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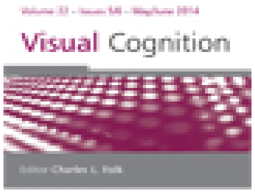

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# Bridging novelty and familiarity-based recognition memory: A matter of timing

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**ABSTRACT**
Novelty detection is essential to adapt to changes. However, the relationship between novelty detection and visual recognition memory remains unclear. To characterize the temporal dynamics of novelty and its connection to familiarity, we probed early behavioural performance of novelty and familiarity in 31 participants using a speeded go/no-go recognition task with a 600-ms response deadline. Responses to familiarity and novelty produced symmetrical biases and correlated accuracies and biases, but novelty decisions were less accurate and had slower minimal reaction times (410 ms). These processes thus appear to be independent, as suggested by a more efficient system in the case of familiarity, but with common factors bringing overlapping contributions to both processes. This may possibly be explained by the more fluent processing of repeated stimuli, but with familiarity and novelty potentially relying on one decision criterion, as suggested by the correlated and remarkably symmetrical biases. This study supports models that conceptualize novelty and familiarity decisions as two partly overlapping processes.

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**KEYWORDS**
Novelty detection; familiarity; visual recognition memory; episodic memory; minimal reaction time; signal detection theory

A fundamental ability of the human nervous system is to detect and respond to novelty in order to avoid dangers and adapt to environmental changes. A novel stimulus generates a rapid orienting response that habituates as the stimulus becomes familiar. The precise cognitive mechanism operating during novelty detection and how it is modulated by prior experience are not yet understood. Here we consider the role of visual recognition memory processes in novelty detection. By definition, detecting novelty implies distinguishing new stimuli (stimulus novelty) or stimuli configurations (associative novelty) from those encountered in the past, and detecting stimuli that are unexpected in the context in which they occur (contextual novelty) (Kumaran & Maguire, 2009; Ranganath & Rainer, 2003). Novelty responses thus depend on prior experience, since they imply the ability to use stored representations to discriminate between what is known and what is new.

Several interpretations co-exist concerning the relationship between novelty detection and familiarity. Familiarity and novelty have been described as representing two ends of a single continuum drawing on the same cognitive mechanism (Brown & Bashir, 2002; Fernandez & Tendolkar, 2006; Grill-Spector, Henson, & Martin, 2006). Alternatively, familiarity and novelty could stem from distinct signals processed separately. According to this view, a given input would be compared with stored memories; recognition would happen as soon as the input found a match, while novelty detection would only be triggered once no match had been found (see Kumaran & Maguire, 2009, for a review). In this view, it is not clear how familiarity and novelty signals would interact to support recognition memory decisions, although this theory does determine that novelty should not be faster than familiarity. Finally, Kafkas and Montaldi (2014, 2015) have suggested that familiarity and novelty detection produce distinct signals that subsequently converge in the computation of a unitary "relative familiarity" signal behaving as expected from a familiarity–novelty continuum despite upstream distinct processing paths. This was supported by fMRI (functional magnetic resonance imaging) data showing familiarity and novelty signals in two distinct sets of partially overlapping brain regions (Kafkas & Montaldi, 2014), and by eyetracking data showing greater pupil dilation when the subject

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detects familiar rather than novel stimuli. The duration of the first fixation allowed discriminating between objective familiarity versus novelty as early as 320 ms post-stimulus (Kafkas & Montaldi, 2015).

Among the few studies that have directly compared familiarity and novelty, none has clearly dissociated familiarity/novelty detection from late processes such as post-retrieval monitoring which also contribute to familiarity/novelty decisions. Both familiarity and novelty detection are thought to be particularly fast (Brown & Aggleton, 2001), unlike these later processes. Under speeded conditions, accurate familiarity decisions are possible as early as 360 ms post-stimulus (Barragan-Jason, Besson, Ceccaldi, & Barbeau, 2013; Besson, Ceccaldi, Didic, & Barbeau, 2012). However, the actual speed of novelty detection has, to our knowledge, never been studied.

In order to control for these late processes and to assess early familiarity and novelty signals, we adapted the Speed and Accuracy Boosting procedure (SAB; Barragan-Jason et al., 2013; Besson et al., 2015, 2012; see Supplemental Material). This recognition memory procedure uses a go/no-go design and a particularly short response deadline (here, 600 ms) in order to constrain participants to use their fastest strategy (Sauvage, Beer, & Eichenbaum, 2010). Here, our adapted procedure had two distinct conditions: a familiarity and a novelty condition. In doing so, we aimed (1) to characterize the temporal dynamics of these two processes while preventing later processes from contributing to the familiarity/novelty decision, and (2) to directly compare them, in order to assess whether, under speed constraints, novelty and familiarity show similar or independent patterns of performance and temporal dynamics.

## Methods

### Participants

We tested 31 healthy subjects (mean age: 24 ± 3, range: 20–32; 19 females, one left-handed) from a pool of undergraduate students; they all had normal or corrected-to-normal vision, gave written informed consent before participation, and received financial compensation for their participation. The experiment was approved by the French National Institute of Health and Medical Research (INSERM) Ethics Committee.

### Materials

Stimuli were 640 cropped colour pictures of everyday objects and animals from the "POPORO" database presented on a grey background (Kovalenko, Chaumon, & Busch, 2012).

### Procedure

Participants were tested individually under the two conditions of the SAB. Five blocks evaluated familiarity and five blocks assessed novelty. Each block started with a study phase in which 30 pictures of objects were presented one by one for a minimum of three seconds before participants pressed a button to move on to the next trial. Participants were instructed to memorize all presented stimuli. Each study phase was followed by a three-minute interference phase filled with colour animations with sound. The last phase was the recognition test. In the familiarity condition, participants were asked to recognize items previously presented intermixed with 30 new stimuli. In the novelty condition, participants were asked to identify new stimuli, intermixed with the 30 studied items. A fixation cross was displayed for a duration of 300 to 600 ms. Participants then had to respond in a go/no-go fashion before the 600-ms deadline. Audio feedback was given for accuracy. In the familiarity condition, if a go response was given before the response deadline, positive feedback was given if the item was familiar (hit) and negative feedback was given if the item was new (false alarm). If a no-go response was made, feedback was positive if the item was new (correct rejection) and negative if the item was old (miss). The opposite pattern of feedback was given in the novelty condition. In both cases, a "miss" could thereby represent either an incorrect rejection of a target, or a failure to reach a decision in time. A self-paced pause was proposed every 20 items. Each condition was preceded by two training blocks of 10 target items each, to be recognized among 10 distractors. Participants completed the conditions one after another. The order of the conditions and of the blocks was counterbalanced across participants. The items of each block were presented in a randomized order.

### Minimal reaction times

In order to determine the minimal processing time required by participants to give a familiarity/novelty decision, an index of minimal reaction time (minimal RT) was computed by determining the time at which the number of hits significantly outnumbered the number of false alarms (Besson et al., 2012). Analyses were performed across participants and across trials, by pooling together data from all participants, building a "meta-participant" reflecting performance over the sample. Minimal RTs across trials were determined as the middle of the first bin showing a significantly higher number of hits compared with the number of false alarms ($\chi^2$-test, $p < .05$), followed by at least four consecutive bins showing a significant difference between the number of hits and false alarms. The bin size was set at 10 ms. In the between-subjects measure, the bin size was set at 30 ms. Fisher's exact test ($p < .05$) was used to accommodate for lower statistical power due to less data than in across-trials analysis. Importantly, a minimal RT cannot be computed if the distribution of hits does not reach a certain threshold above the distribution of false alarms; a minimal RT could not be computed for three participants in the novelty condition.

## Results

Percentages of hits and false alarms as well as $d'$ and normalized bias ($c'$[1]) are presented in Table 1. All participants performed above chance. No effect of the order of the conditions was found on $d'$, bias, median RTs, or minimal RTs, and there were no interactions with order, all $Fs < 1$.

**Table 1.** Performance in both conditions.

| | | Familiarity | Novelty |
|---|---|---|---|
| Accuracy ($d'$) | Mean (SD) | 2.03 (0.64) | 1.24 (0.44)*** |
| | Range | [0.57; 3.06] | [0.34; 2.05] |
| Hits (%) | Mean (SD) | 78.49 (11.01) | 74.28 (8.49)* |
| | Range | [52; 90.67] | [56; 91.33] |
| False alarms (%) | Mean (SD) | 13.08 (9.18) | 29.12 (10.35)*** |
| | Range | [2.67; 36.67] | [12.67; 55.33] |
| Bias ($c'$) | Mean (SD) | −0.1 (0.14) | 0.06 (0.19)*** |
| | Range | [−0.41; 0.18] | [−0.26; 0.66] |
| Median RT for hits | Mean (SD) | 499.79 (22.29) | 492.32 (19.65) |
| | Range | [450; 546] | [449; 538.5] |
| Median RT for FAs | Mean (SD) | 487.48 (27.5) | 467.18 (30.54)*** |
| | Range | [437.5; 546] | [410; 530] |
| Obtained a minimal RT | *N* | 31/31 | 28/31 |
| Minimal RT | Median | 420 | 450* |
| | 1st and 3rd quartiles | [420; 450] | [420; 480] |
| | Range | [390; 510] | [390; 540] |

Notes: All scores correspond to raw scores presented as mean (SD).
*$p < 0.05$ between condition.
***$p < 0.001$ between conditions.

Accuracy ($d'$) was greater for familiarity than novelty, $t(30) = 7.76$, $p < .001$ (Figure 1), with a higher percentage of hits, $t(30) = 2.32$, $p < .05$, and a lower percentage of false alarms, $t(30) = -7.23$, $p < .001$. Minimal RTs were faster for familiarity than novelty, $Z = 2.13$, $p < .05$ (Figure 1), as evidenced using a Wilcoxon test (data did not follow normality, even after a log transformation). The median RTs for hits did not differ across conditions, $t(30) = 1.92$, $p = .06$, although the effect was close to significance. Median RTs computed on false alarms were faster for novelty than for familiarity, $t(30) = 4.12$, $p < .001$. Biases significantly differed between conditions, $t(30) = 3.74$; $p < .001$, revealing a more liberal response bias for novelty (0.06) (reflecting a greater tendency towards go responses) and a more conservative bias for familiarity (−0.10). Because the bias corresponds to the participant's criterion when discriminating targets from distractors, and since targets and distractors distributions are inverted between the familiarity and the novelty condition (old/new vs. new/old), we neutralized the effect of the sign of the bias in order to avoid any artefactual differences in a separate analysis where we compared the opposite value of the bias in the familiarity condition with the value of the bias in the novelty condition. When the effect of the sign is neutralized, the apparent difference between the biases disappeared, $t(30) = -0.92$, $p = .36$.

Accuracy results are particularly consistent when considered at the individual level, with poorer accuracy in novelty in all participants but two. Across-trials analyses showed different minimal RTs for familiarity (390 ms) and novelty (410 ms; Figure 2).

Pearson's analyses revealed positive correlations between novelty and familiarity for hits, $r = .49$; $p < .01$, accuracy, $r = .5$, $p < .01$ (Figure 3A), and median RTs, $r = .47$, $p < .01$. No significant correlation was shown between the two conditions for the minimal RTs, $r = .23$, $p = .23$; this can be attributed to the discrete distribution of the data. A negative correlation between the values of the biases of the two conditions was also shown when the two outliers were excluded, $r = -.49$; $p < .01$ (Figure 3B). Importantly, excluding these outliers did not change any of the reported results, except for the difference between minimal RTs that became only marginal ($p = .052$).

Finally, negative correlations were also found between accuracy and minimal RTs in both familiarity, $r = -.52$, $p < .01$, and novelty conditions, $r = -.68$,

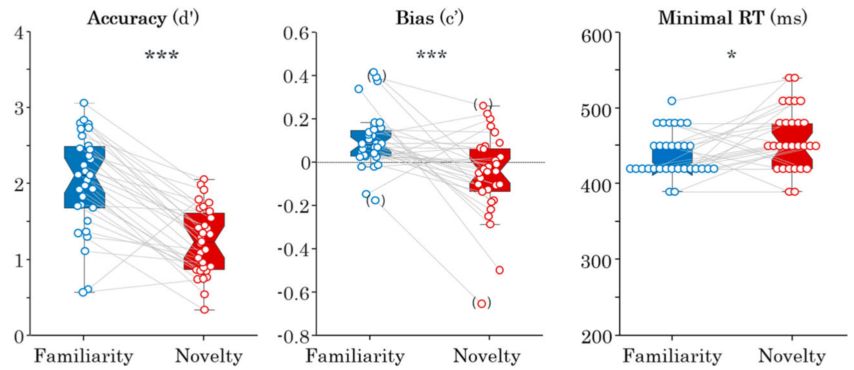

**Figure 1.** Accuracy (*d′*), bias (*c′*), and minimal RTs distribution for hits in the familiarity and novelty conditions. Each circle is a subject. The lines help identifying the same subject in each condition. (◯) denotes outliers. Boxes represent the 25th and 75th percentiles, the lines in the boxes the medians. Notches display the variability of the median between samples. * $p < .05$; *** $p < .001$.

$p < .001$ (Figure 3C), indicating that the participants who had the fastest minimal RTs also showed the best performance.

## Discussion

This study reports the onset of behavioural responses to familiarity at 390 ms, coherent with previous studies (360–390 ms: Barragan-Jason et al., 2013; Besson et al., 2012). It also identifies for the first time the onset of behavioural responses to novelty at 410 ms. If we subtract 110 ms for a decision/motor response to occur (Kalaska & Crammond, 1992; VanRullen & Thorpe, 2001), this minimal RT fits with the temporal dynamics of novelty shown in electrophysiological studies. Event-related potentials associated with novelty indeed peak between 200 and 350 ms (anterior N2) and between 200 and 300 ms for the novelty P3a (Courchesne, Hillyard, & Galambos, 1975; Daffner et al., 2000; Friedman, Cycowicz, & Gaeta, 2001). Moreover, the current results show familiarity to be more efficient than novelty, yielding higher levels of accuracy. Familiarity was also shown to rely on a more conservative strategy and minimal RTs were shorter than for novelty. Although such differences suggest that familiarity and novelty decisions are independent of one another, we have also showed evidence of correlated performance between familiarity and novelty, as well as negatively correlated biases, which may suggest there is at least some common factors in these two apparently independent decision processes. The behavioural paradigm used here does not allow us to directly identify the processes that are overlapping during familiarity and novelty decisions nor to disentangle them from the processes that provide independent influences. Yet, we discuss below how the pattern of results sketches an interesting picture of the relationship between familiarity and novelty, consistent with existing models.

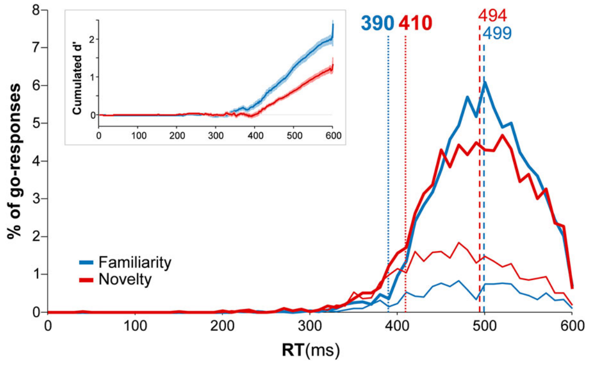

**Figure 2.** Across-trials reaction time distributions of hits (bold lines) and false alarms (thin lines) in the familiarity and novelty conditions. The insert shows the cumulated *d′* in the familiarity and novelty conditions across time. Vertical lines represent across-trials minimal reaction time (bold lines) and median reaction times.

One important factor that most likely contributed differentially to familiarity versus novelty and that may at least partly explain the reported differences is processing fluency, that is, the increased ease with which processing occurs when a stimulus is repeated (Schacter & Buckner, 1998; Tulving & Schacter, 1990). Faster and more accurate responses are observed for repeated than for novel stimuli independent of the task – including recognition memory tasks (Conroy, Hopkins, & Squire, 2005; Wagner & Gabrieli, 1998). Although processing fluency and recognition memory are sometimes considered to be independent, fluency will nonetheless be used as a cue for familiarity (Jacoby & Whitehouse, 1989; Voss, Lucas, & Paller, 2012; Wang, Li, Gao, Xiao, & Guo, 2015).

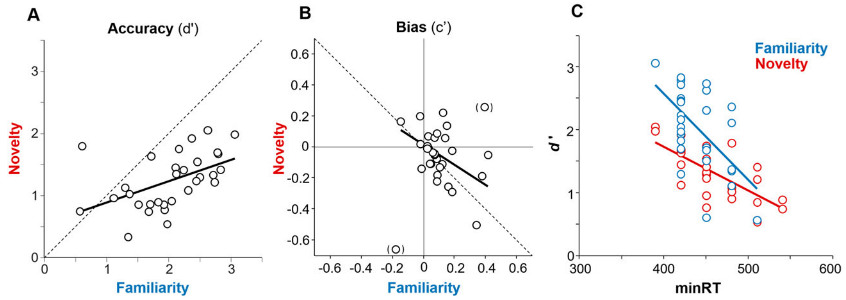

**Figure 3.** Correlations between familiarity and novelty (A) accuracy measures (*d′*), (B) bias measures (*c′*) ([o] = same outliers as in Figure 1), and (C) correlation between accuracy and minimal reaction times in the familiarity condition and in the novelty condition.

Consequently, processing of repeated stimuli should be faster than processing of novel stimuli, and familiarity go responses should be faster than novelty go responses. Fluency may thus lead to the 20-ms difference in minimal RTs observed in this study. Consistently, false alarms in response to familiar stimuli in the novelty condition occurred 20 ms earlier than false alarms in response to novel stimuli in the familiarity condition.

We also showed a *negative* correlation between performance and minimal reaction time: the slower the reaction time, the weaker the accuracy and vice versa. This most likely reflects the fact that, under a short time constraint, the slower that one is, the less time one will have to respond, and so the weaker one's accuracy will be (see also Barragan-Jason et al., 2013). Thus, a slightly slower novelty processing, due to less fluent perceptual processing, may induce lower accuracy rates under a speeded procedure such as the SAB.

Finally, the effect of fluency could also account for the more liberal bias in the novelty condition, characterized here by a higher false alarm rate but a weaker hit rate. Fluency is indeed thought to influence a variety of inferential decisions such as judgements of words' familiarity, fame of names, exemplars' frequency, or truth of statements (Jacoby & Whitehouse, 1989; Tversky & Kahneman, 1973; Wang, Brashier, Wing, Marsh, & Cabeza, 2016). Moreover, recent evidence suggests that intentional recognition memory can be biased by unintentional recognition of distracting stimuli (Bergström, Williams, Bhula, & Sharma, 2016). Here, we suggest that some familiar distractors in the novelty condition triggered unintentional recognition and associated unintentional motor responses through their fluency, compared with the novel distractors in the familiarity condition.

Furthermore, the positive correlation between accuracies and the negative correlation between the biases of the two conditions suggest that at least some overlapping processes underlie fast familiarity/novelty decisions. This is specifically supported by the observation of biases that are remarkably symmetrical around zero in these two conditions, as shown by (1) the correlation between the biases that passes through zero, and (2) their similar amplitudes when we invert the sign of one condition. A criterion value of *c* in one condition is thus mirrored by a –*c* value in the other, this effect being directly explained by the inverted old/new versus new/old distribution of the data across these two opposite conditions (cf. signal detection theory: Snodgrass & Corwin, 1988). This suggests that a process common to both familiarity and novelty decisions could be a unique subjective old/new response criterion. However, this was not true for two outliers. Interestingly, the one outlier that used a conservative response strategy across the two conditions started the task with the familiarity condition, which is characterized by a conservative bias in most participants, while the outlier that used a liberal strategy across the two conditions started the task with the novelty condition, characterized by a liberal bias in most participants. This suggests that these two participants did not switch their response strategy with the change of condition to keep the same response criterion. In contrast, the other participants did switch their response strategy between conditions, consistent with findings that highlight a shift of bias as a function of question format: "old?" vs. "new?" (Mill & O'Connor, 2014).

In conclusion, our results bring further support to existing models in the literature integrating familiarity and novelty decisions as relying on one unique decision mechanism, although familiarity and novelty processing seem to happen at least partly independently from one another, as suggested by a more efficient system in the case of familiarity. This is possibly due to the more fluent processing of repeated stimuli, but with familiarity and novelty potentially relying on one decision criterion probably stemming from one unique relative familiarity/novelty signal. Our findings thus could fit with recent suggestions that familiarity and novelty are brought together to form one unique relative familiarity/novelty signal after an initial stage of independency (Kafkas & Montaldi, 2014, 2015).

## Note

1. Alternative measure of bias of "relative criterion location" (*c*′), i.e., scaling the criterion location relative to performance, because with easier discrimination tasks, a more extreme criterion (as measured by c) would be needed to yield the same amount of bias, as specified in Macmillan and Creelman (2005, p.28).

## Disclosure statement

No potential conflict of interest was reported by the authors.

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