# **Emotional salience enhances the forward flow of memory**

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# **ABSTRACT**

Mnemonic enhancement for oddballs has been described alongside retrograde and anterograde amnesic effects. Conditional response probability (CRP) curves provide a quantitative approach to evaluate free recall and show that recall occurs for contiguous items with forward-directionality. We hypothesized that presenting emotional oddballs would increase CRP curves, increasing the forward-flow of memory and explaining the retrograde amnesic effect. 70 participants encoded 40 lists (13 neutral items, 1 oddball [emotional, perceptual]) at varying SOAs followed by a distractor task before free-recalling. Enhanced recall of both oddball types was accompanied by a mild retrograde and anterograde amnesia. A significant oddball x transition type interaction showed that transitions from emotional oddballs were enhanced, although not correlated to retrograde amnesia, and transitions from perceptual oddballs did not show forwards-directionality. This is the first empirical evidence of CRP modulation by salience which suggests recall patterns after presenting emotional and perceptual oddballs are mediated by different mechanisms.

# **STATEMENT OF RELEVANCE**

iconditional response probabilityconditional response probability

# **INTRODUCTION**

Novel unexpected item presentation induces a mnemonic enhancement for salient items among lists of related items (Von Restorff, 1933) and in the presence of emotionally salient items the mnemonic enhancement is often accompanied by an anterograde (Angelini, Capozzoli, Lepore, Grossi, & Orsini, 1994) and retrograde amnesic effect (Strange, Hurlemann, & Dolan, 2003; Tulving, 1968). Memory enhancement for emotional words has been widely reported (Schmidt & Schmidt, 2016; Strange et al., 2003) however there have been mixed findings regarding the mnemonic effects on the words preceding and following the oddballs which are modulated by stimulus onset asynchrony (SOA), retention intervals and arousal characteristics of the items (Mather & Sutherland, 2011; Schmidt & Schmidt, 2016).

The presentation of salient items at encoding leads to increased arousal and attention to these items via amygdala-frontoparietal interactions (Mather & Sutherland, 2011) and enhanced memory of emotional items via amygdala-hippocampal coupling via the noradrenergic system (Richardson, Strange, & Dolan, 2004; Strange & Dolan, 2004) shortly after encoding. Neurobiological approaches to explain the retrograde amnesic effects using pharmacological manipulations have centered around arousal, valence and the noradrenergic system as this effect is modulated by noradrenaline, specifically, it appears absent upon administration of a 12-adrenergic antagonist (Hurlemann et al., 2005; Strange et al., 2003). This has been proposed to occur as an encoding disruption at the synaptic and/or systems level (Strange et al., 2003; Strange & Galarza-Vallejo, 2016). Others, however, have proposed that the amnesic effects, specifically, retrograde amnesic effects in free recall, could be due to item unavailability at retrieval, and can be reversed by cueing recall (Detterman, 1976). It remains possible that pharmacological influences were still present at the time of retrieval (Hurlemann et al., 2005), complicating untangling encoding vs. retrieval effects on emotion-induced retrograde amnesia. Furthermore, timing effects have also been proposed to influence recall; while some suggest that amnesic effects on items surrounding an oddball occur at very short SOAs (< 2 seconds) (Schmidt & Schmidt, 2016; Tulving, 1968) others have found this effect in longer SOAs (3 seconds) (Strange et al., 2003).

To provide more insight on free recall and interitem organization Kahana (1996) developed a quantitative method to analyze free recall termed conditional response probability (CRP). CRP quantifies, under the fact that x is immediately followed by y, the probability of recalling item x, if y is recalled (Kahana, 1996) and is characterized by the generalizable findings that 1) recall transitions are more likely to be amongst contiguous items and 2) to occur in the forward direction (Kahana, 1996). These *lag contiguity* properties can be accounted for by considering a strengthening of inter-item associations and their shared context when they spend more time together in the short-term storage (Raaijmakers & Shiffrin, 1980). At time of recall, recollection of an item serves as a contextual cue for the recollection of related items (Howard & Kahana, 1999)*.* More recently Polyn et al (2009) developed the Context Maintenance and Retrieval (CMR) model to distinguish between different types of contexts that affect item encoding and recall dynamics.

Electrophysiological studies lend further support for these theories and computational models, by providing neural evidence of context reinstatement. Patterns of neural activity when recalling an item are similar to those when studying the item itself as well as neighboring items and, this similarity, decreases the further away two items are from each other (Folkerts, Rutishauser, & Howard, 2018; Manning, Polyn, Baltuch, Litt, & Kahana, 2011). Neural evidence of the behavioral lag contiguity effect as a recovery of temporal context during retrieval is present in both in single-unit recordings from the hippocampus and amygdala (Folkerts et al., 2018).

To address enhanced memory for emotional items and an amnesic effect for their surrounding items in oddball tasks Talmi et al. (2019) developed a variation of the CMR model: the emotional CMR (eCMR). Talmi et al. (2019) showed in simulated data, that increasing attention to the oddball at encoding would increase its link to temporal context and help promote its recall. However, due to the fact that the oddball has a different source context than the rest of the items in a study list, there would be a decrease in source and semantic similarity between the oddball and the rest of items (Talmi et al., 2019). Although the eCMR model has provided a framework to expand the CMR model to emotional settings, this remains to be investigated empirically in oddball paradigms.

A strong contextual change, produced by an oddball presentation, would predict a contextual item association shift from the oddball presentation onwards and we would expect oddballs to be recalled early in recall order (Elhalal, Davelaar, & Usher, 2014; Talmi et al., 2019). Furthermore, computational models have shown that optimal recall occurs when recall begins at the beginning of a list and there is a strong forward-contiguity (Zhang, Griffiths, & Norman, 2021). Given the shift in source context, we would anticipate for items studied after the oddball at encoding to be strongly coupled with the oddballs at retrieval, and therefore, for items following the oddball to show enhanced CRPs. We hypothesize this forward lag contiguity enhancement accounts for the retrograde amnesic effect, i.e if an oddball is well remembered and involves a forward progression of recall, it will be less likely that preceding items will be recalled.

In the present study, we aim to investigate oddball effects on CRP curves, using emotional and perceptual oddballs, in healthy young participants (N=70), on a Spanish version of the oddball free recall paradigm reported in Strange et al. (2003). In the present task we 1) investigate how recall patterns are modulated by timing by introducing 5 different SOAs (1, 2, 3, 4 and 6 seconds) which were fixed within a list. Furthermore, we recorded the order in which nouns were recalled and studied in order to 2) apply quantitative approaches to empirical data to evaluate how the presentation of an oddball modulates recall and 3) investigate whether there is a forward-contiguity enhancement and how it influences the recall of the words preceding the oddball.

# **METHODS**

**Subjects.** 70 healthy right-handed native Spanish-speaking subjects took part in this study [35 male, 35 female (age range, 18–32 yr; mean age, 22.5)]. All subjects gave informed consent and were free of neurological or psychiatric history. Sample size was calculated using original data from (Strange et al., 2003) and G\*Power software (Erdfelder, FAul, Buchner, & Lang, 2009; Faul, Erdfelder, Lang, & Buchner, 2007) using an a priori power analysis for t-tests (means difference between matched pairs) with an effect size dz=1.84, =0.05 and power set at 0.95. Effect size calculation returned a total sample size of 7 which we then multiplied by 5 SOA groups (n=35) and doubled due to the fact that in the present task there were about half of number of trials compared to the original 2003 paper.

**Stimuli.** Lists were based on those presented in Strange et al. (2003), translated from English to Spanish, and normed for emotional valence and semantic relatedness by a separate group of 11 native Spanish-speaking subjects [5 male, 6 female (age range, 25-34 yr; mean age, 30.2)].

**Task.** Subjects were presented with 40 lists of 14 nouns with the words ‘‘New List’’ presented between lists. For each list, 13 of the nouns were of the same semantic category (e.g animals, occupations…), emotionally neutral, and were all presented in the same font. These are referred to as control nouns. To set the context, the first five nouns in each list were always control nouns (i.e not oddballs). Twenty lists contained an emotional oddball, aversive in content but of the same category and perceptually identical to control nouns. The remaining 20 lists contained a perceptual oddball. All oddballs were randomly allocated to the 7th, 8th, 9th, 11th or 12th serial position. All nouns were presented in Times font, except for perceptual oddballs, which were presented in 20 different fonts. The order of oddball list type was random. Nouns were presented visually in lowercase for 800 ms. Subjects made a push-button response to indicate whether the first letter in each noun contained an enclosed space (shallow encoding task). The rate of stimulus presentation was randomly varied at a stimulus onset asynchrony (SOA) of 1, 2, 3, 4 or 6 s. Thus, for each of the 20 lists for each oddball type, 4 of these lists were presented at a given SOA. Subjects were informed of the presentation rate in each forthcoming list, by presenting the SOA under the “New List” marker.

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| **Figure 1.** Example of items used in the task where E and P are the emotional and perceptual oddballs respectively. -2, -1 or +1 indicate the two (or one) items preceding the oddballs and +1 indicates the item following the oddball. |

The presentation of each 14-word list was followed immediately by a 30-s distractor task, during which subjects were instructed to count backwards in threes (out loud) from a number presented on the screen. The distractor task was followed by instructions to free-recall the words presented in the preceding list. Recall performance in the experiment is expressed relative to one randomly selected control noun in each list. The chosen control nouns, like the oddballs, could not occur within the first five nouns of each list and were at least 3 serial positions apart from oddball nouns.

**Analyses.** Lists that contained data collection errors (e.g missing data, repeats) were excluded from all analyses across all subjects (10 emotional lists, 6 perceptual lists out of a total of 20 emotional and 20 perceptual lists per subject). All analyses were conducted using MATLAB (R2019b, The MathWorks, Inc). Statistical analyses and figures were conducted in Rstudio (version 1.3.1093). All data was tested for normal distribution using Shapiro-Wilk or QQ plots, Greenhouse-Geisser sphericity correction was applied when appropriate. Post-hoc t-tests were FDR-corrected.

Conditional probability analyses were conducted using the Behavioral Toolbox for MATLAB R2019b (<http://memory.psych.upenn.edu/Behavioral_toolbox>) with modified scripts where the CRPs were investigated for the words recalled one serial position before or after the oddball. All analyses and visualization were on lags 5 as previously reported (Healey, Long, & Kahana, 2019; Kahana, 1996).

# **RESULTS**

## **Emotional and perceptual oddballs are remembered rather late during recall and primacy effects are preserved**

We assessed the overall probability of first recall in our dataset, including the first two recalled items. We conducted a three-way RM ANOVA (serial position [1-14] x recall [oddball recalled, oddball forgotten] x oddball type [emotional, perceptual]). We aimed to investigate not only the effects of oddball type and serial position but also to assess whether recalling an oddball produced a change in the probability of first recall curves. The counting backwards distractor task correctly abolished recency effects in all conditions.

We did not find a significant three-way interaction between oddball type x recall x serial position (F(8.44, 582.31)=0.802, p=0.607, nor a significant two-way interaction between oddball type x recall (F(1, 69)=0.184, p=0.670) nor oddball type x serial position (F(8.54, 589.06)=0.988, p=0.447). However, there was a significant recall x serial position interaction (F(8.82, 608.52)=5.527, p<0.001) indicating that the probability of first recall of the word in the 1st serial position was higher when oddballs were recalled vs. when they were not (t(139)=-3.25, p=0.001, *Cohen’s d*=-0.27) as well as in the 7th position (t(139)=-3.70, p<0.001, *Cohen’s d=*-0.31). However, items in the 3rd (t(139)=2.30, p=0.02, *Cohen’s d*=0.19), 12th (t(139)=-3.74, p<0.001, *Cohen’s d*=-0.32) , 13th position (t(139)=3.73, p<0.001, *Cohen’s d*=0.32) or 14th position (t(139)=2.05, p=0.04, *Cohen’s d=*0.17) had a higher probability of first recall in lists in which the oddball was forgotten vs. recalled. Furthermore, there was a significant main effect of recall (F(1, 69)=7.15, p=0.009), which showed that lists in which an oddball was recalled (mean=0.071) had a higher probability of first recall than when oddballs were not (mean=0.067). Lastly, there was also a significant main effect of serial position (F(3.82, 263.26)=61.183, p<0.001), consistent with the primacy effect (Fig. 2A).

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| **Figure 2.** A) Graphs show probability of first recall; bars represent mean. Both graphs show a strong primacy effect in emotional and perceptual lists which is enhanced in trials in which the oddball was recalled. B) Bars show mean 95% confidence intervals. Graph shows the relative recall position of the emotional oddball and the perceptual oddball. Emotional items were recalled slightly later than perceptual oddballs (p<0.001). |

To further investigate whether the oddballs were recalled early-on we calculated the relative recall position of the oddballs to all the words recalled in each list across all trials in which the oddball was recalled. If, say, an item was recalled on the 6th position out of a total of 6 items recalled; that would produce a relative recall position of 1; whereas an item recalled on the 1st position, would have a relative recall of 0.167. An unpaired Wilcoxon rank sum test showed that emotional oddballs were recalled significantly later than perceptual oddballs (W=395538; p<0.001) (Fig. 2B).

We confirmed a primacy effect was maintained and enhanced in trials in which the oddball was recalled. However, contrary to what we expected, both emotional and perceptual oddballs were remembered later on in recall; at a relative recall position of approximately 0.6 [emotional oddballs (0.65); perceptual oddballs (0.59)].

## **Items preceding and following emotional and perceptual oddballs are less well-remembered than the oddballs**

We next sought to investigate overall recall of the oddballs and the items nearby to investigate whether the previously-reported retrograde and anterograde (B.A. Strange et al., 2003) amnesic effects in the words near the oddball were present in the current version of the task. We found an overall mnemonic enhancement of both emotional and perceptual oddballs accompanied with an anterograde and retrograde amnesia for items preceding and following the oddballs at encoding, although less pronounced than the effects observed for the English and German versions of this task.

A repeated measures two-way ANOVA (word position [odd-2, odd-1, odd, odd+1] x oddball type [emotional, perceptual]) showed a significant interaction between the two factors (F(3, 207)=3.61, p=0.01), a significant main effect of word position (F(3,207)=55.19, p<0.001) and a trend towards significance in oddball type (F(1, 69)=3.44, p=0.07). Uncorrected post-hoc t-tests showed a significant enhancement in oddball recall compared to its nearby items (vs. odd-1 t(139)=-10.75, p<0.001, *Cohen’s d*=-0.91; vs. odd-2 t(139)=-9.5, p<0.001, *Cohen’s d*= -0.80; vs. odd+1 t(139)=10.41, p<0.001, *Cohen’s d*=0.88). Furthermore, emotional oddballs were significantly better recalled than perceptual oddballs (t(69)=3.93, p<0.001, *Cohen’s d*=0.47) (Fig. 3).

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| **Figure 3.** All graphs show mean 95% confidence intervals.Graph showing the proportion of normalized recalled words (minus control) items across word positions, oddball (odd), -2 (item presented two serial positions preceding the oddball at encoding), -1 (item presented one serial position preceding the oddball at encoding), +1 (item presented one serial position after the oddball at encoding). Oddballs were better recalled than its surrounding items. |

## **Recall patterns in an oddball task are modulated by SOA**

Previous literature has shown conflicting results regarding SOA manipulations and their effect on retrograde and anterograde amnesia. In the present study we modulated item presentation by varying SOAs to 1, 2, 3, 4 and 6 seconds. The results indicate that longer SOAs show a trend to increased memory compared to shorter ones (Fig. 4), however, since we found no significant interactions between SOA and oddball type or word position, we did not further investigate the issue with follow-up post-hoc tests.

We ran a three-way RM ANOVA (oddball type [emotional, perceptual] x SOA [1, 2, 3, 4, 6] x word position [odd-2, odd-1, odd, odd+1]). There were no significant interactions between oddball type x SOA (F(4,276)=1.50, p=0.20), SOA x word position (F(12,828)=1.21, p=0.27) nor a significant three-way interaction between oddball type x SOA x word position (F(12,828)=1.14, p=0.33). There was a trend towards a significant main effect of oddball type (F(1,69)=3.33, p=0.07), indicating, at a trend level, that overall emotional lists were better remembered than perceptual ones. There was a significant main effect of SOA (F(4, 276)=3.87, p=0.004) which showed, that at SOA 1 all words were less well remembered than at SOAs 2, 3 and 6 (vs. 2 t(559)=-3.78, p<0.001, *Cohen’s d*=-0.16; vs. 3 t(559)=-3.76, p<0.001, *Cohen’s d*=-0.16; vs. 6 t(559)=-5.11, p<0.001, *Cohen’s d*=-0.22). Furthermore, words shown at SOA 4 were less well remembered than at SOAs 2 (t(559)=2.90, p=0.008, *Cohen’s d*=0.122), 3 (t(559)=2.81, p=0.009, *Cohen’s d*=0.12) and 6 (t(559)=-4.03, p<0.001, *Cohen’s d*=-0.17).To further confirm that recall improved as SOA increased, we plotted the overall item recall per list by SOA (Fig. 4B). The results showed a main effect of word position (F(3,207)=55.87, p<0.001) in which the oddball, regardless of oddball type and SOA, was always better remembered than its surrounding items (vs. odd-2 t(699)=-9.44, p<0.001, *Cohen’s d*=-0.36; vs. odd-1 t(699)=-10.99, p<0.001, *Cohen’s d*=-0.42; vs. odd+1 t(699)=10.77, p,0.0001, *Cohen’s d*=0.41). Furthermore, there was a significant interaction between oddball type x word position (F(3,207)=3.55, p=0.02); showing that emotional oddballs were better recalled than perceptual ones (t(349)=3.34, p<0.001, *Cohen’s d*=0.18).

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| **Figure 4.** A) Modulation of normalized recall as a function of SOA. Bars show normalized recall (- control) with mean 95% confidence intervals by SOA. B) Total amount of items recalled per list across SOAs. |

## **The influence of emotional and perceptual oddballs on Conditional Response Probability Curves**

Analyses were focused on lags 5 for both statistical analyses as well as visualization purposes.

### **Do conditional response probability curves preserve a forward-contiguity effect?**

Firstly, taking all recalled words, we evaluated CRP curves in both emotional and perceptual oddball lists. Overall, CRP curves showed a preserved forward-contiguity effect i.e words nearby each other were more likely to be recalled and more so in the forwards direction. This effect was preserved both when oddballs were recalled as well as when they were forgotten (Fig. S1).

A three-way RM ANOVA (oddball type [emotional, perceptual] x lag [1-5] x direction [backwards, forwards]) did not show a significant main effect of direction (F(1,69)=1.61, p=0.21), oddball type x lag (F(4, 276)=0.93, p=0.47), oddball x direction (F(1,69)=0.252, p=0.62) nor a significant 3-way interaction F(4,276)=0.54, p=0.71). However, there was a trend of a significant main effect of oddball type (F(1,69)=4.07, p=0.048), lag (F(2.95,203.77)=105.11, p<0.001) and lag x direction interaction (F(3.06, 210.95)=13.58, p<0.001). Uncorrected post-hoc t-tests showed enhanced CRP for contiguous lags, specifically lags 1 and 2 as well as a significant forward effect for lags 1 (t(139)=-5.11, p<0.001, *Cohen’s d*=-0.43) and 5 (t(139)=4.15, p<0.001, *Cohen’s d*=0.35).

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| **Figure 5.** CRP curves show a preserved forward-contiguity effect for both emotional and perceptual oddball lists. |

### **Do transitions to and from oddballs modulate conditional response probability curves?**

Our main hypothesis was that transitions from the oddballs would show enhanced CRP curves due to a strong contextual change which would serve as an anchor to strongly move forwards in recall after recalling the oddballs, thereby, contributing to the retrograde amnesic effect.

We calculated CRP curves for items recalled right before the oddballs (to evaluate transitions to the oddballs) and for items recalled right after the oddballs (to evaluate transitions from the oddballs). Again, we found a significant main effect of lag (F(4, 36)=0.02), which showed a contiguity effect for lag 1 (vs. 2, t(506)=3.44, p=0.002, *Cohen’s* d=0.15); vs. 3, t(493)=3.75, p<0.001, *Cohen’s* d=0.17; vs.4, t(479)=4.29, p<0.001, *Cohen’s* d=0.20; vs. 5, t(482)=4.63, p<0.001, *Cohen’s* d=0.21) a trend of direction (F(1,9)=4.63, p=0.06) and, importantly, a significant oddball x transition interaction (F(1,9)=14.34, p=0.004) that revealed an enhancement in CRP in transitions from emotional oddballs compared to perceptual oddballs (t(573)=4.47, p<0.001, *Cohen’s d*=0.19) as well as a significant difference in transitions to emotional oddballs vs. transitions from emotional oddballs (t(584)=4.18, p<0.001, *Cohen’s d*=0.17) (Fig. 6C). Indicating that transitions from emotional oddballs onwards were enhanced compared to transitions from perceptual oddballs. None of the other effects reached significance levels.

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| **Figure 6.** A) Examples of a subset of items presented at encoding in emotional (E) and perceptual (P) lists. B) Example of item transitions (in relation to lag values) depending on whether transitions were to or from oddballs. C) CRP curves in transitions to and from emotional and perceptual oddballs. Transitions from emotional oddballs show enhanced CRP compared to perceptual oddball lists. |

## **Does enhanced forward contiguity in emotional oddball lists explain retrograde amnesia?**

In lists containing emotional and perceptual oddballs we found that while transitions to the oddballs preserved a contiguity effect, the forward effect was modulated (Fig. 6C). As hypothesized, transitions from emotional oddballs showed an enhancement in the CRP curves which was not present in transitions from perceptual oddballs. We next sought to test whether this CRP enhancement in transitions from emotional oddballs (specially at lag +1) explained retrograde amnesia for E-1 items. A Spearman’s rank correlation, however, did not show a significant relationship between the two variables [E-1 normalized recall and lag +1 values], (rho=-0.04, p=0.76) (Fig. S2).

# **DISCUSSION**

We calculated CRP curves on recalled items from an oddball paradigm that presented word-item lists which contained either an emotional oddball (aversive in content) or a perceptual oddball (presented in a different font). Overall CRP curves showed preserved key properties of free recall in which contiguous items are better recalled and more so in the forwards direction (Kahana, 1996). We further looked at transitions to and from the oddballs to evaluate whether these core properties remained present. Interestingly, while we found a significant main effect of lag which showed that contiguity was maintained throughout, in perceptual oddballs, the forward transitions effect was reduced; however, it was enhanced in transitions from emotional oddballs.

Although the current version of the oddball paradigm showed that overall recall was worse at short SOAs, we did not find as strong retrograde amnesic effects as previously described (B.A. Strange et al., 2003). The present items used were translated from Strange et al. (2003) and normed for emotional content and semantic relatedness, therefore, the differences in the current task with previous studies are not attributable to differences in word valence. On the other hand, differences in experimental design and choice of control words could explain the hindered retrograde amnesic effect. For instance, the paradigm in Strange et al. (2003) consisted of 16-item lists which contained both an emotional and a perceptual oddball as well as a semantic oddball and two control nouns. In our current task, recall improved as SOA increases. It remains possible that in previous experimental designs the presentation of emotional oddballs increased salience for perceptual oddballs, and therefore, contributed to their increased recall (Sutherland & Mather, 2012) which did not occur in the present task.

The present findings provide empirical data to the eCMR computational model. However, we found a later-than-expected oddball recall and an enhancement in forward transitions from emotional oddballs but transitions from perceptual oddballs show a diminished forward transition effect, in line with the predictions of the eCMR (Talmi et al., 2019). The idea of increased attention to the oddballs has been the basis for the development the eCMR (Talmi et al., 2019) where, by calculating CRP curves, they simulated that increased recall of an emotional oddball hindered recall of its nearby items. Increased attention due to increased arousal produced by item presentation can occur due to a variety of interacting factors. Behavioral studies investigated the influence of emotional modulations on attention and perception by presenting fearful faces followed by an orientation-decision task on Gabor stimuli; Phelps et al. (2006) provided evidence that emotion modulates attention i.e how we ‘‘see’’ upcoming stimuli as well as it enhanced perceptual processing. E(Long, Danoff, & Kahana, 2015),p

Pharmacological approaches have shown that the beta-adrenergic blocker, propranolol, blocks memory for emotional but not perceptual oddballs (B.A. Strange et al., 2003). It is possible that carry-over effects after exposure to emotional oddballs (Schmidt & Schmidt, 2016) induce a bias, mediated by the adrenergic system, which underlies the forward-recall enhancement. If this were the case, we would expect propranolol to diminish the forward-transitions enhancement.

Previous studies using oddball paradigms had found a mnemonic enhancement for oddballs accompanied by a strong retrograde amnesic effect (Schmidt & Schmidt, 2016; Strange et al., 2003; Tulving, 1968), however, the precise timing effects on the retrograde amnesic effects remained to be further investigated. A key manipulation of the present paradigm was that items were presented at varied SOAs to unravel how timing affected memory. Whilst overall we found a mnemonic enhancement for oddballs accompanied by a decline in recall for items preceding oddballs, this effect was less strong than previously reported at SOA of 3 seconds (Strange et al., 2003). We found a significant main effect of SOA which showed that overall, the shortest SOA demonstrated worse recall than longer SOAs. We next decided to focus on emotional oddballs and evaluated whether the CRP forward-flow enhancement in transitions from emotional oddballs explained the retrograde amnesic effect, however, we did not find such significant correlation which could be explained by the fact that the retrograde amnesia in the present task was not strong, thereby not allowing us to investigate this relationship.

This was the first study to apply CRP curve analysis on a free-recall paradigm to investigate emotional and perceptual salience (via oddball presentations). We found that whilst transitions from emotional oddballs were enhanced in the forwards direction, transitions from perceptual oddballs were reduced. We had hypothesized that this enhancement in transitions from emotional oddballs would explain the widely reported retrograde amnesic effect in these paradigms, however, it did not seem to be the case. This could be because the present version of the task did not induce as strong retrograde amnesic effects as previously reported. Future work could re-evaluate this approach in tasks which induce a stronger retrograde-amnesic effect such as in the English and German versions conducted by Strange et al. (2003). The current results, which indicate a dissociation in emotional and perceptual salience, provide empirical evidence that could be used to update the emotionality component in the eCMR*.*

The present findings could help the study of memory in disorders where strong emotion plays a key role, such as posttraumatic stress disorder as retrograde amnesia and dissociative experiences are present in the disorder (Brewin & Holmes, 2003; van der Kolk & Fisler, 1995). Applying quantitative approaches such as done in the present study to investigate memory recollection would help elucidate the underlying mechanisms of memory recall underlying the disorder.

# **AUTHOR CONTRIBUTION**

B.S designed the experiment. B.S, A.P.Y and D.F analyzed the data and wrote the manuscript.

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We thank X for data collection for this study.

# **OPEN PRACTICES STATEMENT**

The experiments were not pre-registered. Raw data, analysis pipelines and code used in the present paper can be found here: <https://github.com/TheStrangeLab/Odd_SOA_CRP>

# **ETHICAL CONSIDERATIONS**

The present work had ethical approval from the Universidad Politécnica de Madrid under the project ‘Estudio de los efectos de la emoción sobre la cognición humana’.

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