The Cost of Precision: Memory Discrimination and its Relationship to Traumatic Memories

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Abstract

Traumatic memory is marked by a paradox: after trauma exposure, individuals show overgeneralization of fear alongside vivid and over-specific sensory intrusions. Pattern Separation (PS), the orthogonalization of similar inputs into distinct memory traces, is typically considered protective against fear generalization, but its role in the formation of intrusions remains unclear. Here, we combined an Emotional Mnemonic Similarity Task (E-MST) with a Trauma Film Paradigm in healthy participants (n = 30-38 across analyses). Negative arousal significantly enhanced lure discrimination [$F(1,32) = 39.66$, $p<.001$, $\eta^2p = .55$], with the largest gains on visually distinct ("low-similarity") lures ($d = 0.93$). This effect was driven by suppression of gist responses and slowed reaction times, consistent with an adaptive vigilance mechanism. Critically, individual differences in negative-arousal precision for visually similar (hard to discriminate) lures predicted traumatic intrusion frequency, controlling for baseline neutral discrimination [partial $r = .41$, $p = .026$, 95% CI (.05, .68)]. Mnemonic flexibility, i.e., the magnitude of the negative-vs-neutral LDI shift, was associated with greater symptom recovery after extinction. These findings support a trade-off model in which negative arousal drives item-specific precision at the expense of contextual integration, generating potent yet decontextualized memory traces that subsequently lead to intrusions.

Keywords: pattern separation; fear overgeneralization; traumatic memory; intrusive memories; hippocampus.

Introduction

The cognitive phenotype of Post-Traumatic Stress Disorder (PTSD) presents a paradox: patients simultaneously suffer from over-generalization of fear (responding to safe, neutral contexts as if they were dangerous) and over-specificity of traumatic memory, manifested as vivid sensory intrusions or "flashbacks" (Ehlers & Clark, 2000; Brewin et al., 1996). The former represents a failure to discriminate safety from threat; the latter represents preservation of specific threat details, classically described as "tunnel vision" or the "weapon focus effect" (Loftus et al., 1987). Hence, high arousal in trauma induces a trade-off, creating memory traces that are centrally vivid but contextually impoverished.

To understand the neural mechanisms of this paradox, research has increasingly turned to Pattern Separation (PS), a computational process that relies on the hippocampal Dentate Gyrus (DG; Leutgeb et al., 2007). Pattern separation orthogonalizes similar neural inputs into distinct non-overlapping memory representations, allowing the brain to distinguish between a current safe experience (e.g., a loud noise at a party) and a past dangerous memory (e.g., a gunshot in combat). Behaviourally, PS is most commonly assessed using the Mnemonic Similarity Task (MST; Stark et al., 2013), in which participants must distinguish previously seen targets from highly-similar lures and entirely new foils. The Lure Discrimination Index (LDI) quantifies the propensity to correctly classify lures as "similar" rather than mistakenly as "old," and is widely used as a behavioural proxy for hippocampal pattern separation.

The prevailing view is that PTSD is characterized by a deficit in pattern separation. Numerous studies show that patients struggle to discriminate similar lures, leading to the conclusion that impaired hippocampal function drives fear over-generalization (Lissek et al., 2014; Besnard & Sahay, 2016). Reduced PS has been identified as both a risk factor for, and a consequence of, PTSD and other trauma-related disorders (Lange et al., 2017; Teicher & Samson, 2016; Lecei & van Winkel, 2020). High PS capacity is thus traditionally framed as a uniform protective factor against the spreading of fear from threatening to safe contexts.

However, this deficit model fails to account for the genesis of intrusive memories, a hallmark PTSD symptom characterized not by a lack of detail but by an excess of it. If the hippocampal system simply fails to separate patterns, why are sensory details of the trauma retained with such maladaptive precision? Why are flashbacks so vivid, intrusive, and resistant to decay?

We propose that the relationship between pattern separation and trauma is nonlinear and depends on the object of attention and the level of arousal. According to Arousal-Biased Competition (ABC) theory (Mather & Sutherland, 2011), emotional arousal amplifies the processing of high-priority stimuli while inhibiting the processing of low-priority background information. Applied to memory, acute stress may upregulate pattern separation for the central threat object (item hyper-specificity) while simultaneously inhibiting the binding of that threat to its spatiotemporal context (contextual generalization; Bisby & Burgess, 2014). Better discrimination of negative stimuli is therefore not purely protective, but may reflect rigid hyper-vigilance, a maladaptive strategy in which the brain applies excessive scrutiny to distinct threat cues. While vigilance reduces recognition errors in the short term, it may over-encode the traumatic event into a trace that is too specific to fade and too isolated to integrate.

To test this Cost-of-Precision hypothesis, we combined an Emotional Mnemonic Similarity Task (E-MST) with a Trauma Film Paradigm. The E-MST adapts the standard MST by introducing emotional valence (negative vs. neutral)

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and a graded-similarity manipulation, yielding within-subject contrasts that assess how arousal modulates pattern separation across conditions with varying discrimination difficulty. The Trauma Film Paradigm allows the controlled induction of analogue intrusive memories in healthy participants, enabling a direct correlation between mnemonic profiles and intrusion frequency.

We posited three hypotheses. (1) Vigilance Effect: negative arousal will enhance discrimination, with the largest gain on visually-distinct (low-similarity) lures, mediated by slowed reaction times reflecting an override of gist heuristics. (2) Precision Paradox: contrary to the view that better memory uniformly protects, individuals with higher vigilance-based negative precision will experience more frequent traumatic intrusions. (3) Flexibility Role: resilience reflects not static memory capacity, but mnemonic flexibility, i.e., the magnitude of the shift in pattern separation from neutral to negative conditions, with more flexible systems showing more initial threat encoding and more effective extinction-related recovery.

Methods

Participants.

Forty-five participants (all females; age range: 18-32; M = 21.1; SD = 3.3) were included in the study; depending on data availability and task-specific quality screening, samples ranged from n = 30 (subjects with complete merged E-MST and intrusion data after outlier exclusion) to n = 38 (fear-conditioning manipulation checks). Four participants were flagged as outliers based on E-MST response patterns and excluded from all primary E-MST analyses. Exclusion criteria included a history of neurological or psychiatric disorders, current use of psychotropic medication, and uncorrected visual impairment. The study was conducted inside a 7-Tesla MRI scanner; the present report focuses exclusively on behavioural data. All procedures were approved by the local ethics committee and participants provided written informed consent.

Experimental Procedure.

A two-day protocol linked associative fear learning, traumatic memory formation, and pattern separation. *Day 1 (Acquisition & Trauma Exposure).* A modified differential fear-conditioning paradigm integrated the Trauma Film Paradigm. Twenty-second neutral movies served as conditioned stimuli (CS); CS+ were paired with 30-s aversive video clips depicting real-life physical violence, injury, or fatal accidents (US), selected to induce analogue trauma symptoms, while CS- were followed by neutral footage. Fear acquisition was indexed by the differential US-expectancy ratings (CS+ minus CS-) at the end of acquisition. Immediately after the scan, participants completed an intrusion check, reporting the frequency of spontaneous intrusive images or thoughts during a 15-min post-task window (T1). *Day 2 (Extinction & E-MST).* Twenty-four hours later, participants viewed repeated CS+ and CS- without the aversive US (extinction learning), reported intrusions during a second 15-min window (T2), and finally completed the E-MST.

Emotional Mnemonic Similarity Task.

We adapted the Stark et al. (2013) MST to incorporate emotional valence. *Stimuli:* 128 pairs of object images, half negative (high arousal, negative valence) and half neutral (low arousal). *Encoding:* 128 images (64 negative, 64 neutral) were presented for 2,500 ms each with an incidental "indoor vs. outdoor" semantic judgment. *Retrieval:* 192 images: 64 Targets (exact repetitions of encoded images), 64 Lures (similar but not identical), and 64 Foils (entirely new), were classified as "Old," "Similar," or "New." *Similarity bins:* lures were sorted, based on independent similarity ratings collected in a separate sample (1 = clearly different from the target, 10 = visually identical), into a High-Similarity (visually similar, hard discrimination) bin and a Low-Similarity (visually distinct, conceptually related, easy discrimination) bin. Pilot ratings showed slightly lower similarity for negative than for neutral pairs ($p = .07$; see Figure 1). To prevent any confound between valence and raw lure-target similarity, all primary analyses used only lures whose ratings overlapped between the negative and neutral sets ("matched" bins).

Data Analysis.

Pattern separation was quantified using the Lure Discrimination Index (LDI = p("Similar"|Lure)-p("Similar"|Foil)). We computed three constructs: Baseline Precision (Neutral LDI), Vigilance (Negative LDI), and Mnemonic Flexibility (ΔLDI = Negative-Neutral). Intrusion dynamics were analysed at T1 (post-acquisition), T2 (post-extinction), and as the within-subject difference T2-T1 (recovery). Behavioural effects were tested with 2(Valence)×2(Similarity) repeated-measures ANOVAs. Brain-behaviour associations used Pearson correlations and partial correlations controlling Neutral LDI to isolate negative-arousal-specific effects. Robustness was assessed with bootstrap 95% confidence intervals (10,000 resamples), label-permutation tests (10,000 permutations), and Spearman rank correlations. All tests were two-tailed; $\alpha = .05$. Sample sizes vary by analysis because the full cohort underwent task-specific quality screens (n = 45 with usable fear-conditioning data; n = 37 with usable E-MST response data). Four participants flagged as outliers based on E-MST response patterns were excluded from all primary analyses involving the E-MST. The resulting analysis-specific N are reported with each test: the LDI ANOVA and response-decomposition ANOVAs used n = 33; fear-conditioning manipulation checks used n = 38 (acquisition) and n = 35 (extinction); and brain-behaviour correlations used the merged n = 30 (subjects with both E-MST and intrusion data after outlier exclusion).

Results

Stimulus Calibration: Matched Similarity.

An independent participant sample rated the perceived similarity of each lure-target pair on a 1-10 scale (Figure 1). The two valence conditions were descriptively similar but

with a marginal trend for negative pairs to be rated as slightly less similar (i.e., easier) than neutral pairs (p = .07). To rule out this potential confound, all subsequent valence contrasts were restricted to matched lure pairs whose similarity ratings overlapped fully between the negative and neutral sets. The matched subset preserves the within-bin similarity distribution while equating it across valences.

Fear Acquisition and Extinction: Manipulation Check.

Differential US-expectancy ratings confirmed successful fear acquisition: at the end of the acquisition phase, ratings to CS+ (M = 5.52) substantially exceeded those to CS- (M = 1.98), t(37) = 9.96, p<.001, d = 1.62. Extinction reduced this differential, but residual discrimination remained at the end of the extinction phase (CS+ M = 1.98, CS- M = 1.32, t(34) = 2.87, p = .007, d = 0.49), consistent with partial extinction at the group level. The magnitude of acquisition-phase CS+/CS- discrimination did not significantly correlate with trauma-related intrusion counts (r = .18, p = .33), indicating that the intrusion-PS associations reported below are not reducible to individual differences in associative-learning success.

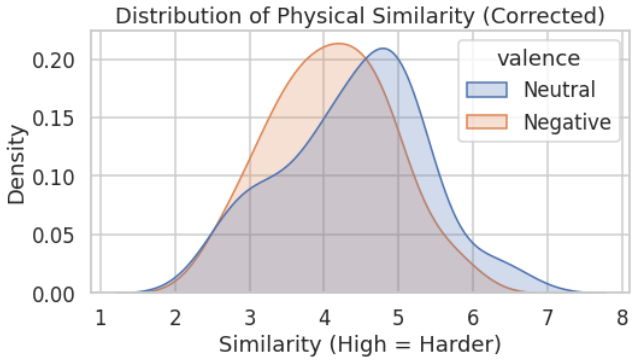

Figure 1. *Distribution of physical similarity ratings for negative and neutral lure pairs.* Kernel density estimates of perceived similarity (1 = clearly different from target, 8 = visually identical) for negative-valence (orange) and neutral (blue) lure pairs as rated by an independent sample. Negative pairs were descriptively rated as slightly less similar (i.e., easier to discriminate) than neutral pairs (p = .07). Primary analyses were restricted to matched lures whose ratings overlapped between conditions.

Emotional Modulation of Pattern Separation.

A 2 (Valence)× 2 (Similarity) repeated-measures ANOVA on LDI revealed significant main effects of Valence [F(1,32) = 39.66, p<.001, η^2p = .55] and Similarity [F(1,32) = 98.73, p<.001, η^2p = .76]. The interaction was non-significant [F(1,32) = 1.29, p = .26]. Negative arousal increased LDI in both bins but with larger absolute gain in the Low-Similarity (visually-distinct) condition [t(32) = 5.44, p<.001, d = 0.93] than in the High-Similarity (visually-similar) condition [t(32) = 2.26, p = .03, d = 0.39] (Figure 2).

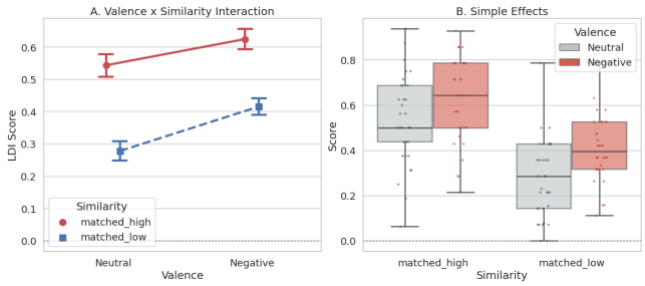

Figure 2. *Effects of valence and lure similarity on memory discrimination (LDI).* (A) Valence × Similarity interaction plot. LDI is plotted as a function of valence (Neutral, Negative) for High-Similarity (matched_high; visually-similar, "hard") and Low-Similarity (matched_low; visually-distinct, "easy") lures. Negative arousal increases LDI in both bins with larger absolute gain in the Low-Similarity bin. LDI is higher for High-Similarity than Low-Similarity lures (see Figure 3 for explanation). Error bars: 95% within-subject confidence intervals. (B) Boxplots of LDI by Valence × Similarity, with individual subject points (jitter) and full distribution shown.

Contrary to standard MST findings, LDI was lower for Low-Similarity (visually-distinct) than for High-Similarity (visually-similar) lures (Figure 2). This is counterintuitive, as distinct lures should be easier to discriminate from targets, not harder. We hypothesized that the Low-Similarity bin encouraged heavy reliance on conceptual gist rather than fine-grained visual discrimination, leading participants to mistakenly classify visually distinct but conceptually related items as "Old." To test this directly, we decomposed responses into their three categories.

Response Decomposition: Negative Arousal Suppresses Gist.

A 2×2 ANOVA on the rate of "Old" responses to lures (i.e., gist-driven false alarms) confirmed strong main effects of Valence [F(1,32) = 28.18, p<.001, η^2p = .47] and Similarity [F(1,32) = 156.72, p<.001, η^2p = .83]. Negative arousal substantially reduced gist responses in the Low-Similarity bin (.591→.453; t(32) = -4.98, p<.001, d = -0.87), and to a lesser extent in the High-Similarity bin (.260→.202; t(32) = -1.97, p = .058, d = -0.34). Correspondingly, correct "Similar" responses to Low-Similarity lures rose under negative valence (.268→.409; t(32) = 5.44, p<.001, d = 0.95), with a smaller increase in the High-Similarity bin (.536→.617; t(32) = 2.24, p = .03, d = 0.39) (Figure 3). Crucially, this reveals that under neutral conditions, the system defaults to a "lazy" gist heuristic for visually distinct items: it concludes "it's the same type of object, must be old," while negative arousal inhibits this heuristic, enforcing item-specific scrutiny.

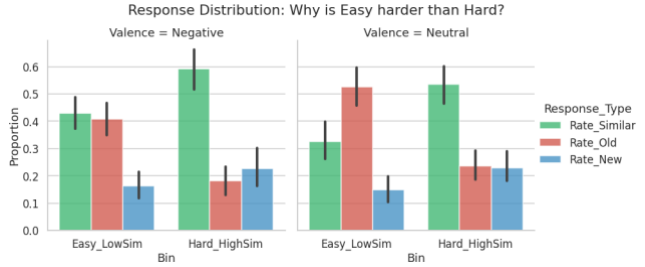

Figure 3. *Response distribution decomposition: why the "Easy" bin paradoxically yields lower LDI.* Proportion of "Old" (false alarm/gist), "Similar" (correct discrimination), and "New" responses to lures, separately by lure-similarity bin (Easy_LowSim, Hard_HighSim) and valence (Negative, left; Neutral, right). In the Neutral × Easy_LowSim cell, "Old" responses dominate: participants treat distinct-but-related items as identical. Negative arousal suppresses these gist responses, increasing correct "Similar" responses, elevating LDI. The Hard_HighSim bin elicits fewer gist errors in either valence as visual similarity itself triggers item-level scrutiny by default. Error bars: 95% confidence intervals.

Reaction-Time Mechanism (Stop-and-Check).

Reaction times for correct "Similar" judgments showed a significant main effect of Valence ($p<.05$): correct discrimination of Negative lures took longer than Neutral lures, with the slowing concentrated in the Low-Similarity bin (Figure 4). Critically, even the gist-error ("Old"-response) RTs were slower under negative than neutral valence. Negative cues, hence, induce extra processing time even when participants ultimately fall back on a heuristic response. Together, these patterns support a stop-and-check vigilance mechanism: negative arousal triggers active inhibition of the automatic "Old" response, forcing slower scrutiny of stimulus features.

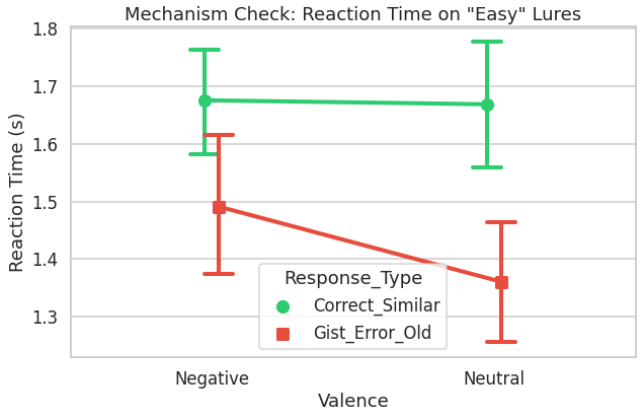

Figure 4. *Reaction-time mechanism check ("Stop-and-Check").* Mean reaction time for correct "Similar" responses (green) and gist-error "Old" responses (red) to Easy (Low-Similarity) lures, separately for Negative and Neutral valence. Error bars: ± 1 SE. Correct discriminations take systematically longer than gist errors in both valences (stop and check). Gist-error RTs are slower under Negative than Neutral valence: negative cues induce additional checking.

Hyper-Precision Predicts Traumatic Intrusions.

We next examined whether vigilance-based pattern separation predicted the frequency and persistence of traumatic intrusions induced by the trauma film. Pattern-separation precision for visually-similar (High-Similarity) negative lures positively predicted total trauma-related intrusion frequency [$r(28) = .371$, $p = .043$, 95% bootstrap CI (.11, .58); permutation $p = .041$]. Critically, this association was specific to negative-arousal precision: a partial correlation that controlled for the participant's Neutral LDI on the same lures isolated a stronger relationship [partial $r = .41$, $p = .026$, 95% CI (.05, .68)], with a parallel association for acquisition-phase intrusions specifically [partial $r = .41$, $p = .028$]. A multiple regression with both Neg-LDI and Neu-LDI as simultaneous predictors confirmed the specificity: only Neg-LDI was associated with intrusions ($\beta = 9.34$, $p = .026$), whereas Neu-LDI was not ($\beta = -3.26$, $p = .31$). Neither the bin-collapsed Negative-LDI summary ($r = .15$, $p = .42$) nor the Low-Similarity bin ($r = -.15$, $p = .44$) showed a comparable association. This pattern indicates that the vulnerability marker is specifically the maintenance of high precision under difficult discriminations, i.e. the condition in which arousal-driven scrutiny is diagnostic of rigid item-specificity (Figure 5A).

A second, complementary finding emerged from the response decomposition. Residual gist responses (i.e., "Old" errors) to negative Low-Similarity lures (reflecting incomplete suppression of the gist heuristic under negative arousal) also predicted acquisition-phase intrusions ($r = .41$, $p = .026$). This pattern goes in the opposite behavioural direction from the High-Similarity finding: there, more successful discrimination predicts intrusions; here, more failed gist-suppression does. We do not interpret these markers as identical; rather, both indicate a system that is poorly tuned to context, applying either over- or under-effortful processing in a way that is not optimally matched to lure difficulty. Both can therefore be interpreted as facets of a disrupted strategic flexibility in pattern separation under negative arousal, rather than as two instances of the same elementary deficit.

Mnemonic Flexibility and Recovery.

Trauma-related intrusions decreased substantially from acquisition ($M = 3.83$) to extinction ($M = 1.00$) [$t(29) = 6.96$, $p<.001$, $d = 1.27$], a 74% reduction. This group-level recovery validates the trauma-induction paradigm and provides an index of individual variability in symptom updating. The magnitude of the negative vs. neutral LDI shift in the High-Similarity bin (ΔLDI) was associated with greater intrusion frequency at acquisition [$r = .36$, $p = .054$] but with greater recovery from acquisition to extinction [$r = -.33$, $p = .071$] (Figure 5B). Together, these trends suggest that participants whose system reactively creates precision initially encode trauma more vividly, but are subsequently better able to update that representation when the context shifts to safety. Static Negative LDI alone did not predict recovery ($r = -.17$, $p = .37$), highlighting that flexibility, not capacity, is related to resilience.

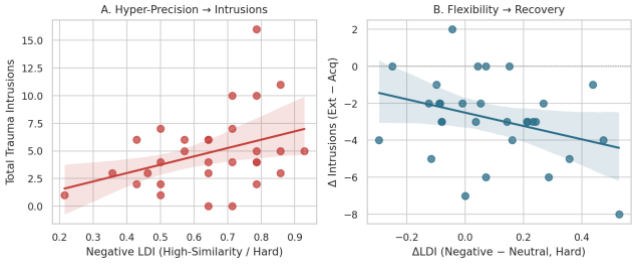

Figure 5. *Individual-difference associations between negative-arousal pattern separation and trauma-related intrusions* ($n = 30$). (A) Total trauma-related intrusion counts (combining acquisition and extinction phases) plotted against Negative LDI in the High-Similarity (Hard) bin. (B) Mnemonic flexibility predicts symptom recovery: intrusion change (Extinction - Acquisition; negative values = improvement) plotted against the negative-vs-neutral LDI

shift (ΔLDI) in the High-Similarity bin. Statistics in body text. Shaded bands: 95% CI of the regression line.

Table 1. *Summary of associations between MST metrics and trauma-related intrusions (N = 30).*

Predictor	r	p	95% CI
Negative LDI (Hard) → Total intrusions	.37	.043	(.11, .58)
partial r controlling Neutral LDI	.41	.026	(.05, .68)
Negative LDI (Hard) → Acq intrusions	.33	.077	(.05, .54)
partial r controlling Neutral LDI	.41	.028	-
ΔLDI (Hard)→Acq intrusions	.36	.054	-
ΔLDI (Hard)→Δ Intrusions (Ext-Acq)	-.33	.071	-
Negative LGI (Easy)→Acq intrusions	.41	.026	(.09, .65)
Neutral LDI→Total intrusions (n.s.)	.01	.94	-

Note. "Hard" = High-Similarity (matched_high) bin; "Easy" = Low-Similarity (matched_low) bin. LDI = Lure Discrimination Index. LGI = Lure Generalization Index (rate of "Old" responses to lures). ΔLDI = Negative LDI - Neutral LDI. Bootstrap CIs from 10,000 resamples.

Discussion

The present study aimed to resolve a fundamental paradox in the trauma literature: why do traumatic memories persist as vivid, hyper-specific intrusions despite the well-documented generalization deficits associated with PTSD? By combining an Emotional Mnemonic Similarity Task with a trauma film paradigm, we identified a behavioural signature of adaptive vigilance, which enhances immediate threat discrimination, but contributes to the formation of intrusive memories.

The Cost of Precision: Hyper-Vigilance vs. Gist.

Our behavioral results demonstrate that negative arousal significantly improves pattern separation performance, with the largest absolute gain observed for visually distinct (Low-Similarity) lures. The reaction-time slowing under negative valence and the systematic suppression of gist ("Old") responses converge on a stop-and-check mechanism: under neutral conditions, the brain efficiently relies on gist (pattern completion), accepting easy lures as "old" to conserve resources. However, threat cues trigger an override of this heuristic, enforcing detailed item-level scrutiny. This finding is highly consistent with Arousal-Biased Competition (ABC) theory (Mather & Sutherland, 2011): arousal amplifies high-priority stimuli at the expense of low-priority background. The presence of a negative cue narrows neural tuning mechanisms (putatively in the dentate gyrus), suppressing the "it's the same" gist signal in favor of a higher-fidelity "it's different" signal.

Crucially, this improvement may represent a zero-sum trade-off: the system cannot simultaneously maximize broad generalization (context/gist) and specific discrimination (item/detail). By reallocating resources toward hyper-scrutiny of the threat object, the brain successfully avoids false alarms on "easy" lures, but sacrifices the binding that normally anchors an event in its broader spatiotemporal context. This explains why the greatest performance divergence emerged in the Low-Similarity condition: negative arousal disabled the automatic pattern-completion mechanism, replacing it with a rigid, vigilance-based specificity.

Hyper-Specificity as a Risk Factor for Intrusions.

Our individual-difference analyses provide the central empirical link to clinical phenomenology: precision for visually similar (hard-discrimination) negative lures robustly predicted trauma-related intrusions. The signal survives partialling out general memory ability, regression with a neutral control predictor, bootstrap resampling, label permutation, and rank-based correlation. A complementary finding, i.e., incomplete gist-suppression for easy negative lures also predicting intrusions, goes in the opposite behavioural direction, but converges conceptually. Both reflect a system whose pattern-separation strategy is poorly matched to lure context. Together, the two findings challenge the prevailing deficit model (Besnard & Sahay, 2016) by suggesting that strategic inflexibility of arousal-driven PS (rather than its average level) is the vulnerability marker. This is consistent with the classic Weapon Focus Effect (Loftus et al., 1987): central threat detail is over-encoded at the expense of contextual integration. The trauma memory thus emerges as a vivid, central item, loosely integrated into a generalized, imprecise context.

This leaves open the question: Why the High-Similarity bin specifically? In the Low-Similarity bin, the dominant cognitive mode at baseline is gist: arousal's primary effect there is to suppress an inappropriately applied heuristic. In the High-Similarity bin, by contrast, item-level scrutiny is engaged in both valences (the visual similarity itself triggers vigilance); individual variability in how rigidly that scrutiny is maintained becomes diagnostic. Therefore, maintaining high LDI for difficult negative discriminations represents the behavioural signature of hyper-precision driven by negative arousal.

Flexibility as a Resilience Factor.

Static memory capacity alone did not predict recovery, but mnemonic flexibility (measured by the magnitude of the negative-vs-neutral LDI shift) did. Participants whose systems react with precision under threat (high ΔLDI) and relax otherwise initially encoded trauma more vividly but showed the greatest reduction in intrusions during extinction. This aligns with proposals that contextual updating is the core deficit in PTSD (Liberzon & Abelson, 2016): a flexible hippocampal system can encode threat-specific representations and update them when the context shifts to safety. The implication is that resilience is dynamic, depending on the system's ability to switch between vigilance and gist modes relative to contextual needs.

Reconciling with the Deficit Literature.

How can our findings be reconciled with prior reports of reduced pattern separation in PTSD and childhood-trauma populations (Lecei & van Winkel, 2020)? Two

considerations are relevant: First, most prior studies have relied on valence-neutral MST tasks; our results suggest that group-level deficits observed in these tasks may reflect dysregulation of contextual PS rather than item PS, and that this picture inverts when emotional valence is introduced. Second, there is no necessary contradiction, as a system that hyper-encodes negative items at the expense of contextual binding may appear deficient on a neutral task (because it under-binds context) while paradoxically over-performing on emotional discrimination. Our healthy sample, with intact baseline PS, allows us to isolate the arousal-specific component of this trade-off. Future work in clinical samples should test whether the same arousal-specific signature is amplified in PTSD or, alternatively, is masked by e.g. ceiling or floor effects.

Toward a Neural Model: The Dual Pathology.

Although the present design is purely behavioural, our results invite an interpretive bridge to neural models. Hyper-specificity of *content* alongside loss of *context* would be consistent with a dissociation between item-specific pattern separation, putatively involving amygdala-perirhinal pathways, and contextual pattern separation, mediated by hippocampal-parahippocampal pathways under arousal (Bisby & Burgess, 2014). It would also be consistent with arousal-driven sharpening of dentate-gyrus detection curves at the expense of associative binding within entorhinal-hippocampal circuits. Future work could allow direct examination of subfield-specific contributions to the precision-context trade-off.

Limitations and Future Directions.

Three limitations constrain the translational claims of this work. First, the sample comprised healthy participants undergoing analogue trauma; we cannot determine whether the observed mnemonic profile reflects a normative response to arousal, a marker of prior trauma exposure, or a marker of disorder. A future design including a PTSD group, a trauma-exposed resilient group, and a non-exposed control group is required to disentangle these possibilities and to determine whether the precision-intrusion link is a candidate clinical biomarker. Second, N = 30 limits statistical power for individual-difference analyses; the reported effect sizes (r's in the .3-.4 range) should be considered preliminary and require replication in larger samples. Third, neural mechanisms are not directly tested here, and any references to subfield-specific or pathway-specific contributions are interpretive rather than empirical.

Several future directions are worth mentioning. The high-resolution 7-T fMRI data acquired in the present cohort will allow direct examination of subfield-specific (CA3/DG/CA1) contributions to the precision-context trade-off, testing whether negative-arousal-driven LDI gains are accompanied by increased DG pattern-separation activity and reduced hippocampal-parahippocampal binding. Behaviourally, the present paradigm could be extended to test whether sleep-dependent consolidation amplifies or attenuates the precision-intrusion link, and whether targeted memory reactivation interventions can selectively modulate the flexibility of the precision system. Finally, the convergence between hyper-specificity for hard items and incomplete gist-suppression for easy items raises the question of whether these two markers are dissociable phenotypes or facets of an underlying construct, which could be addressed by latent-variable modelling in bigger samples.

Conclusion

These results suggest that pattern separation is not a static protective mechanism against trauma. Rather, the inability to disengage vigilance (rigid hyper-specificity for threat cues) is a candidate risk factor for intrusive memories, while reactive precision combined with flexible updating is a candidate resilience factor. Future therapeutic interventions might benefit from targeting the flexibility of attentional precision rather than memory capacity per se.

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