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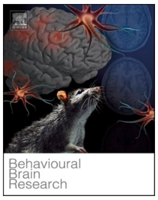

Research report

Mnemonic discrimination is associated with individual differences in anxiety vulnerability

Meghan Davis Caulfield [a,*], Alexandra L. Vogel [b], Mia R. Coutinho [b], Irene P. Kan [a]

[a] Villanova University, Psychological and Brain Sciences, United States
[b] Lafayette College, Program in Neuroscience, United States

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ABSTRACT

Increased generalization between fear-inducing stimuli (e.g., looking over the edge of a tall building) and perceptually-similar neutral stimuli (e.g., an aerial photograph) is observed in all subtypes of anxiety disorders, leading to avoidance behaviors that feed forward from the feared stimulus to other, seemingly unrelated stimuli. However, recent research suggests a much more nuanced relationship between generalization, discrimination, and behavior. This study seeks to extend current understanding by using a mnemonic discrimination task to explore the relationship between risk for anxiety and differences in mnemonic discrimination abilities. Participants self-reported trait anxiety and behavioral inhibition (a temperamental construct linked to risk for anxiety), and also completed a memory task. After incidental encoding of color photographs of neutral everyday objects, participants performed a surprise recognition task, where they categorized each test image as “old” (identical to a previously viewed image), “similar” (new but perceptually-similar to a studied image, with half the images being highly similar and the other half being less similar to the studied images), or “new” (new and perceptually-dissimilar to studied images). We found that those with high behavioral inhibition are more successful at discriminating between previously seen “old” items from highly similar items. In contrast, those with high trait anxiousness are less successful at the same kind of discrimination. Interestingly, these relationships were not apparent in low similarity items. Our data suggest that behavioral inhibition and trait anxiety may be associated with unique aspects of individual differences in mnemonic discrimination abilities.

1. Introduction

1.1. Discrimination and anxiety

Discrimination is our ability to distinguish and respond appropriately to differences among stimuli and is a central feature of successful memory processes. At times, this process falters, leading to a failure to discriminate among similar cues and resulting in incorrect behavioral responses. While such failures are common occurrences in everyday life, they may also be indicative of individual differences in learning and memory processes that underlie anxiety disorders. Indeed, poor discrimination is observed in all subtypes of anxiety disorders, leading to avoidance not only of the feared stimulus but also of other, seemingly unrelated cues. For example, in generalized anxiety disorder, individuals may have difficulty distinguishing between a fear inducing-stimulus (e.g. rooftop of a tall building) and other moderately related events (e.g. a magazine that may contain aerial photographs), leading to avoidance in an increasing number of situations [1]. In panic disorder, individuals may begin to demonstrate a physiological response (e.g. panic attack) to an increasing number of cues, indicating an inability to distinguish between the original stressor and moderately related, neutral stimuli [2]. Reduced discrimination is also evident in the case of posttraumatic stress disorder (PTSD), where patients frequently fail to distinguish between cues associated with fear and safety signals [3–6].

Research linking discrimination to anxiety frequently relies on fear conditioning procedures. In these studies, an aversive stimulus (e.g. an electric shock) is paired with a danger cue (e.g. a small circle), and safety (no shock) is signaled by a perceptually similar safety cue (e.g. a large circle). Once the distinction between danger and safety has been learned, researchers can examine the degree to which participants can differentiate among similar safe stimuli along a generalization gradient (e.g. circles of increasing size between the danger signal and safety signal). With this protocol, researchers have observed fear responses to neutral, safe stimuli in every type of anxiety disorder, suggesting that

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* Corresponding author.
E-mail address: Meghan.caulfield@villanova.edu (M.D. Caulfield).

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individuals with anxiety may have difficulty discriminating between a fear-inducing stimulus and a highly perceptually similar safety stimulus [3,7–10].

Mnemonic discrimination tasks provide another means for measuring discrimination of visual details for previously encountered items[1]. Recent research using mnemonic discrimination in young adults found that discrimination performance for highly similar visual items was linked to fear conditioning. Specifically, those with lower discrimination scores showed increased generalization of shock expectancy (increased expectation of shock to neutral safe stimuli along a generalization gradient) in a fear conditioning paradigm [11]. This result demonstrates a possible link between mnemonic discrimination and fear conditioning.

Other studies have examined the effects of emotion and arousal in similar tasks of mnemonic discrimination, attempting to understand the relationship between enhanced threat processing and memory encoding. One study reported that participants who viewed disturbing images prior to encoding neutral images had enhanced subsequent discrimination performance compared to those who did not, suggesting that enhanced arousal during encoding of neutral stimuli may facilitate later memory processes [12]. To further examine the relationship between encoding, retrieval, and anxiety, Balderston and colleagues [13] used a similar paradigm and compared the effects of both perceived threat and safety during encoding and retrieval. They found that discrimination was best when images were encoded during periods of threat and retrieved during periods of safety, suggesting a complex interplay among encoding and retrieval contexts, and discrimination processes in anxiety.

As reviewed above, studies examining the link between discrimination and anxiety have, for the most part, used either emotional stimuli [12,13] or fear conditioning procedures to assess learning of neutral stimuli [11]. One exception is a recent study that evaluated discrimination differences of neutral stimuli in Veterans with PTSD [14]. In that study, participants performed a visual match-to-sample discrimination task using simple, neutral stimuli (dots). Participants viewed the initial location of a dot on the screen, and then following a filled temporal delay (5-s, 10-s, 20-s, 30-s), during which they performed a digit naming distraction task, they were shown two dots separated by varying levels of spatial separation (e.g. low, medium, or high difficulty). Participants were asked to indicate whether the dot that was initially presented was on the left or right in the two-dot pairing. Veterans with PTSD symptoms demonstrated better discrimination performance on the most difficult trials (those where the two dots were closest together) when compared to Veterans without PTSD. This pattern is consistent with other studies where Veterans with PTSD symptoms show decreased generalization of newly learned information to novel situations [15].

Thus, while the relationship between discrimination abilities under high arousal conditions and anxiety is relatively well characterized, whether that relationship extends to neutral learning situations is less clear. This is a crucial gap to fill in the literature, as differences in discrimination in neutral learning situations will suggest that individual differences in basic learning and memory processes may be a key mechanism underlying the development and maintenance of anxiety.

1.2. Behavioral inhibition and risk for anxiety

One way of measuring risk for anxiety is through the construct of behavioral inhibition, a stable temperamental tendency to avoid or withdraw from novel objects, people, or situations [16–18]. Early work demonstrated that infants classified as behaviorally inhibited had a greater avoidance of social interactions and higher prevalence of clinical anxiety disorders in childhood and adolescence [19–22].

Since the publication of these early longitudinal studies, self-report measures have been developed to measure behavioral inhibition in adults. One such scale is the Adult Measure of Behavioural Inhibition (AMBI; [23]), which is a validated measure of trait behavioral inhibition in adulthood. Recent research using AMBI in PTSD populations provides support for the effectiveness of this approach, where AMBI scores are found to be positively correlated with PTSD symptom severity in Veterans [24] and active duty military [25]. Furthermore, AMBI was able to capture differences in avoidance learning in non-fear based paradigms (eyeblink classical conditioning) in Veterans with PTSD [24]. Together, this research suggests that AMBI provides a useful means of predicting severity of PTSD symptoms and distinguishing individual differences in avoidance learning.

AMBI also effectively captures the influence of temperament on behavior in nonclinical populations. Comparisons between high and low AMBI participants show enhanced acquisition and retention in tasks measuring avoidance behavior [26,27] and learning [28–31]. It is notable that behavioral inhibition, as indexed by the AMBI, not only differentiates learning abilities, but does so in tasks that use minimally aversive paradigms (e.g., loss of points in an avoidance task [27] or eyeblink classical conditioning [28–31]). Therefore, behavioral inhibition provides a useful mechanism for studying how behavioral inhibition may be related to individual differences in avoidance that are not necessarily mediated by high arousal situations. Given the key role of discrimination in anxiety, it is important to understand the relationship between discrimination and behavioral inhibition. If individual differences in behavioral inhibition are related to discrimination abilities, this may represent another important component of learning differences that contribute to the development and maintenance of anxiety disorders.

1.3. Current study

The few studies that have examined the potential relationship between risk for anxiety and discrimination abilities varied in their approach and results. Lange and colleagues [11] reported that poorer mnemonic discrimination was related to increased fear generalization but did not examine whether discrimination differences extended to neutral situations. Bernstein and colleagues [32] reported no correlation between visual perceptual discrimination and measures of depression, anxiety, stress, and worry. However, they used the Depression Anxiety Stress Scale (DASS [33];), a measure of emotional states differentiating depression, anxiety, and stress. The DASS may not accurately capture behavioral inhibition, a key construct present in healthy individuals that may underlie the development and maintenance of anxiety.

As described earlier, the primary goal of the current study is to understand how individual differences in behavioral inhibition may be related to mnemonic discrimination. Thus, we opted to administer the AMBI, a validated measure of trait behavioral inhibition in adulthood. In addition, to better understand the broader mechanisms that may underlie this relationship, we also included the State-Trait Anxiety Inventory (STAI-Y [34]), a measure commonly used to assess temperamental anxiousness. The STAI-Y is comprised of two parts, State and Trait: State anxiety is assumed to change with mood and emotion and asks questions about current emotional states, whereas Trait anxiety is a relatively stable personality characteristic and asks general questions about feelings and behaviors. Although the STAI-Y is often considered as the definitive instrument in measuring anxiety, its effectiveness in capturing individual differences in mnemonic discrimination and anxiety is less clear [39]. In sum, even though both behavioral inhibition and trait anxiousness are related to the broader construct of "anxiety", each aspect likely makes a unique contribution to behavior. By including both measures in our study, we aim to better characterize how these two temperamental attributes may influence mnemonic discrimination.

To extend the current literature, we investigated whether mnemonic discrimination differences related to risk for anxiety can be observed

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[1] This type of task is also frequently referred to as a behavioral pattern separation task.

using neutral stimuli and how behavioral inhibition and trait anxiousness may contribute to this relationship. To this end, we administered a mnemonic discrimination task and assessed behavioral inhibition (with AMBI) and trait anxiousness (with STAI-Y) in a sample of young adults.

2. Materials and methods

2.1. Participants

A total of 83 young adults ages 18–22 (*M* = 19.41, *SD* = 1.01) from a small liberal arts college volunteered in return for credit in an undergraduate psychology course. An initial group of 17 participants (11 female, 6 male) took part in a pilot study that determined mnemonic similarity of the test items, followed by the experimental cohort of 66 participants (47 female, 19 male). All participants provided informed consent, and all study materials and procedures were approved by the Lafayette College Institutional Review Board.

2.2. Self-report measures

Participants completed the Adult and Retrospective Measures of Behavioral Inhibition [23] at the beginning of the study. The Adult Measure of Behavioral Inhibition (AMBI) and Retrospective Measure of Behavioral Inhibition (RMBI [23];) are self-report measures that assess behavioral inhibition or avoidant behaviors in response to new stimuli or social situations. The AMBI and RMBI are reliable, with high discriminant validity in separating anxiety, depression, and control groups [23]. Recent research examining behavioral inhibition in PTSD populations has further demonstrated their efficacy, reporting that AMBI is positively correlated with PTSD symptom severity [24], and is also related to individual differences in avoidance behavior [27] and learning in young adults [30,31].

The AMBI includes 16-items with questions about current behaviors, such as “Do you tend to withdraw and retreat from those around you?”, and “Do you tend to introduce yourself to new people?”. Each question is scored from 0 to 2, with scores ranging from 0 to 32. Higher scores indicate stronger behavioral inhibition in adulthood. The RMBI consists of 18-items (scores range from 0 to 36) with similar questions about behavior during elementary school. We included both measures because AMBI and RMBI are typically administered together; however, given our interest in current behavioral inhibition, we did not include RMBI in any of the subsequent analyses.

We also administered the State-Trait Anxiety Inventory (STAI-Y; [34]), a 40-item self-report questionnaire measuring anxiousness. The STAI-Y is separated into two parts: state anxiety, a measure of current emotional state, and trait anxiety, a measure of stable personality characteristics related to anxiousness. Given our interest in trait anxiousness, we did not include state scores in the analyses. Due to a technical error, complete STAI-Y data were available for only a subset of participants (n = 34).

2.3. Mnemonic discrimination task

Participants were seated at a Dell Computer with a 19” color monitor. The stimulus set consisted of 120 color images of everyday objects (approximately 4” x 4”) presented in the center of the screen [35]. PsychoPy software [36] was used for stimulus presentation and response recording. First, participants completed an incidental encoding task, where they viewed 60 randomly selected color images (2-s each, 0.5-s ISI) and indicated by button press whether each object was “likely or unlikely to be found in a kitchen” (see Fig. 1A).

Immediately following encoding, participants were given a surprise recognition test, where they indicated whether each item was “old” (i.e., exactly the same as before), “similar” (i.e., new but perceptually-similar to a previously encountered items), or “new” (i.e., new and perceptually-dissimilar to previously encountered items). Participants were informed that similar items might be alike to previous items but have small or large changes in color, shape, size, or orientation (see Fig. 1B). A total of 90 test trials were included: 30 old trials, 30 similar trials, and 30 new trials. Items across the three conditions were randomly intermixed in the test phase (2-s each, 0.5-s ISI). Participants responded by pressing marked buttons on a keyboard.

To manipulate the level of mnemonic similarity of the similar lure items, we included two types of “similar” lures in the test set: items that are highly similar to encoded items and those that are slightly similar to encoded items (see Fig. 1C). Item-level mnemonic similarity was determined based on results from a pilot study (n = 15, *M* age = 19.60), which allowed us to separate the lure items into two categories: easy (high discriminability) and hard (low discriminability). Pilot subjects performed the mnemonic discrimination task as described above, and an item-level analysis was conducted. Data from two subjects were removed because their overall accuracy was greater than two standard deviations below the mean of the sample.

Given the purpose of the pilot study – to determine degree of difficulty of similar lure items – we only report performance on the similar items below.[2] We used the same method as Lacy and colleagues [37] when assigning items to each level of difficulty. We first calculated the probability of responding “old” for each “similar” lure and then separated the items into two bins of approximately the same size. To be clear, a response of “old” to a “similar” item suggests that subjects had difficulty discerning a similar item’s mnemonic status and erroneously identified it as previously encountered. This procedure yielded 14 items in the hard bin (having high mnemonic similarity, *M* = 52.38 % incorrect “old” responses, *SD* = 13.30 %) and 16 items in the easy bin (having low mnemonic similarity, *M* = 15.00 % incorrect “old” responses, *SD* = 11.80 %). An independent *t*-test confirmed that the two sets of stimuli are significantly different in terms of their mnemonic similarity, $t(28) = 8.16, p < .001$. An example of easy and hard similar items are included in Fig. 1C.

2.4. Data analysis

Participant data were removed from analyses if overall accuracy was greater than two standard deviations below the mean. This resulted in the removal of six experimental participants from analyses, leaving data from 60 experimental participants. All statistics were calculated in SPSS 24.0 (SPSS Inc., Chicago, IL) software. Pairwise comparisons were corrected for family wise error using Bonferroni correction unless otherwise noted.

3. Results

3.1. Psychometrics

Mean scores on AMBI, STAI-Y and demographic information are reported in Table 1.

3.2. Overall performance on the memory task

3.2.1. Overall accuracy

Recognition memory accuracy for each condition was calculated for each subject. We found that participants had the highest accuracy for old items (*M* = 73.8 %, *SD* = 17.5), followed by new foil items (*M* = 59.8 %, *SD* = 17.7) and similar lure items (*M* = 47.8 %, *SD* = 15.3). A one-way analysis of variance (ANOVA) confirmed that the conditions differed from each other ($F(2,118) = 54.890, p < .001$), and follow-up paired *t*-tests revealed all pairwise comparisons to be significant (old vs similar, *t*

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[2] The pilot subjects performed quite well on the task, with *M* “old” accuracy = 66.44% (*SD* = 24.99%), *M* “similar” accuracy = 47.33% (*SD* = 15.90%), and *M* “new” accuracy = 55.33% (*SD* = 18.64%)

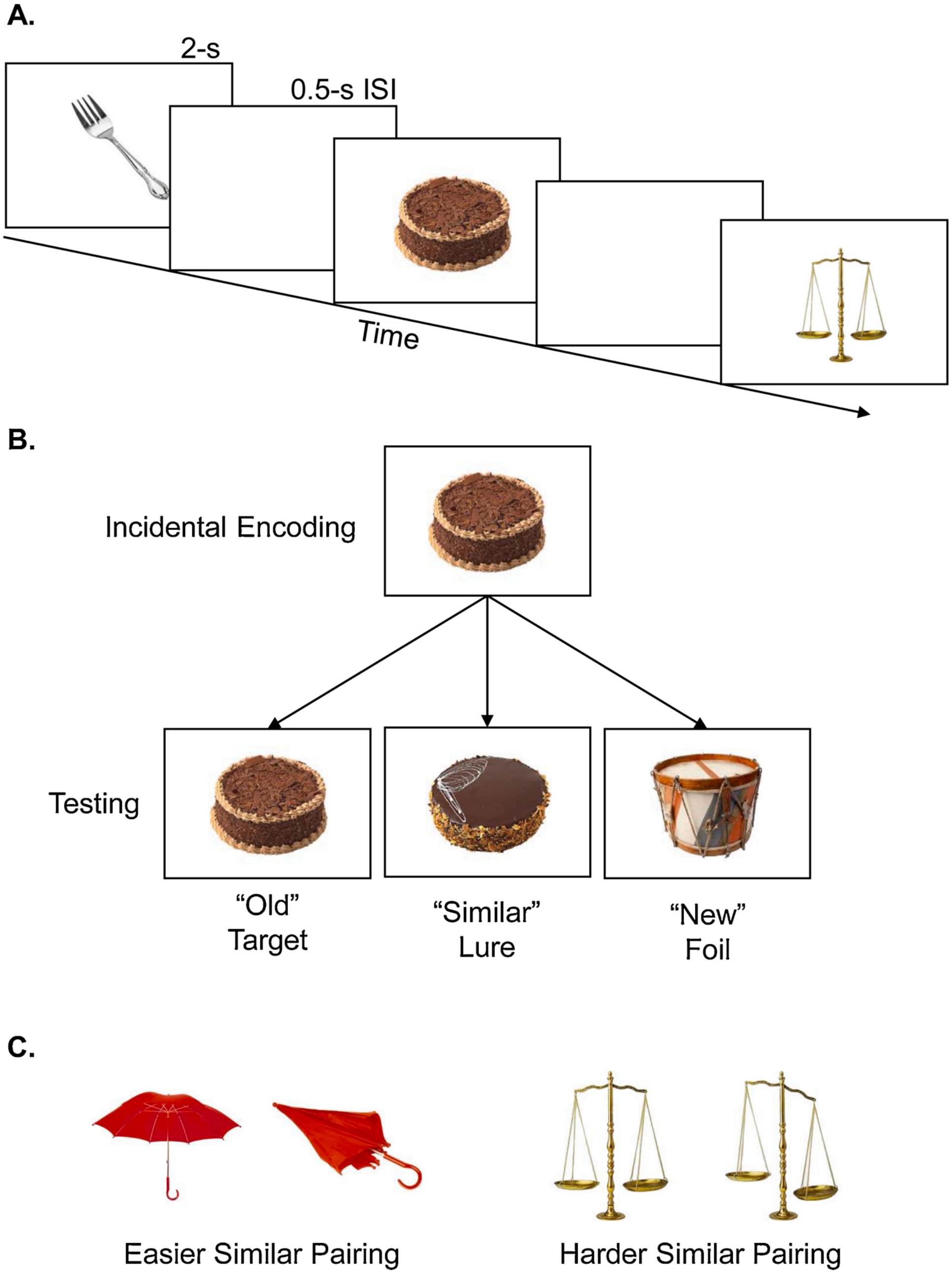

Fig. 1. (A) Sample stimuli from incidental encoding procedure. Each image appeared for 2-*s* with a 0.5-*s* blank ISI between trials. (B) Example of visual similarity between target, lure, and foil items to item encoded during incidental encoding. (C) Images representing easier and harder similar lure pairings.

Table 1
Demographic information, AMBI score, and STAI-Y score.

	Mean	Standard deviation
Age	19.35	0.97
AMBI	14.18	5.30
STAI-Y Trait[*]	39.26	8.26

Pearson correlation between AMBI & STAI-Y Trait: $r(32) = .552$, $p = .001$.

[*] Due a technical error, STAI-Y score is only available from a subset of participants ($n = 34$).

(59) = 9.986, $p < .001$; old vs new, $t(59) = 6.154$, $p < .001$; similar vs new, $t(59) = -4.690$, $p < .001$).

Furthermore, a paired *t*-test confirmed that individuals had greater difficulty distinguishing hard similar items from previously encountered items (M "old" responses to "similar" items = 48.1 %, $SD = 18.5$) than discriminating easy similar items from previously encountered items (M "old" responses to "similar" items = 18.9 %, $SD = 11.6$), $t(59) = 13.230$, $p < .001$. This pattern is consistent with our intended manipulation.

3.3. *Relative contribution of behavioral inhibition and trait anxiousness to mnemonic discrimination between perceptually-similar items*

3.3.1. *Mnemonic discrimination*

To evaluate mnemonic discrimination, we focus on individuals' ability to tell apart visually similar items from previously encountered "old" items. Specifically, we examine how behavioral inhibition and trait anxiousness may influence individuals' ability across three measures: (a) accurate mnemonic discrimination (i.e., correctly identify similar items as "similar"), (b) discrimination errors (i.e., incorrectly categorize similar items as "old"), and (c) discrimination efficiency (i.e., difference in correct discrimination and erroneous generalizations). Table 2 summarizes performance on similar trials across all participants and the subset of individuals who also completed the STAI-Y.

3.3.2. General approach

To evaluate the unique contribution of behavioral inhibition (indexed by AMBI) and trait anxiousness (measured by STAI-Y) to mnemonic discrimination, we conducted a series of multiple regression analyses that separately examined these relationships in easy and hard similar trials. Specifically, AMBI and STAI-Y scores were included as predictors and different measures of mnemonic discrimination were included as dependent measures. It should be noted that these analyses are based on a smaller sample due to a technical error in the administration of the STAI-Y (see section 2.2).

3.3.3. Accurate mnemonic discrimination

The ability to correctly categorize “similar” items reflects success in mnemonic discrimination between perceptually-similar representations. For the easy similar items, the overall regression model failed to reach significance, with both predictors together explaining only 10.7 % of the overall variance ($R^2 = .107$, $F(2,31) = 1.858$, $p = .173$, AMBI $\beta = -.210$, $p = .310$, STAI-trait $\beta = -.160$, $p = .437$). In contrast, the overall model for hard similar items was significant, with both predictors together explaining 23.3 % of the overall variance ($R^2 = .233$, $F(2,31) = 4.712$, $p = .016$). Specifically, we found that both AMBI ($\beta = .385$, $p = .050$) and STAI-Y ($\beta = -.573$, $p = .005$) scores significantly predicted accurate mnemonic discrimination. Interestingly, the two relationships were in opposite directions: higher AMBI scores predicted more accurate mnemonic discrimination, whereas higher STAI-Y scores predicted less accurate mnemonic discrimination, when perceptual similarity was high (Fig. 2).

3.3.4. Failure in mnemonic discrimination

In this analysis, we focus on errors that result from erroneously identification of new perceptually-similar items as previously encountered (i.e., responding “old” to “similar”). Such a failure to discern the item’s mnemonic status likely reflects an increased generalization between perceptually-similar representations.

The multiple regression analysis on the easy similar items revealed that the overall model failed to reach significance, with both predictors together explaining only 5.4 % of the overall variance ($R^2 = .054$, $F(2,31) = .877$, $p = .426$, AMBI $\beta = -.258$, $p = .227$, STAI-trait $\beta = .227$, $p = .287$). In contrast, the overall model for hard similar items was significant, with both predictors together explaining 22.0 % of the overall variance ($R^2 = .220$, $F(2,31) = 4.368$, $p = .021$). Specifically, we found that both AMBI ($\beta = -.408$, $p = .040$) and STAI-Y ($\beta = .548$, $p = .007$) scores significantly predicted mnemonic discrimination errors. Similar to our preceding analysis, the two relationships are in opposite directions: higher AMBI scores predict fewer false alarm errors, whereas higher STAI-Y scores predict more false alarm errors, when perceptual similarity is high (Fig. 3).

Table 2
Distribution of responses on “easy similar” and “hard similar” trials across all participants and for the subset of participants who also completed the STAI-Y.

	Easy Similar Mean Proportion (SD)		Hard Similar Mean Proportion (SD)	
	All participants	Subset*	All participants	Subset*
“Similar” responses	.554 (.163)	.520 (.155)	.389 (.187)	.353 (.184)
“Old” responses	.189 (.116)	.197 (.113)	.481 (.185)	.513 (.201)
“New” responses	.208 (.137)	.221 (.151)	.080 (.095)	.082 (.093)
No response	.049 (.058)	.063 (.062)	.050 (.056)	.053 (.062)

* The values in the Subset columns are derived from those individuals who also completed the STAI-Y.

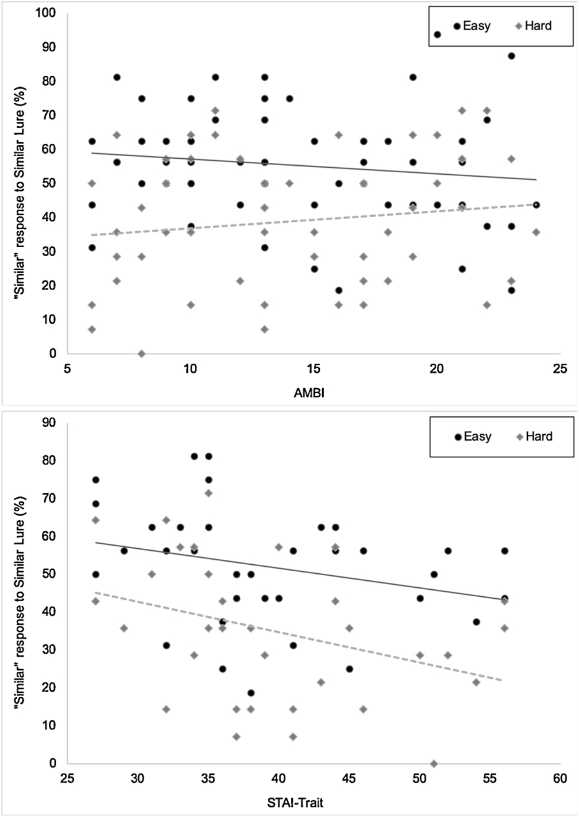

Fig. 2. Scatterplot with linear regression line demonstrating the unique contribution of AMBI (top) and STAI-Trait (bottom) to accurate mnemonic discrimination behavior. (correct “similar” responses to similar lures). X axis represents self-reported scores on the measures and Y axis represents percentage of correct “similar” responses to similar lures. Black is performance on easy similar trials and gray is for performance on hard similar trials.

3.3.5. Discrimination efficiency

Another way to conceptualize mnemonic discrimination is to derive a score that captures discrimination efficiency, which is often characterized as the difference in correct discrimination (i.e., hits, correct “similar” responses to “similar” items) and erroneous generalization (i.e., false alarms, incorrect “old” responses to “similar” items). This difference score is a corrected recognition score that represents a bias toward pattern separation [38]. It is derived by subtracting false alarms from hits, where higher positive scores are interpreted as more efficient discrimination. Once again, we conducted two multiple regression analyses to assess the relative influence of behavioral inhibition and trait anxiousness on discrimination efficiency.

Similar to the above analyses, the overall model for the easy similar trials failed to reach significance, with both predictors together explaining only 5.3 % of the overall variance ($R^2 = .053$, $F(2,31) = 0.872$, $p = .428$, AMBI $\beta = -.015$, $p = .944$, STAI-trait $\beta = -.222$, $p = .297$). In contrast, the overall model for hard similar items was significant, with both predictors together explaining 24.5 % of the overall variance ($R^2 = .245$, $F(2,31) = 5.033$, $p = .013$). We found that both AMBI ($\beta = .414$, $p = .035$) and STAI-Y ($\beta = -.584$, $p = .004$) scores significantly predicted mnemonic discrimination efficiency. Similar to our preceding analyses, the two relationships are in opposite directions: higher AMBI scores predicted higher discrimination efficiency, whereas higher STAI-Y scores predicted lower discrimination efficiency, when mnemonic discrimination demands are particularly high (Fig. 4).

3.3.6. Summary

Taken together, these analyses yielded a complementary picture. When mnemonic discrimination demands are high (i.e., similar hard

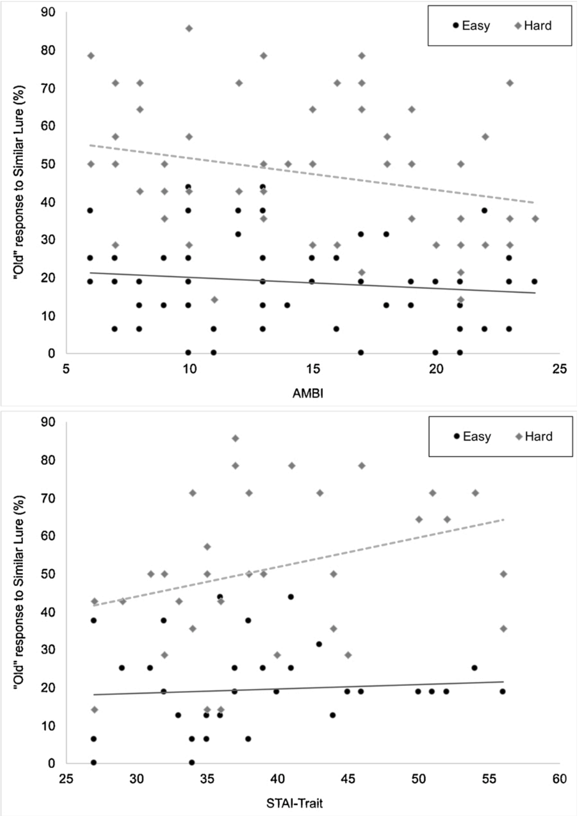

Fig. 3. Scatterplot with linear regression line demonstrating the unique contribution of AMBI (top) and STAI-Trait (bottom) to errors in mnemonic discrimination behavior. X axis represents self-reported scores on the measures and Y axis represents percentage of incorrect “old” responses to similar lures. Black is performance on easy similar trials and gray is for performance on hard similar trials.

trials), individuals with higher behavioral inhibition perform better on mnemonic discrimination (more accurate categorizations, fewer generalization errors, and higher discrimination efficiency) and individuals with higher trait anxiousness perform worse on mnemonic discrimination (fewer accurate categorizations, more generalization errors, and lower discrimination efficiency). When mnemonic discrimination demands are low (i.e., similar easy trials), neither behavioral inhibition nor trait anxiousness appear to predict discrimination performance.

3.4. Individual differences in mnemonic discrimination between perceptually-dissimilar items

Another aspect of discrimination that we have not yet considered is the ability to distinguish the difference between a similar lure and a new foil. In contrast to the type of discrimination failure that we described above (Section 3.3), this type of error is unlikely to be driven by overgeneralization, as the new items had never been encountered and are perceptually-dissimilar to previously encountered stimuli. Although this analysis does not directly address the central question of our study — to understand individual differences that may underlie the ability to differentiate previously encountered (old) and perceptually-similar yet novel (similar) stimuli — it may provide insight into the relationships among these traits and memory abilities more broadly.

To do so, we calculated a lure discrimination index (LDI), by subtracting incorrect “similar” responses to “new” trials from correct “similar” responses to similar trials [11,39]. This index accounts for one’s bias to respond “similar”, even to new items that were not perceptually similar to previously encountered items. Since there is only one type of new trials, we are unable to calculate separate LDI for easy and hard similar trials. Thus, in this analysis, we collapsed across all similar trials, with the goal of exploring whether individual differences in behavioral inhibition and trait anxiousness contribute to LDI.

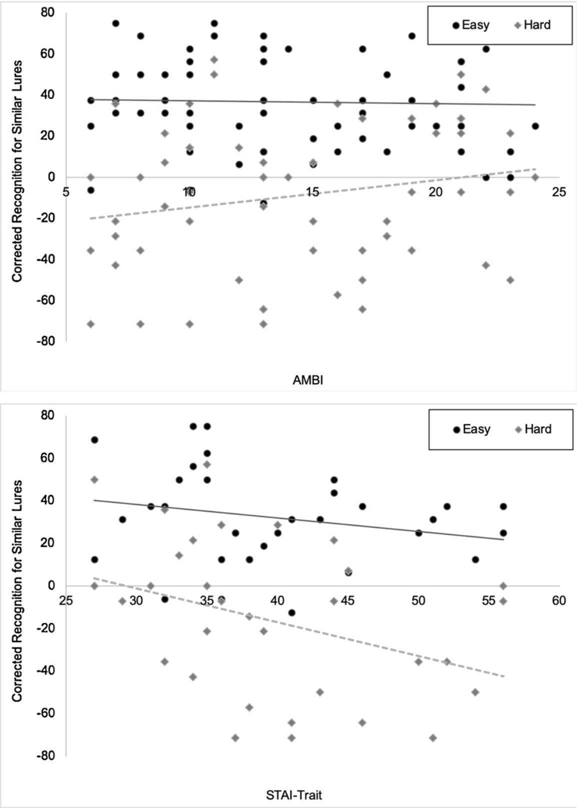

Fig. 4. Scatterplot with linear regression line demonstrating the unique contribution of AMBI (top) and STAI-Trait (bottom) to discrimination efficiency. X axis represents self-reported scores on the measures and Y axis represents corrected recognition with higher positive scores indicating more efficient discrimination [38]. Black is performance on easy similar trials and gray is for performance on hard similar trials.

We found that the overall multiple regression model was significant, with both predictors together explaining 18.6 % of the overall variance ($R^2 = .186$, $F(2,31) = 3.539$, $p = .041$. While there is not sufficient evidence to suggest that behavioral inhibition influences LDI (AMBI $\beta = .278$, $p = .162$), trait anxiousness was revealed as a significant predictor of LDI (STAI-Y $\beta = -.517$, $p = .012$). As trait anxiousness increases, LDI decreases. Fig. 5 summarizes these relationships.

Although behavioral inhibition appears to have a differential influence on the two types of discrimination (i.e., distinguishing old from similar vs. discriminating between similar and new), it should be noted that based on prior findings, we expected AMBI to be predictive of discrimination abilities only under when mnemonic discrimination demands are high (i.e., discrimination between hard similar and old). Thus, these results should be interpreted with that context in mind.

3.5. Individual differences in response times

Given the behavioral profile of persons with high behavioral inhibition, one might expect those with higher behavioral inhibition to be generally more cautious in their responding, leading to slower reaction times. To examine this possibility, we conducted a Pearson correlational analysis to determine whether self-reported AMBI is related to response

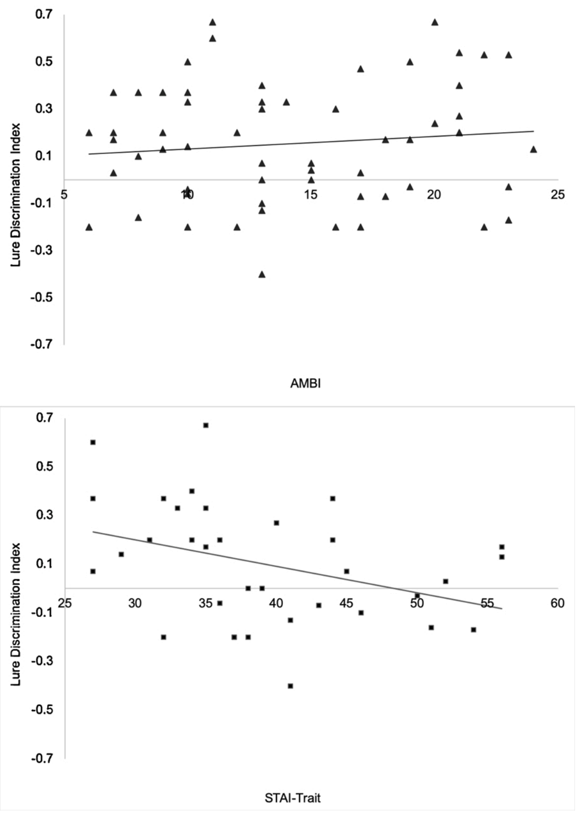

Fig. 5. Scatterplot with linear regression line demonstrating the unique contribution of AMBI (top) and STAI-Trait (bottom) to lure discrimination across all similar trials. X axis represents self-reported scores on the measures and Y axis represents ability to discriminate among similar items, with higher values indicating better discrimination [11].

times on similar trials (in milliseconds for correct responses only). There was no evidence of a relationship between response times and AMBI scores in either the easy similar condition *r*(58) = .016, *p* = .905, or the hard similar condition *r*(57) = .162, *p* = .221[3], suggesting that slower reaction times did not relate to AMBI scores in this sample. A similar pattern was found between STAI-trait and response times on correct easy similar trails, *r*(32) = -.023, *p* = .896, with the relationship between hard similar trials approaching significance, *r*(31) = .344, *p* = .050[3].

4. Discussion

In this study, we examined if individual differences in mnemonic discrimination is related to differences in risk for anxiety. Building on prior work that examined this relationship under high arousal conditions [11–13], we used neutral images of everyday objects in a mnemonic discrimination task. Furthermore, we also explored the relative contribution of behavioral inhibition and trait anxiousness to mnemonic discrimination. Two key findings emerged from our study. First, we found that both behavioral inhibition and trait anxiousness predict mnemonic discrimination abilities, but only when mnemonic similarity is high. Importantly, these observations are consistent across different measures of mnemonic discrimination: correct categorization of similar items, incorrect endorsement of "similar" items as "old", and discrimination efficiency. Second, these relationships are in opposite directions, with higher behavioral inhibition associated with *better* mnemonic discrimination and higher trait anxiousness associated with *worse* mnemonic discrimination.

Better performance on more difficult similar trials by individuals with higher behavioral inhibition may be understood within the context of recent work that links behavioral inhibition with enhanced acquisition and reduced extinction in avoidance learning and classical eyeblink conditioning [40,41]. Both participants with PTSD and Veterans with high behavioral inhibition learn faster in non-aversive tasks measuring avoidance and associative learning [27,28,30,31,42–44], suggesting that basic learning differences exist prior to the development of PTSD. Here, we extended the observation of those differences to a mnemonic discrimination task, furthering the scope of learning differences observed in behavioral inhibition. Together, these results suggest key differences in how people with behavioral inhibition learn and remember information. Further research examining processes related to attention, encoding, and recall is necessary to fully understand the range and limits of these differences and their contribution to the development and maintenance of anxiety disorders.

The observed negative relationship between trait anxiousness and mnemonic discrimination abilities in our study was (in part) in contrast with prior results. For example, recent studies failed to find a relationship between STAI-trait and mnemonic discrimination [39] and between other measures of anxiousness (the DASS-Anxiety) and mnemonic discrimination [32,45]. The divergence of our findings in comparison with Dohm-Hansen & Johansson [39], who also used the STAI-Y trait, may be due to our sample characteristics. While of similar sample sizes (34 in our study vs 30 in Dohm-Hansen & Johansson), our sample had a lower mean STAI-Trait (*M* = 39 vs 43) and a reduced range (27–56 in our sample vs 26–71). Another possibility is that while our task utilized single items, Dohm-Hansen and Johansson's stimuli were objects-in-contexts, which may involve additional relational processing demands that are absent in our study. Finally, in our study, the relationship between STAI-trait and mnemonic discrimination varied as a function of mnemonic similarity, where the relationship was apparent only when discrimination demands are high (i.e., hard trials), which was not considered in Dohm-Hansen and Johansson's study.

Furthermore, similar to previous research in PTSD [14], our analysis did not reveal a relationship between behavioral inhibition and response times. While all participants took longer to respond on more difficult trials, there was no difference as a function of risk for anxiety. Taken together, these findings suggest that the observed relationship between mnemonic discrimination abilities on difficult trials and behavioral inhibition cannot be explained by this aspect of decision-making processes.

Enhanced performance on the most difficult discrimination trials by subjects with high behavioral inhibition may also suggest key differences in underlying neural structure and function. This is supported by the observation that there are structural hippocampal differences (specifically volume reductions) in those with PTSD [46,47], as well as in those at risk for PTSD [48]. For example, it has been reported that volume loss may be specific to the same subregions of the hippocampus linked to mnemonic discrimination [37,49,50], namely the dentate gyrus (DG) and cornu ammonis 3 (CA3) [51]. While it may seem that structural volume reductions would lead to poorer discrimination performance, evidence suggests that reductions in hippocampal functioning may actually serve to improve discrimination performance on difficult trials. Support for this possibility comes from recent research that has reported that hyperactivity in hippocampal regions responsible for discrimination (e.g., CA3) is related to poorer discrimination performance in older adult participants [52–55], suggesting that the inverse (reduced DG/CA3 activity) may lead to improved performance. Accordingly, studies measuring hippocampal recruitment during discrimination tasks in behaviorally inhibited participants are necessary to better understand the role of hippocampal differences in risk for anxiety.

The contribution of the amygdala to individual differences in

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[3] One participant did not have any correct "similar" responses for hard mnemonic discrimination trials, and thus was not included in the reaction time analysis for hard similar trials.

discrimination should also be considered. Differences in amygdala functioning is commonly observed in anxiety prone individuals [22, 56–58] as well as in clinical anxiety (for a review see [59]). Connections between the amygdala and hippocampus have also been demonstrated to be relevant in an emotional mnemonic discrimination task [60]. Leal and colleagues [60] found heightened amygdala activity and a negative correlation between depressive symptoms and DG/CA3 activity during discrimination of negatively valenced stimuli, suggesting that the perceived valence of stimuli and engagement of the amygdala may influence discrimination processes in the hippocampus. It is interesting to consider this finding in the context of prior research that demonstrated better discrimination performance in situations where arousal may be enhanced (e.g. via viewing disturbing images prior to encoding [12], or when encoding during periods of threat [13]). Given the well-established role of the amygdala in arousal [61,62], these findings together suggest that amygdala influences on the hippocampus may play an important role in mnemonic discrimination performance. It is possible that behaviorally inhibited participants have altered amygdala-hippocampal functional connections, possibly due to biased emotional processing [63], which may result in heightened amygdala activity even in non-threat or neutral circumstances. This presents a key avenue for future research understanding the links between emotional processing, amygdala-hippocampal functional connectivity, and behavioral inhibition.

It should be noted that the results of this study (and of [30]) found *better* discrimination between similar objects on most difficult trials for those with high behavioral inhibition, are possibly at odds with recent research that reported poorer discrimination scores being related to increased generalization of shock expectancy [11]. One reason that these findings may seem contradictory may be that Lange and colleagues [11] used a fear learning paradigm where participants acquired the association between a conditioned stimulus that was paired with a shock (CS+) and similar stimuli that were not paired with shocks (e.g. visually similar circles of decreasing size). Thus, while it may be that visual object discrimination performance is related to fear generalization, our study addresses whether it is related to other, neutral forms of discrimination. Taken together, these findings suggest a complicated picture of generalization, discrimination, and learning.

In sum, we found that discrimination differences in participants with high behavioral inhibition extend to a task of mnemonic discrimination (using neutral everyday objects) in a sample of young adults, raising important questions regarding individual differences in learning and memory processes that may underlie risk for anxiety. Continued research is necessary to determine whether these differences are present only in the visual domain, as has been observed so far, or whether they extend to discrimination in other modalities.

5. Limitations and conclusions

The current findings contribute to our understanding of the relationships among behavioral inhibition, trait anxiousness and learning and memory processes, which has important relevance to mental health. However, some aspects of our results are limited and will need further corroboration from future studies.

First, participants were undergraduates in Psychology courses who voluntarily participated for research credit or coursework. Participants did not undergo a clinical interview, nor were they asked to self-report the presence of anxiety symptoms or provide a history of clinical diagnoses, limiting our ability to parse the impact of clinical symptoms on performance. Given recent research demonstrating the correlation between self-reported symptoms of PTSD and AMBI [24,65], it is possible that AMBI is capturing the presence of PTSD symptoms in our sample. Future research examining the distinction between PTSD symptoms, AMBI scores, and performance on learning and memory tasks is warranted to determine the precise contribution of each factor to individual differences in learning and memory.

Second, although we found that both behavioral inhibition and trait anxiousness are significant predictors of mnemonic discrimination abilities, those analyses were only based on a subset of subjects (due to technical difficulties during collection of STAI data). Thus, future research with larger groups who have completed both the AMBI and STAI-Trait is necessary to understand the complex contribution of each of these measures to mnemonic discrimination performance.

Third, the sample included a majority of female participants. There have been observations of sex differences in the prevalence of PTSD diagnosis and symptoms [66,67]. Even though the reported sample of males and females was skewed with over 2/3 female, Chi-square test for independence did not show a difference in the distribution between male/female in the AMBI groups. Furthermore, while some prior studies have demonstrated sex differences in emotional memory [68], we found no differences between male and female performance on the neutral discrimination task used here. Future studies with larger samples and emotionally salient stimuli may better highlight the relationship between discrimination and sex differences.

Finally, the retention interval was relatively short (on the order of minutes). As generalization in PTSD and other anxiety disorders occurs on a much greater temporal magnitude, future research examining whether discrimination differences persist for neutral stimuli over longer durations will improve the generalizability of these results to real-life situations observed in anxiety disorders.

Our results indicate that young adults with high behavioral inhibition have better discrimination performance for the difficult trials. Further research of how risk for anxiety may be associated with individual differences in learning and memory is important to understand the neural and behavioral processes underlying the development of clinical anxiety. Furthermore, it will also be important to specify how behavioral inhibition and trait anxiousness differentially predict memory abilities. Our findings suggest that whereas both traits predict discrimination between perceptually-similar representations (although in opposite directions), only trait anxiousness predicts discrimination between new and similar items. Such an understanding would not only highlight basic learning and memory differences essential in anxiety disorders but may also lead to better prevention, assessment, and treatment of anxiety.

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CRediT authorship contribution statement

Meghan Davis Caulfield: Conceptualization, Methodology, Software, Formal analysis, Resources, Data curation, Writing - original draft, Writing - review & editing, Visualization, Supervision, Project administration. **Alexandra L. Vogel:** Conceptualization, Methodology, Investigation, Data curation, Writing - original draft. **Mia R. Coutinho:** Conceptualization, Methodology, Investigation, Data curation, Writing - original draft. **Irene P. Kan:** Writing - review & editing, Formal analysis, Visualization, Supervision.

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