory could influence selection in a purely top-down manner. In addition, and in contrast with previous studies, we have found some preliminary evidence to suggest that, under certain conditions, bottom-up priming may also be able to guide attention.

The modular architecture of working memory (Baddeley, 1999) presents a number of possible sources of influence on the allocation of attention. Traditionally, working memory effects are thought to represent the influence of visual working memory; however, it may be that participants verbalise stimuli that they have been asked to remember and that verbal, rather than visual working memory is therefore the mediating mechanism. Further research would be required to distinguish between the two possibilities. Potter (1975) suggested that observers recognised target pictures in rapid serial visual presentation streams as accurately and "*almost as rapidly*" (p.965) when only the name of the picture was presented vs. when the picture itself was presented. Cooper (1974) showed that the content of spoken language could influence eye movements, participants fixating the referents of the words being heard. Huettig and Altman (2005) showed that this also applied to referents semantically related to those being heard. Thus, in Experiment 3 in particular, it could be considered relatively unsurprising that stimuli that have not been presented visually, but probably have been internally verbalised in working memory, attract attention. The experiments presented here were not designed to tease out verbal vs. visual working memory effects. Rather, we aimed to show that bottom-up priming is not necessary for such effects to occur and that top-down selection is sufficient.

Although some caution needs to be exercised in interpreting our marginal effect suggesting that bottom-up priming can have effects on attention, we could speculate why our results hint towards this, whereas no such effect was found in Soto et al (2005). One possible reason is because the stimuli may not have been sufficiently primed in Soto et al (2005) since participants did not have a task to perform on them, stimuli were ignored with no further consequences for performance. Second, Soto et al (2005) used a visual search task~~s~~ where the memory and search target stimuli were presented simultaneously. Under these conditions, the presence of the search target may have 'won the competition' against the basic bottom-up priming effect originating from the prior presentation of the memory cue (see also Moores, Laiti and Chelazzi, 2003). Further, in Soto et al (2006) memory effects were observed with a 'pop-out' search target which in itself captured attention automatically. Under these conditions, bottom-up priming effects may be less noticeable. In our study, there were no competing stimuli presented with the target, since the prime display was presented before the probe. This could have facilitated the manifestation of bottom-up priming effects in our study.

We found no evidence to support the argument made by Downing (2000) that responses made to previously exposed stimuli are subsequently *weakened* if they are not remembered. In Experiments 2 and 5 there was no interaction between condition (one object vs. two objects) and probe match; in both conditions a more or less equal increase of either speed or accuracy was found when the probe appeared on the object matching that in working memory. Furthermore, in Experiment 3 a marginal effect of prior exposure occurred only when the numbers were bottom-up primed and not when the initial display effectively had to be inhibited. As noted above, Soto et al (2005) found no effect at all of prior exposure or priming. Further research may be able to elucidate the reason why different procedures seem to result in different effects.

In conclusion, our results provide support for the view that stimuli held in working memory guide attention in a largely involuntary fashion. In addition, we show that stimuli do not have to have been shown previously for the guidance to take place, but instead that conceptual representations retrieved from long-term memory can be sufficient. Furthermore, we provide preliminary evidence that previous exposure or priming can result in similar effects under some circumstances, although further research will be required to elucidate the full nature of this effect.

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Figure 1. Procedure for Experiment 1

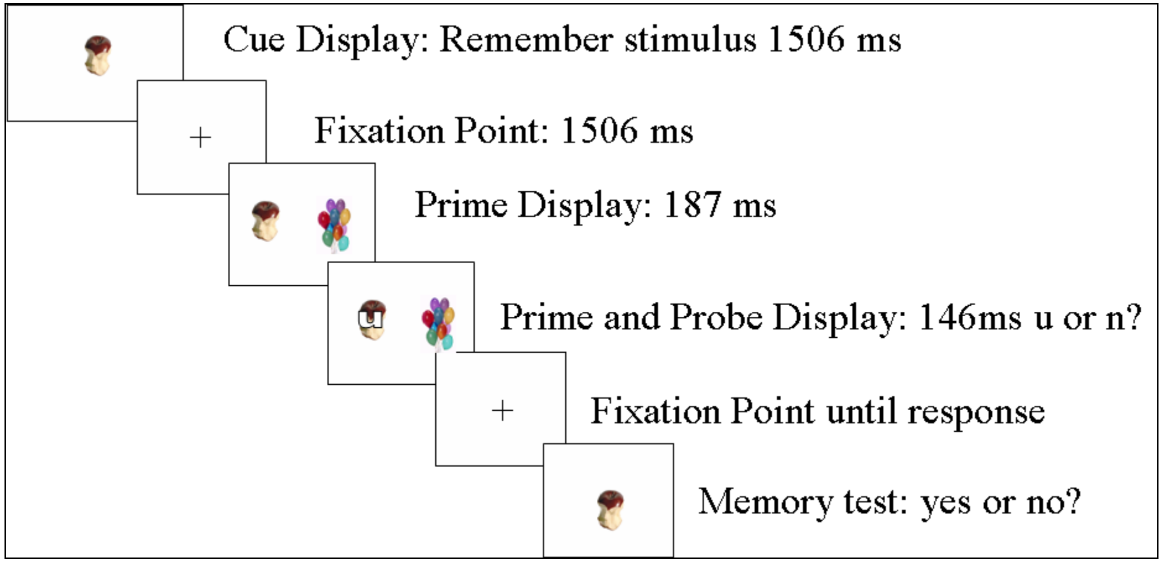


Figure 2. Display Procedure for Experiment 3 . In this example, the number to be remembered is three (because there are three stimuli shown), the novel numeral is 4 and the neutral numeral is 1.

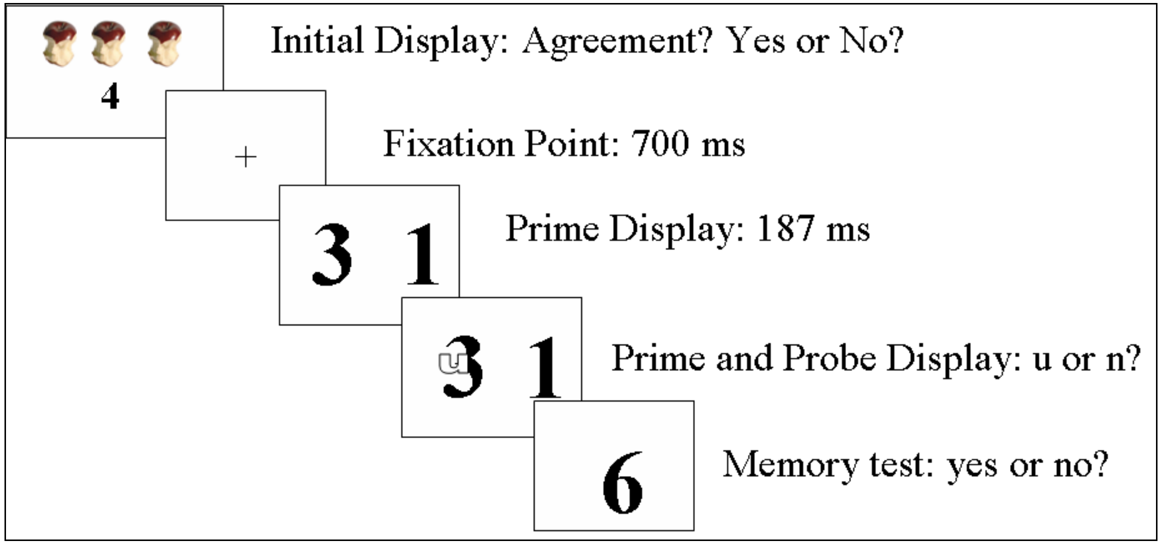


Table 1. Median RTs and percent accuracy in the different conditions of Experiment 2.

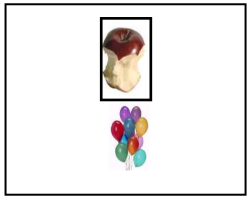
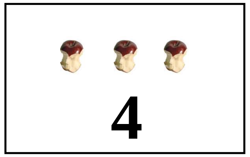
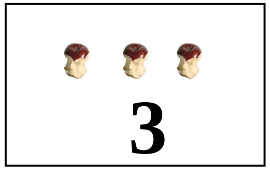
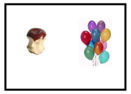
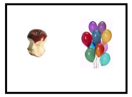
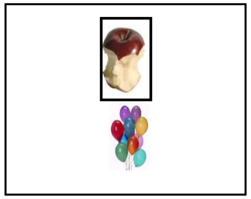
	One object present 	Two objects present 	One vs. two object significance
Probe match RT Probe match Accuracy	735ms 83%	729ms 85%	n.s. n.s.
Probe mismatch RT Probe mismatch Accuracy	791ms 76%	746ms 75%	n.s. n.s.
Significance RT Significance Accuracy	p=0.06 p<0.05	n.s. p<0.001	

Table 2.Mean of median RTs and mean percent accuracy in the different conditions of Experiment 3.

	Non-primed 				Primed 	
Comparison (stimulus considered the "match" given first and in bold type)	**Number** vs. Novel **3** 1	**Neutral** vs. Novel **4** 1	**Number** vs. Neutral **3** 4	**Picture** vs. Novel picture 	**Number** vs. Novel **3** 1	**Picture** vs. Novel picture 
Probe match RT/Acc	892ms 99%	908 ms 98%	873 ms 98%	957 ms 99%	874 ms 98%	928 ms 99%
Probe mismatch RT/Acc	934 ms 96%	899 ms 97%	939 ms 97%	950 ms 97%	909 ms 97%	979 ms 97%
Significance RT* Significance Acc.*	p<0.05, n.s.	n.s. n.s.	p<0.001 n.s.	n.s. n.s.	p<0.005 n.s.	p=0.05 n.s.

- p values are for paired t-tests testing match vs. mismatch in the conditions concerned

Table 3. Median RTs and percent accuracy in the different conditions in Experiment 5.

	One object present 	Two objects present 	One vs. two object significance
Probe match RT Probe match Accuracy	759ms 99%	746ms 99%	n.s. n.s.
Probe mismatch RT Probe mismatch Accuracy	856ms 98%	839ms 99%	n.s. n.s.
Significance RT Significance Accuracy	$p<0.0001$ n.s	$p<0.001$ n.s	