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Active versus passive maintenance of visual non-verbal memory

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Abstract

Forgetting over the short-term has challenged researchers for more than a century, largely because of difficulty in controlling what goes on within the memory retention interval. But the "recent negative probes" procedure offers a valuable paradigm, by examining influences of (presumably) unattended memoranda from prior trials. Here we used a recent probes task to investigate forgetting for visual non-verbal short-term memory. Target stimuli (2 visually presented abstract shapes) on a trial were followed after a retention interval by a probe, and participants indicated whether the probe matched one of the target items. Proactive interference, and hence memory for old trial probes, was observed whereby participants were slowed in rejecting a non-matching probe on the present trial that nevertheless matched a target item on the previous trial (a recent negative probe). The attraction of the paradigm is that, by uncovering proactive influences of past trial probe stimuli, it is argued that *active* maintenance in memory of those probes is unlikely. In two experiments we recorded such proactive interference of prior trial items over a range of interstimulus (ISI) and intertrial (ITI) intervals (between 1 and 6 seconds respectively). Consistent with a proposed two-process memory conception (the active-passive memory model or APM), actively maintained memories on current trials decayed but passively "maintained," or unattended, visual memories of stimuli on past trials did not.

(abstract 221 words)

Keywords Visual short-term memory, decay, attention, forgetting, non-verbal memory.

Introduction

In reporting the findings of a series of experimental tests of visual short-term memory in the years 1896 to 1897, a design that might well raise an eyebrow of a contemporary researcher, Madison Bentley (1899) reports only a slight decrease in accuracy of judgements over intervals extending from 2 to 60 seconds. His statement that the weakening of memory fidelity over time undoubtedly has the primary function “to prepare the organism for future adjustments” (p. 46) would appeal to contemporary investigators, even if they would debate the mechanisms of forgetting, whether through some form of decay of the memory trace or interference-based forgetting (e.g., Barrouillet & Camos, 2009; Barrouillet, Portrat, & Camos, 2011; Lewandowsky, Oberauer, & Brown, 2009; Oberauer & Lewandowsky, 2008). Yet the main difficulty facing the investigator today is the same one acknowledged by Bentley: the difficulty of demonstrating 'pure' decay (increased forgetting as we extend the retention time interval) demands that we rule out both straightforward verbal rehearsal, as well as any form of interference within brief memory by events within the retention interval. This problem has not been successfully addressed. Notably, active rehearsal may be countered by introducing some rehearsal-preventing task (introducing some form of “articulatory suppression” is the familiar approach) but this in turn may introduce interference of the memoranda.

Recently, however, one approach to the problem of active rehearsal of memoranda has been particularly promising. In the recent negative probes procedure adopted by Berman, Jonides & Lewis (2009), participants were presented with a group of four words, followed by blank retention interval and then presented with a probe word. This probe word either belonged to the current word group (positive probe), or was taken from the previous trial (recent negative probe) or was a completely new word (non-recent negative probe). The crucial measure was the slowed response times due to proactive interference on trial N caused by the recent negative probe from trial N-1 (Monsell, 1978). Interestingly, Berman et al found no significant effect of increasing the intertrial interval from about 4 seconds to 19 seconds, a finding counting against decay of short-term (verbal) memory. More recently, however, Campoy (2012) attempted to replicate the Berman et al study, but did report decay using a much smaller range of decay intervals (between 1.6 and 3.8 seconds).

In contrast to this suggestion by Campoy (2012) of rapid decay, recently we (Mercer & McKeown, 2013; McKeown & Mercer, 2012; Mercer & McKeown, 2010a, 2010b) have documented very *gradual* decay of short-term memories over periods of 30 seconds and beyond. We developed a non-verbal immediate memory (*nime*) task in which the stimuli were abstract stimulus patterns (complex tones with distinct timbres) that did not lend themselves to verbal labelling, and thereby avoided any form of maintenance by verbal rehearsal throughout the retention interval. However, we could not rule out another form of maintenance, active "refreshing" (Raye, Johnson, Mitchell, Greene, & Johnson, 2007) which is believed to be a bringing back of the memoranda into the focus of attention, a mechanism that may be distinct from verbal rehearsal. In the present series of two experiments we therefore attempted to combine the advantages of the recent negative probes procedure (notably, making unlikely active maintenance through rehearsal or refreshing) and our non-verbal immediate memory task (ruling out verbal maintenance).

Our stimuli here were abstract non-verbal visual patterns. The *nime* task has a number of desirable features: the discrimination is based upon non-obvious changes to the stimulus patterns, so preventing some form of category labelling; the patterns are abstract and so cannot be verbally labelled; and they are taken from a large stimulus pool, again making unlikely that participants develop category labels throughout experimental sessions. Our motivation was to detail the persistence of a form of sensory or non-verbal memory which does not require active attentional refreshing or rehearsal for maintenance. We propose a highly detailed representation which preserves fine details of stimuli, yet is resistant to decay, endures for several seconds and can withstand non-specific interference. We term this passive memory. In contrast we propose (McKeown & Mercer, 2012) that actively attended memories are gradually lost over the passage of time, and it is not possible to reverse this information loss by prompting the observers' attention. We speculate this decay takes place despite participants' intention to maintain the memory trace through active attention, and indeed is disrupted *precisely because* of the bringing of the trace into the focus of attention (on the assumption that such "translation" is noisy). In our active-passive conception (active-passive memory or APM), active memory gradually decays, whereas unattended sensory memory does not decay, is essentially passive, and may correspond to a form of short-term memory recently documented in the repetition suppression paradigm of passive, unconscious memory maintenance for visual patterns in visual cortex (Emmanouli, Burton, & Ro, 2013). Thus, unattended non-verbal memory is protected from disruption *precisely because* it is *not* brought into the focus of attention. The recent negative probes paradigm would appear ideal for uncovering this form of stimulus memory.

Experiment 1

Like Berman et al. (2009), here we recorded accuracy and response times to probes that occasionally matched those on prior trials (recent-negative probes). According to APM actively refreshed stimulus memory traces on trial N will be gradually degraded, whereas the traces of memories from trial N-1 will undergo little diminution across the intertrial interval, on the assumption that participants have no incentive for actively refreshing them. We also manipulated temporal distinctiveness of our stimuli (c.f. Brown, Neath, & Chater, 2007): the memory trace of the standard stimulus on trial N is distinct to the extent that it is well separated from surrounding stimuli (the comparison stimulus on trial N-1 and the comparison stimulus on trial N). Therefore, according to distinctiveness accounts, performance should be determined not by the absolute retention interval duration, but by the ratio of this interval to the interval separating the standard from the previous comparison tone (the intertrial interval or ITI).[1]

Method

Participants

Participants were 15 naive observers who had normal (self-reported) or corrected-to-normal vision.

Apparatus and Stimuli

The stimuli were presented on a 17-in. monitor and the experiment was run using E-Prime 2.0 software (Psychology Software Tools, Inc. www.pstnet.com/eprime). The viewing distance from the computer screen was approximately 70 cm. The stimuli

[1] We do not expand on the distinctiveness account in this brief report, but refer the reader to Brown et al. (2007). However, it is an important consideration in any memory study that manipulates intertrial and interstimulus intervals.

were taken from the revised set of the Snodgrass and Vanderwart (1980)'s object databank (Rossion & Pourtois, 2004). The 260 objects were distorted in Photoshop until they appeared abstract and meaningless (see Figure 1). The memory display consisted of two different objects subtending each 4.3° x 4.3° of visual angle and presented laterally (centre deviating 4° from fixation) against a white background. The probe display consisted of a single object presented at fixation.

Fig. 1 Examples of stimuli used in the two experiments

Procedure and Design

As shown in Figure 2 each trial began with the presentation of a central fixation cross (0.5° x 0.5°) for 500 ms followed by the memory display for 500 ms. After a retention period (ISI = interstimulus interval) of either 1000 or 6000 ms, the probe display was presented for 2000 ms and participants were required to report whether the probe object had been presented on the previous memory display using *s* key for "yes" and *l* key for "no". After the response, the screen went blank for either 500 or 5500 ms and a new trial began with the warning cross for 500 ms. The intertrial interval (ITI) was therefore either 1000 or 6000 ms (i.e., blank screen after the response + cross).

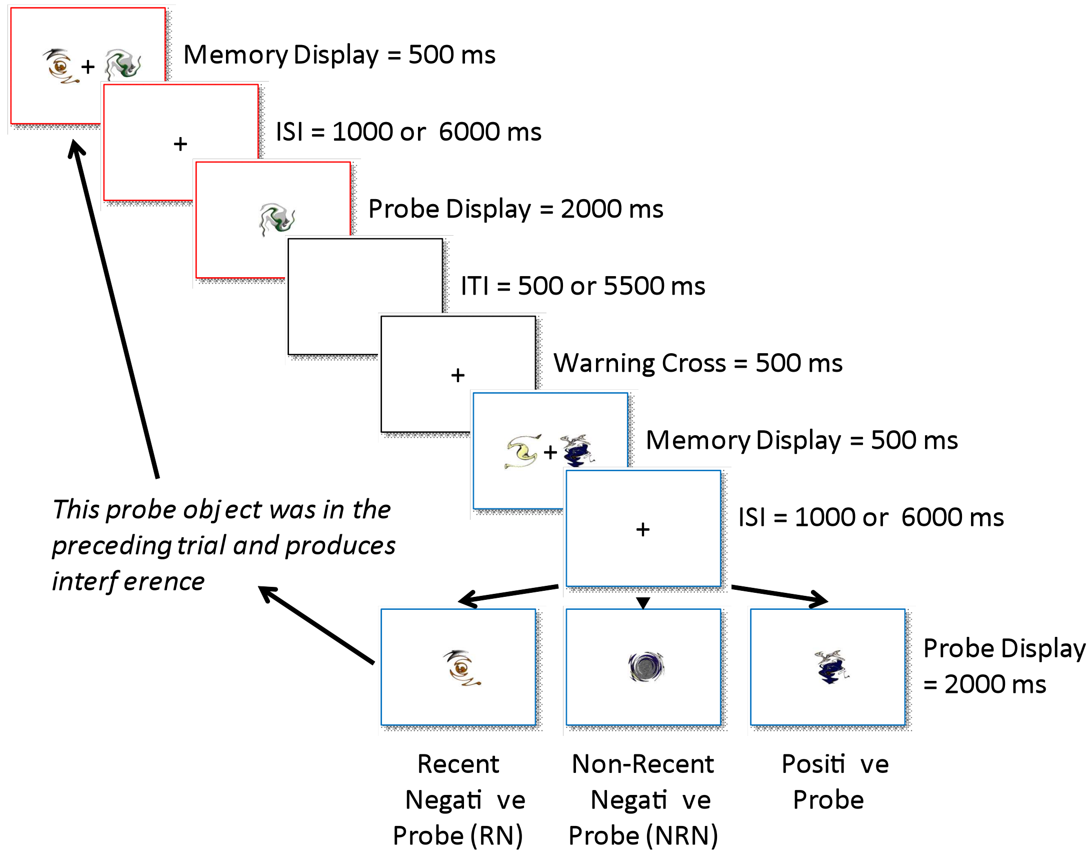

Fig. 2 Experimental procedure used in Experiment 1

The probe either matched one object from the memory display ("positive probe"; 50% of the trials), matched one object from the memory display of the preceding trial ("recent negative probe" (RN); 25% of the trials), or did not match any object from a minimum of 48 preceding trials ("non-recent negative probe" (NRN); 25% of the trials). The objects in the memory display never repeated within the same block and every combination of objects in the memory display was original (i.e., the same pair never repeated throughout the experiment).

Each participant performed 16 practice trials and then proceeded to the testing stage that consisted of 192 trials, with 96 positive probe, 48 RN and 48 NRN trials. Of all the trials, 50% were from each of the different ISI and ITI values. There were four blocks of 48 trials in total that contained an equal number of each trial type. All conditions were randomized within blocks to prevent predictability.

Results and discussion

In order to investigate the effect of RN trials, RT and accuracy were analysed in a 2 (trial type: RN, NRN) x 2 (ITI: 1000, 6000) x 2 (ISI: 1000, 6000) repeated measures ANOVA. Analysis on RT (including correct response trials only) revealed a main effect of trial type [$F(1, 14) = 47.44$, $p < .001$] showing slower performance in RN trials relative to NRN trials, and a main effect of ISI [$F(1, 14) = 14.39$, $p < .005$] revealing slower RTs in trials with an ISI of 6000 ms relative to 1000 ms. The partial eta squared values were large for each analysis ($\eta^2 = .77$ for trial type, and $\eta^2 = .51$ for ISI). No other main effects or interactions were shown. The same analysis on accuracy revealed an effect of trial type [$F(1, 14) = 21.34$, $p < .001$] showing greater accuracy in NRN trials relative to RN trials, and a marginally significant main effect of ISI [$F(1, 14) = 4.43$, $p = .054$] highlighting greater accuracy in trials with an ISI of 1000 ms relative to 6000 ms. For accuracy, the partial eta squared values were large for trial type ($\eta^2 = .60$), and modest for ISI ($\eta^2 = .24$). No other main effects or interactions were revealed.

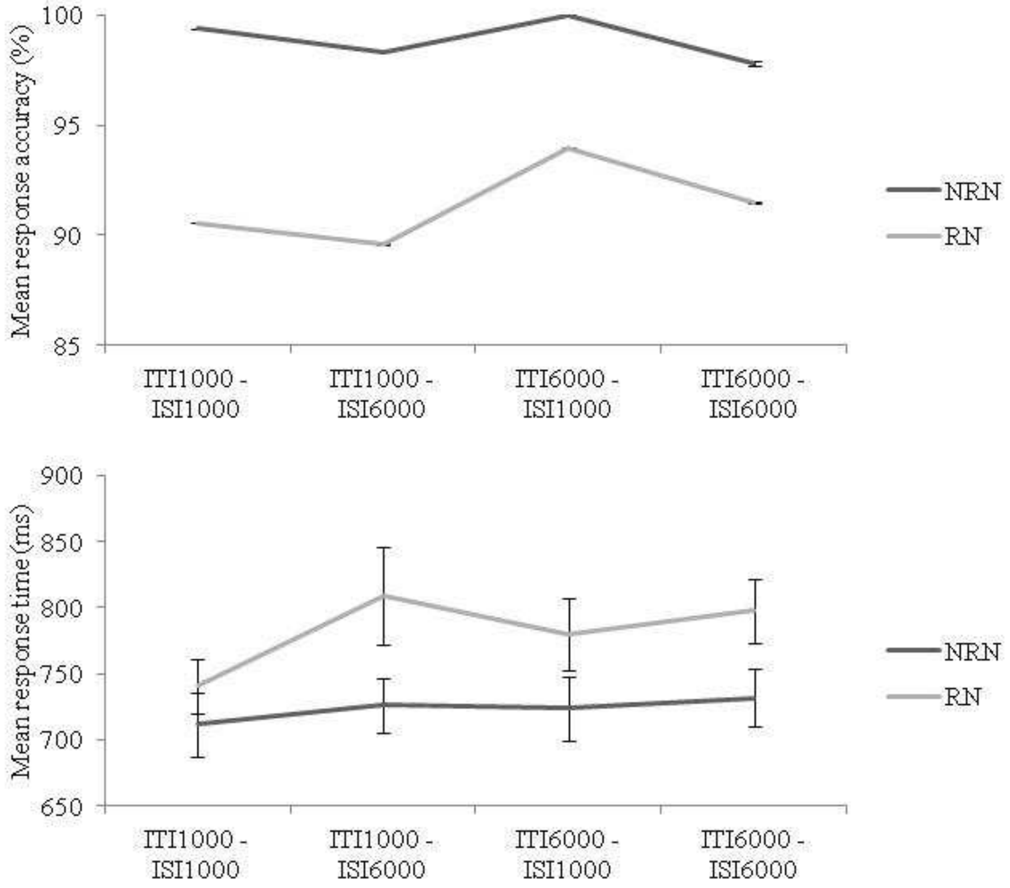

Fig. 3 Results of Experiment 1. Mean response accuracy and response times for recent negative (RN) and non recent negative (NRN) trials by condition (ITI 1000, ISI 1000; ITI 1000, ISI 6000; ITI 6000, ISI 1000; ITI 6000, ISI 6000). Vertical bars are standard errors (though barely visible for the accuracy measure)

The RN-NRN contrast was calculated for each condition for accuracy and RT, giving the RN penalty in performance. Across each condition, varying the ITI and ISI resulted in four total decay intervals, starting from the offset of the first memory display to the onset of the second probe display (5500 ms, 10500 ms, 15500 ms, 20500 ms). A one-way repeated measures ANOVA revealed no effect of the total decay interval on the RN penalty for RT [$F(3, 42) = 1.45$, $p = .24$] or accuracy [$F(3, 42) = .48$, $p = .70$]. In addition, a 2 (ITI: 1000, 6000) x 2 (ISI: 1000, 6000) repeated measures ANOVA revealed no main effects or interactions for accuracy or RT (see Figure 3). In summary, a mild decrease in performance is observed within a retention interval when we extend that interval from 1 to 6 s, whereas the "recent negative effect”, that is the influence of the memory trace extending across the intertrial interval, does not appear to diminish as we extend that interval from 1 to 6 s. We have no reason for supposing that our participants had any inclination to attend or rehearse old trial stimuli, so we might conclude that old unattended visual memories do not decay. Finally, the failure to observe an interaction between ISI and ITI counts against a temporal distinctiveness explanation of our data.

Experiment 2

In this second experiment we reduced the “window” over which we examined the RN effect, to further test Campoy’s (2012) argument that rather rapid decay is completed within 2 seconds or so. One possible difficulty with the recent negative probes arrangement used here and by Berman et al. (and by Campoy, 2012), is that the memory trace of the trial items on trial N-1 is always assessed *following* presentation of the set of target stimuli on trial N and that trial’s probe and response. So as an additional precaution in the next experiment we removed at least some of the intervening material by introducing “dummy” trials without a probe or response.

Method

Participants

Participants were 17 new naive observers who had normal (self-reported) or corrected-to-normal vision.

Procedure and Design

This experiment replicated Experiment 1 with the following timing changes: (i) the presentation of the warning cross and memory display was reduced to 250 ms; (ii) the ISI and ITI were either 750 or 2250 ms. In addition, in an attempt to remove some of the intervening material between the first and the second memory representations, the probe display that normally follows the first memory display was removed in some trials (relevant trials) and no responses were required; the next trial began with a new pair of target stimuli (see Figure 4). For the rest of the trials (irrelevant trials), a probe display followed the first memory display as in Experiment 1 to prevent predictability.

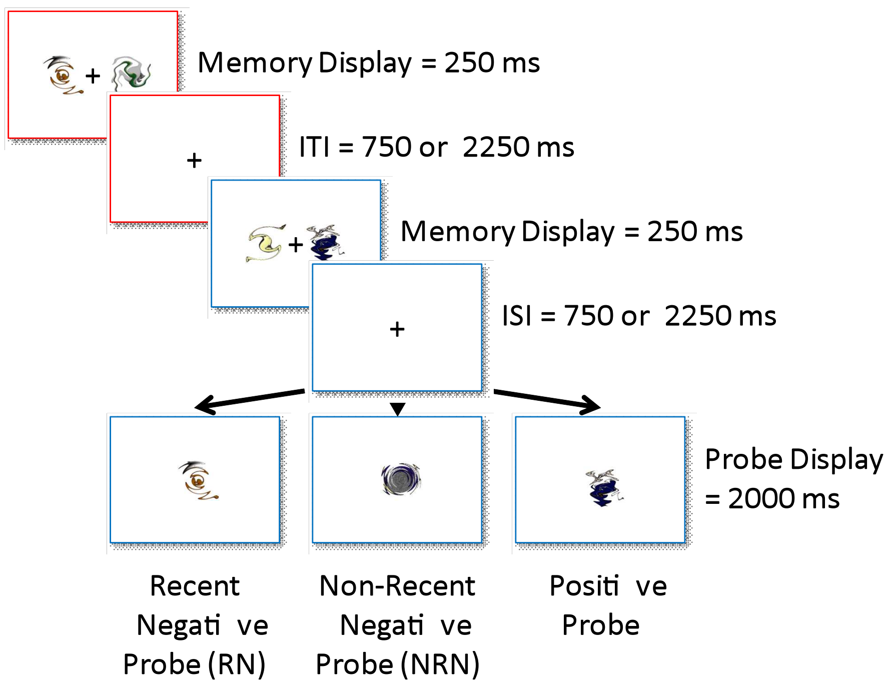

Fig. 4 Experimental procedure used in Experiment 2

The experiment involved a total of 288 trials, of which 192 trials were relevant and 96 trials were irrelevant. The analyses were made on relevant trials only, of which 96 were positive probe, 48 were RN and 48 were NRN trials. Of all the trials, 50% were from each of the different ISI and ITI values. Each participant performed 16 practice trials and then proceeded to the testing stage that consisted of six blocks of 48 trials in total and contained an equal number of each trial type. All conditions were randomized within blocks.

Results and discussion

In order to investigate the effect of RN trials, RT and accuracy were analysed in a 2 (trial type: RN, NRN) x 2 (ITI: 2250, 750) x 2 (ISI: 2250, 750) repeated measures ANOVA. Analysis on RT (including correct response trials only) revealed a main effect of trial type [$F(1, 16)= 27.20$, $p< .001$] showing slower performance in RN trials relative to NRN trials, and a main effect of ISI [$F(1, 16) = 19.54$, $p < .001$] revealing slower RTs in trials with an ISI of 750 ms relative to 2250 ms. This slight increase in performance with the longer delay contrasts strongly with Campoy (2012), and might reflect a lack of preparedness for responding, or perhaps the reduced time available for consolidation of the memory trace at the shorter delay (see Ricker & Cowan, in press). The partial eta squared values were large for each analysis ($\eta^2 = .63$ for trial type and $\eta^2 = .55$ for ISI). No other main effects or interactions were shown. The same analysis on accuracy revealed an effect of trial type [$F(1, 16) = 27.90$, $p < .001$] showing greater accuracy in NRN relative to RN trials, and a main effect of ITI [$F(1, 16) = 5.62$, $p < .05$] showing greater accuracy in trials with an ITI of 2250 ms relative to 750 ms. For accuracy, the eta squared values were large for trial type (η^2 = .64) and modest for ITI (η^2 = .26). No other main effects or interactions were revealed.

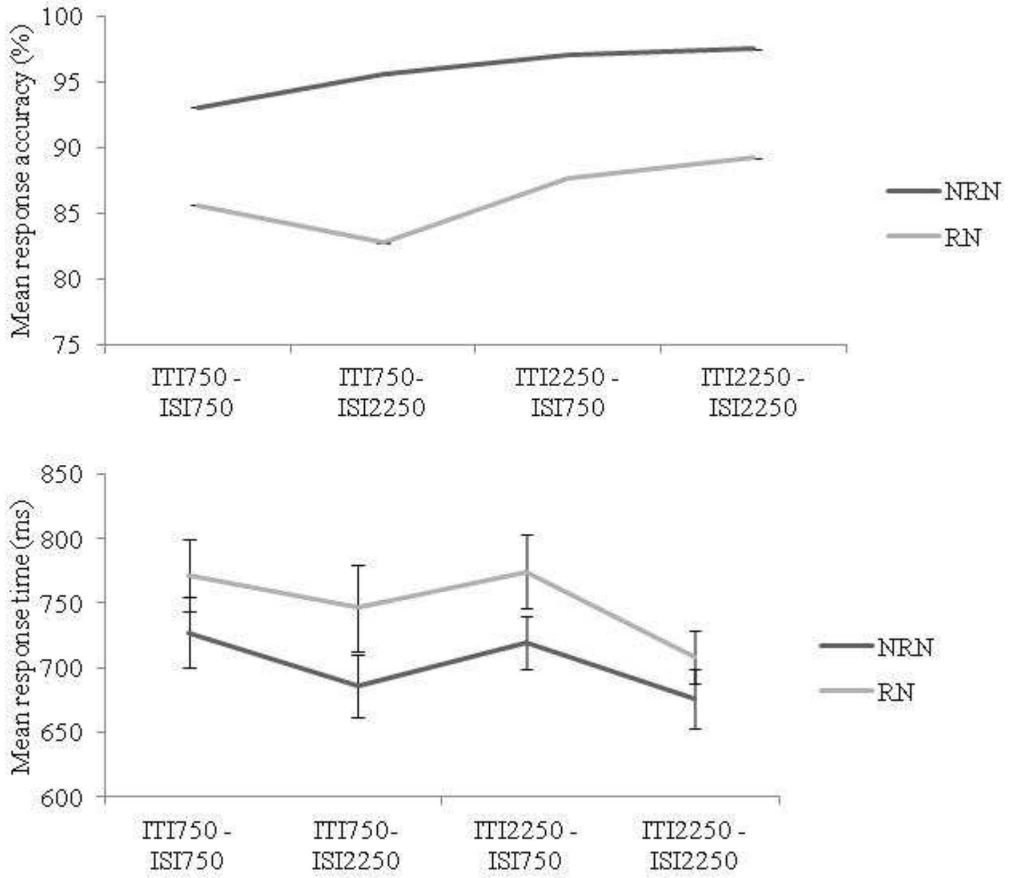

Fig. 5 Results of Experiment 2. Mean response accuracy and response times for recent negative (RN) and non recent negative (NRN) trials by condition (ITI 750, ISI 750; ITI 750, ISI 2250; ITI 2250, ISI 750; ITI 2250, ISI 2250). Vertical bars are standard errors

The RN-NRN contrast was calculated for each condition for accuracy and RT, giving the RN penalty in performance. Across each condition, varying the ITI and ISI resulted in three total decay intervals (1750 ms, 3250 ms, 4750 ms). A one-way repeated measures ANOVA revealed no effect of the total decay interval on the RN penalty for RT [F(2, 32) = .38, p = .69] or accuracy [F(2, 32) = .46, p = .64]. In addition, a 2 (ITI: 2250, 750) x 2 (ISI: 2250, 750) repeated measures ANOVA revealed no main effects or interactions for accuracy or RT (see Figure 5). Thus, the failure to observe any influence of the ratio of ISI and ITI further rules out a "distinctiveness" account for our data (but see Horoufchin, Phillipp, & Koch, 2011). Contrasting with Campoy, decay was not evident across the brief ISI intervals tested (750 or 2500 ms), and nor was it evident as we extended the ITI across the same intervals.

General Discussion

In our Introduction we presented a dual-process conception of brief or short term memory (active-passive memory or APM) composed of actively maintained traces which are susceptible to time-based decay, and passively maintained traces which are not. Consistent with this proposal of decay or corruption of the fidelity of the visual pattern memories within the retention interval, Experiment 1 uncovered time-based forgetting over several seconds. In contrast, the enduring influence of the trace of a previous trial (the recent negative effect) revealed a form of representation of short-term visual pattern memory that did not decay. And our Experiment 2 revealed little influence of decay intervals over shorter intervals of time, in contrast to Campoy (2012). But, whereas the opportunity for active verbal rehearsal makes difficult interpretation of the findings of both Berman et al. and of Campoy, our *nime* task does not suffer from this problem. This is not to say that attentional orientation cannot act to select and maintain items within short-term visual memory (VSTM), perhaps prioritizing task-relevant items among competitors. The "gating" of task-relevant items within VSTM is well documented, especially early in the period following stimulus presentation (e.g., Gazzaley, 2011; Schmidt, Vogel, Woodman, & Luck, 2002), consistent with top-down modulation of visual processing and short-term memory storage, and attentional orienting to task-relevant items held within VSTM (Gazzaley & Nobre, 2012; Nobre, Griffin, & Rao, 2008). Possibly attentional selection is beneficial very early following stimulus presentation and when tasks demand spatial selection among competing objects. Yet when we greatly extend the memory retention interval beyond several seconds, and the task does not introduce competing objects, attentional selection and top-down maintenance may (we speculate) promote little advantage in memory trace maintenance, but rather may hinder it.

In an influential report, Zhang and Luck (2009; also see Zhang & Luck, 2008) charted a form of sudden forgetting of memory for colors whereby items appeared to drop out of memory ("sudden death"), rather than underegoing gradual decay. Their participants' color matching performance showed high precision on correct trials at time delays of 2, 4 and 10 seconds, but a sudden increase in random errors at 10 seconds which they explained as a complete loss of the memory trace. However, their task introduced a contrasting verbal distractor task to prevent verbal encoding and rehearsal of their memoranda, and we suspect that it was the maintenance of the color label itself that dropped out of memory, so that the chosen color for the matching response was itself random. Again, our *nime* task avoids such possible confounds. Note though that the form of forgetting under attentional refreshing we envisage in our active-passive conception is not time-based 'decay' as usually envisaged, but rather interference through a process of revisiting the memoranda into and out of the focus of attention repeatedly throughout the memory task interval (ISI), on the assumption that the point of translation into an attentional or refreshing buffer is noisy. Increasing the number of opportunities for this revisiting of the trace will further degrade the fidelity of the trace, and one might speculate on the rate of this process. But an important consideration is that the recent-negative probes themselves will have almost certainly been refreshed according to the task demands of the preceding trial. The recent-neagtive probes procedure is not an uncontaminated window onto the precision of the memory trace.

Conclusion

Self-evidently, if attentional selection and attentional maintenance were necessary for the encoding of everyday information (whether the fleeting features of the visual or auditory or haptic environment or the episodic narrative of everyday life), when attention was diverted or focused on a problem at hand, one might conceive of an episodic record that is peppered with holes, that is fragmented. That it is not so is strong evidence we believe in favour of the sort of automatic encoding and passive maintenance that we present here. In conclusion, the present findings suggest that extended visual non-verbal short-term memory does not decay, but may be disrupted if attempts are made to bring it into the foreground of attention. Such a two-process memory conception, which we here term active-passive memory (APM), offers an exciting framework in resolving some of the contradictions of the forgetting literature extant since Bentley's day.

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