SHORT REPORT

Reinstatement of odour context cues veridical memories but not false memories

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**Abstract**

The sense of smell has made a recent return to the forefront of research on episodic memory. Odour context cues can reactivate recently encoded memories during sleep-dependent memory consolidation (e.g., Rasch et al., 2007), and reinstating the odour experienced during encoding at test results in superior recall and recognition (e.g., Isarida et al., 2014). However, whether the impact of odour cues is restricted to the specific memories studied in the presence of the odour, or whether reinstating the odour also cues unstudied memories that are semantically related to the studied memories (i.e., false memories) is unknown. We used the Deese-Roediger-McDermott false memory paradigm to quantify the impact of odour cues on both veridical memory and false memory. Reinstating the odour presented during study of the DRM word lists at the test phase resulted in better free recall of the studied words, but had no statistically significant impact on the number of false memories produced. We argue that odour cues influence recall of the memories they co-occurred with during study but potentially not semantically related memories.

Keywords: Memory; false memory; DRM; context effects; odours

Eighty years ago, Laird (1935) invited 254 “living men and women of eminence” (p. 126) to share their experiences of occasions where the perception of an odour had evoked memories of past events. Over 80% were able to report one or more such occasion. Furthermore, many reported that odours evoked memories that other cues did not evoke, such as one correspondent for whom the smell of sawdust brought back vivid childhood memories, while the sight of sawdust had no such effect. The broad effect of contextual cues in episodic memory has been intensely researched since (Smith & Vela, 2001), but relatively little has been done to investigate odour context cues specifically.

Studies looking at odour cues typically involve an encoding phase with an odour present or no odour. Stimuli to be encoded have tended to be word lists, with some studies using images of faces (Cann & Ross, 1989), or longer passages of text (Pointer & Bond, 1998) instead. After a retention interval, which has ranged from minutes (e.g., Isarida et al., 2014) to several weeks (Parker et al., 2001), participants enter a test phase where the same or a different odour from that used in the encoding phase has been presented. The most common test tasks have included recognition memory (Cann & Ross, 1989) or free recall (Schab, 1990; Hertz, 1997), with others using relearning paradigms (Smith, Standing & de Man, 1992) or word stem completion (Ball et al., 2010). These studies have typically shown that reinstating at test the odour from the encoding phase improves memory relative to conditions with a different odour or no odour.

Interest in cueing memories with odours has expanded to memory consolidation during sleep. Rasch et al. (2007) had participants memorise object locations while being exposed to an odour. Participants were then presented with the same odour or an odourless vehicle during slow-wave sleep (SWS). Memory was tested after sleep in the absence of an odour. Participants who were cued with the odour during SWS recalled more than participants who received the vehicle suggesting that odour cues reactivated the memories associated with the odour, and this reactivation during sleep facilitated consolidation of those memories. Diekelmann et al. (2011) showed that odour cueing during SWS makes new memories robust against interference, but that odour cueing during wakefulness makes new memories more susceptible to interference. The authors interpret these findings as support for a reconsolidation mechanism. Odour cueing during wake activated the previously encoded memory associated with that odour, rendering it labile, and thus allowing later interference learning to modify the original memory.

The impact of environmental contextual cues may not be limited to the veridical memories that were experienced during encoding. Arndt (2010) showed this using the Deese-Roediger-McDermott (DRM) false memory paradigm (e.g., Roediger & McDermott, 1995). Participants first encoded lists of semantically associated words (e.g., *door, glass, pane, shade, ledge, sill, house, open, curtain,* etc.). Each of the studied DRM lists was printed in a distinct font which constituted a unique visual context for each list. Recognition memory for the words was then tested. Importantly, this included “critical lures”, that is, unstudied words that were semantically associated to the words in a DRM list (e.g., *window*). Participants were more likely to incorrectly believe that a critical lure was a studied word if it was printed in the same font as the DRM list encoded in the study phase.

Theories of false memory make predictions about environmental cues that largely match the above finding. According to the Fuzzy-Trace Theory (FTT; e.g., Brainerd & Reyna, 2002), the surface form and semantic properties of DRM study list words are processed in parallel at encoding and stored separately, as verbatim traces and gist traces. Verbatim traces are episodic representations of the studied words which include the context in which they were studied. Gist traces are representations of the semantic content of the words extracted at the time of encoding from the verbatim traces. At test, recall is based on a mix of retrieval of *both* types of trace, sometimes giving rise to false memories. Since verbatim traces include information about environmental context, it is easy to see how environmental cues might improve veridical memory, but false memories might also be promoted by these cues if the gist trace is assumed to represent not only semantic commonalities across the different studied words, but also environmental ones (Arndt, 2010).

The Activation/Monitoring Theory proposes two processes that influence false memory (e.g., Roediger, Balota, & Watson, 2001). The first, activation, involves spreading of activation in the lexical/semantic system during encoding or recall to words that are unstudied but closely related to the studied words, leading to false recall of unstudied words. During this process both studied words and the co-activated lures can become associated with the environmental context, predicting that both veridical and false memory can be affected by environmental cues. The second process, monitoring, involves monitoring of recovered memories for cues, such as episodic details, which can help discriminate between actual experiences (veridical memories) and imagined experiences (false memories).

Arndt’s (2010) data suggest that visual context can cue both veridical memories directly associated with the environmental context, and critical lures that were not presented in the study phase. This broad impact of visual cues may not necessarily be shared by odour cues however. While there are no studies that have used odour cues in false memory paradigms, there is some evidence to suggest that odours cue those specific items they were associated with at encoding, and not other items encoded in the same session in the absence of the odour. Hauner et al. (2013) showed that reinstating an odour during SWS benefitted only those memories that were associated with that odour and did not generalise to other memories that had been encoded in the same pre-sleep session but did not coincide with the odour. Whether this means that odours do not cue false memories that are semantically associated with veridical memories remains unknown.

Here we for the first time investigated the ability of odour context to cue non-veridical memories. Participants encoded DRM lists in the presence of an odour, and were shortly afterwards tested in a free recall task with the same odour reinstated or in the presence of a different odour. We predicted that reinstating the same odour should facilitate veridical memory. If odour cues function like visual contextual cues, odour reinstatement could also increase number of false memories. If on the other hand odour cues have a more specific impact than other environmental cues, odour reinstatement could have less or no impact on false memories. While neither outcome would necessarily discriminate between different theories of the DRM effect, both have theoretical implications that we will return to in the Discussion. Given that little is known about the interaction between olfaction and other domains of cognition, it is important to understand better the extent to which odour can affect different forms of memory.

**Method**

**Participants**

80 native English speakers (age range 18-30, 37 male) took part in the experiment. 40 were randomly allocated to the same-odour condition, and 40 to the different-odour condition. Previous DRM research suggests this sample size is sufficient to detect between-participants differences in veridical and false memory (e.g., Payne et al, 2009). Power calculation confirmed that this sample size is sufficient to detect effects of medium size (d=0.56 or higher), with power set to 0.8, alpha to 0.05, one-tailed, consistent with effect sizes observed by Payne et al. (2009). None of the participants suffered from language-related impairments, or impairments that might reduce sense of smell (such as colds).

**Materials**

Two essential oils which are easily distinguishable from each other, peppermint and cinnamon, were used as the odour stimuli. Six DRM word lists were selected from Staedler et al. (1999) corresponding to the critical lure words (with mean backward associative strength of the list in parentheses): *window* (.188)*, sleep* (.477)*, doctor* (.239)*, mountain* (.184)*, slow* (.173)*, cold* (.301). Each list was composed of 12 words with the highest relatedness ratings for that critical lure word. The lists were selected such that none the words referred to smells, or were semantically related to peppermint or cinnamon.

**Procedure**

The experiment started with the encoding phase. Four drops of one of the odour oils were applied on a piece of cotton wool sitting at the bottom of a small clear glass jar. Participants were first exposed for 30 seconds to the odour by opening the lid of the jar and asking the participant to inhale the odour for the full 30 seconds. The experimenter then read aloud all six DRM lists, and participants were instructed to memorise as many of the words as possible in anticipation of a later recall test. Participants continued to inhale the odour for the duration of presentation of all lists. Words in each list were presented at a natural speech rate, pausing between words, in descending order of association to the critical lure word, while the order of the six lists was newly randomised for each participant. A five-second pause separated each list. The glass jar was sealed and removed at the end of the encoding phase.

During the retention interval participants were first asked to smell an odour (coffee granules in a glass jar) that is dissimilar to the encoding (and testing) odour for one minute in order to clear the odour from the encoding phase. This has been shown by Isarida et al. (2014) to be an effective method to allow participants recover from olfactory adaptation to the encoding odour. After this the coffee odour was removed by sealing the jar and participants completed arithmetic problems for four minutes in the absence of any odour.

The test phase involved free recall of words from the encoding phase with participants writing them on a blank piece of paper. Participants were given three minutes to complete the task and instructed to write down all words they were certain or reasonably certain having been presented. Participants inhaled one of the two odours (same or different as in the encoding phase, depending on experimental condition) for 30 seconds before the beginning of the recall task, and continued to inhale it for the duration of the three-minute task.

In the different-odour condition both odours were used in the encoding and test phases an equal number of times. In the same-odour condition both odours were used an equal number of times.

**Results**

Recalled words were categorised as studied words (words heard during the encoding phase), critical lure words (the unstudied lure words associated with a list), and intrusions (other unstudied words that did not appear in any list). For studied words we entered the proportion of words recalled into the analysis. However, following previous DRM studies (e.g., Payne et al., 2009) we also calculated a corrected score for the studied words by deducting the number of intrusions from the number of recalled studied words. This correction accounts for participants’ potential recall bias. For the lures we entered the proportion of lure words recalled, for intrusions we entered the number of words produced.

Independent-samples t-tests[[1]](#footnote-1) showed that participants in the same-odour condition recalled significantly more studied words (M=0.17, SEM=0.01) than participants in the different-odour condition (M=0.12, SEM=0.01), t(78)=3.42, p =.001, d=0.76 (Figure 1). The same pattern of results was found when replacing the proportion of studied words with the bias-corrected proportion of studied words. However, no significant difference between different (M=0.37, SEM=0.03) and same (M=0.43, SEM=0.03) odour conditions were observed in the case of critical lure words, t(78)=1.60, p=.12, d=0.36, or in the case of intrusions, t(78)=-0.54, p=.60, d=0.12. Given the non-significant difference in the lure condition, it is important to try to understand whether this can be considered as reliable evidence that odour cueing has no impact on lure recall. We calculated the Bayes factor associated with the odour context difference in the lure condition (Dienes et al., 2018) using a half-normal distribution with a standard deviation (SD) of 0.0875. As there are no directly comparable studies in the published literature, the SD was chosen based on the effect of sleep on free recall of lures reported in Experiment 1 of Payne et al. (2009), making it a reasonable estimate of the size of effect that can be observed using an experimental DRM design and sample size similar to ours. We found a Bayes factor of 2.22. Bayes factors higher than one-third but lower than 3 indicate that the evidence is not strong enough to reliably either reject or accept the null hypothesis (Dienes et al., 2018).

FIGURE 1 ABOUT HERE

**Discussion**

The present study is the first to look at the impact of odour context cues on false memories. As predicted, we found that reinstating at test the odour context in which the DRM lists were encoded facilitated memory for the studied words. This shows that odour context cues veridical memories in the DRM paradigm. We found no significant effect of odour cueing on number of critical lure words produced, suggesting that odours cue veridical memories but may not increase false memories to the same degree in free recall, although the Bayesian analysis indicated that more work is needed before accepting the latter conclusion.

While our findings do not favour one theory of the DRM effect over another, it is useful to consider them in the context of the theories outlined in the Introduction. Given that odour cues did not reliably promote false memories, it may be that the spreading of activation to lure words, postulated by the Activation/Monitoring Theory, was unlikely affected by our odour manipulation. The second process, monitoring, may have been affected by odour cues. Perceptual overlap between the odour associated with studied words and the odour present at time of test, when the same odour is present at both times, could be used as a reliable cue for identifying studied words as part of the monitoring process. This mechanism would be unreliable however when the odour at study and test is different. This might explain why presenting the same odour at study and test resulted in better veridical memory.

According to the Fuzzy-Trace Theory recall is based on a mix of retrieval of both verbatim traces and gist traces. Our data suggest that verbatim traces may have been more strongly cued by odour, probably as these traces include information about environmental context. Alternatively, the match between odour cues in the same odour condition may have biased retrieval in favour of verbatim recall, resulting in higher veridical memory.

As alluded to earlier, memory reactivation through odour cueing during sleep has provoked much interest recently. We speculatively suggest that odour cueing during sleep might result in no or weak effects when investigating memory for stimuli that were not directly associated with the odour before sleep. Therefore it may not be a coincidence that sleep reactivation studies looking at generalisation have used primarily auditory rather than odour cues (e.g., Batterink & Paller, 2017). Research directly comparing different types of cue is required to confirm or disconfirm this speculation.

One possibility for why odour might only cue veridical memory is offered by an anatomical point of view to the sense of smell. Compared to other sensory modalities, olfactory input has uniquely direct access to the hippocampus (Saive et al., 2014). The hippocampus is key to the representation of episodic, veridical memories, and therefore olfactory stimuli are optimally placed to affect these memories. False memories in the DRM paradigm on the other hand arise in the temporal pole, argued to be a store of abstract semantic knowledge (Chadwick et al., 2016), possibly explaining why these memories may be less affected by odour cues. However, to conclusively test the hypothesis that odour cues have a different impact from other types of environmental cues one would need to directly compare odour cues with a different type of cue in the same experiment. For example, room change is a much used environmental cue and could be easily adapted to the DRM paradigm in future research. In the absence of such data, we must limit our conclusions to odour cueing specifically.

Our findings partially support previous work on visual cues in the DRM paradigm (Arndt, 2010). It is important to acknowledge however that our study differs from that of Arndt (2010) in key aspects. Importantly, Arndt (2010) tested recognition memory while we tested free recall. This is not a trivial difference, as some variables can have dramatically different impact on recall and recognition in the DRM paradigm. For example, sleep after encoding has been shown to *increase* false memories in recall (e.g., Payne et al., 2009) but to *decrease* them in recognition (e.g., Fenn et al., 2009). Therefore the current conclusions must be limited to recall. It is difficult to see how the font manipulation could be carried out on free recall, but odour context is easily manipulated regardless of the task, and future work should therefore be carried out to see if our findings generalise to recognition memory. Another limitation of the current study is that the presentation rate of the DRM lists could have have unintentionally varied across conditions, as they were read aloud by the experimenters who were not blind to the odour manipulation. Computerised presentation in future work should eliminate this limitation. In the meantime we propose that our data constitute the first step in beginning to understand the boundary conditions of the types of memory odour cueing influences, and that recall of veridical memories appears to be susceptible to odour cueing while its impact on abstract or gist memory remains less clear.

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**Disclosure of interest**

The authors report no conflicts of interest.

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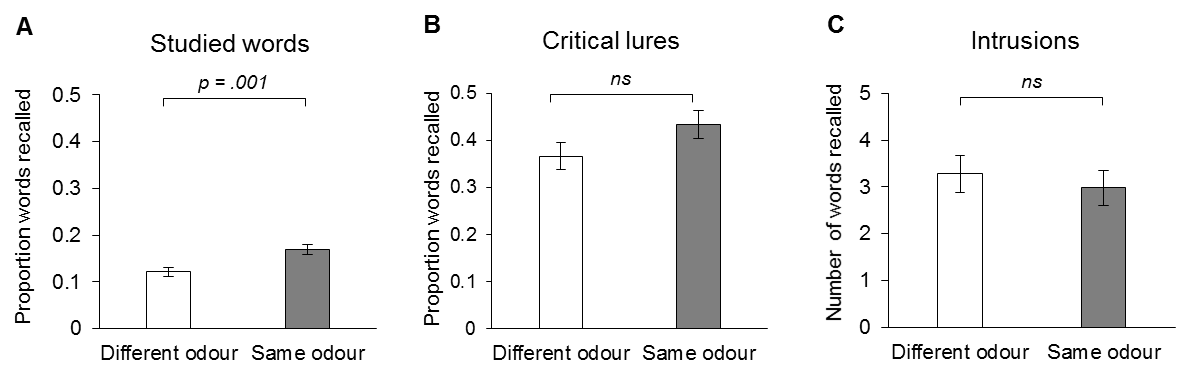
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**Figure Captions**

Figure 1. Proportion of studied words correctly recalled (A), and proportion of critical lures (B) and number of intrusions (C) entered in the free recall test in the same and different odour groups. Error bars represent standard error of the mean.

Figure 1.



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SUPPLEMENTAL MATERIALS

**Supplemental analysis: ANOVA with *number of words* recalled**

Number of words correctly recalled was analysed with an ANOVA with odour condition (same or different at encoding and test) and recall category (studied words, critical lure words, intrusions) entered as factors. A significant main effect of odour condition indicated that overall participants in the same-odour condition recalled more words than participants in the different-odour condition, F(1,78)=8.30, p=.005, =0.10. We also found a significant main effect of recall category, F(2,156)=182.86, p<.001, =0.70, which merely reflects the differences in the number of responses entered in the different categories. Critically, we also found a significant interaction between odour condition and recall category, F(2,156)=9.05, p<.001, =0.10.

To ensure that the odour condition had a different impact on recall of studied words and recall of critical lure words, we entered only these two recall categories into an ANOVA. We found a significant interaction between odour condition and recall category, F(1,78)=9.76, p=.003,  =0.11, showing that the magnitude of the odour effect was indeed significantly different in these two recall categories.

**Supplemental analysis: ANOVA with *proportion of words* recalled**

Proportion of words correctly recalled was analysed with an ANOVA with odour condition (same or different at encoding and test) and recall category (studied words, critical lure words) entered as factors. A significant main effect of odour condition was found, F(1,78)=5.88, p=.018, =0.07. We also found a significant main effect of recall category, F(1,78)=156.69, p<.001, =0.67. No significant significant interaction between odour condition and recall category was found, F(1,78)=0.21, p=.65, =0.003.

1. See Supplemental Materials for an omnibus ANOVA including factors of recall type and odour and their interaction, as well as analyses using number of words recalled rather than proportions. [↑](#footnote-ref-1)