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SHORT COMMUNICATION

Determining the mechanisms through which recent life stress predicts working memory impairments: precision or capacity?

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ABSTRACT
Prior research has found that recent life stress exposure is related to poorer working memory performance, but it remains unclear which aspects of working memory are related to stress. To address this important issue, we examined the extent to which recent life stress exposure was associated with working memory capacity (i.e., the number of items that can be held in working memory) and working memory precision (i.e., the quality of representations of items held within working memory) in a sample of 260 healthy young adults (M_{age} = 19.95 years old; range = 18–33). Recent life stress exposure and working memory were assessed with the Stress and Adversity Inventory for Daily Stress (Daily STRAIN) and color wheel task, respectively. We found that recent life stress was selectively associated with lower working memory capacity; moreover, the association of recent life stress with capacity was significantly stronger in magnitude than the non-significant association of recent life stress with precision. These associations were robust while controlling for potential confounds, including demographic factors, negative affect, and cumulative lifetime stress exposure. These results thus suggest that stress-related degradations in working memory capacity may help explain how recent life stress exposure affects working memory performance.

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Introduction

Although stress is a common occurrence, it can have particularly detrimental effects on our lives. Prior research has indicated that *recent life stress* (i.e., stressors experienced over a short period in the recent past) is associated with poorer working memory (Shields, Doty, et al., 2017). Exactly how such stress relates to worse working memory, though, is still unclear. To address this issue, we designed this study, which examined how recent life stress relates to component processes involved in working memory.

Working memory is a complex construct. In particular, both the number of items able to be held in working memory (i.e., *capacity*) and the ability to maintain high quality representations of items held in working memory (i.e., *precision*) are critical to working memory (Zhang & Luck, 2008). These working memory components show interesting clinical dissociations. For example, individuals with greater trait anxiety or suffering from schizophrenia show impaired working memory capacity but intact precision (Luck & Vogel, 2013; Yao, Chen, & Qian, 2018), whereas age-related impairments in working memory stem more from impaired precision than capacity (Pertzov, Heider, Liang, & Husain, 2015; Zokaei, Burnett Heyes, Gorgoraptis, Budhdeo, & Husain, 2015).

Although numerous studies have examined how stress influences overall working memory performance (Bogdanov & Schwabe, 2016; Evans & Schamberg, 2009; Luettgau, Schlagenhauf, & Sjoerds, 2018; Schoofs, Preuβ, & Wolf, 2008; Shields, Sazma, & Yonelinas, 2016), to date, no study has examined how stress modulates working memory precision and capacity. As a result, it is difficult to develop hypotheses about whether recent life stress will relate more to worse capacity or precision based upon prior literature alone. Nevertheless, studies of schizophrenia, as well as studies of the neurobiology of working memory precision and capacity, may help to generate predictions. For example, schizophrenia spares working memory precision but impairs capacity by narrowing attentional focus, as fewer items are attended to and, therefore, encoded (Luck & Vogel, 2013). Stress also narrows attentional focus (Shields et al., 2016), so stress may impair capacity. Similarly, working memory capacity is highly dependent upon the prefrontal cortex (Arnsten, 2009), and stress impairs prefrontal cortical function (Arnsten, 2009), so stress may thus impair capacity. Alternatively, working memory precision is highly dependent upon the hippocampus (Goodrich & Yonelinas, 2016; Yonelinas, 2013), and stress alters and can impair hippocampal function (Diamond & Rose, 1994; Gianaros et al., 2007; Shields, Sazma, McCullough,

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Supplemental data for this article can be accessed here.

& Yonelinas, 2017); therefore, stress may impair precision. In sum, recent life stress may relate to impaired working memory through worse precision, capacity, or both.

Current study

We examined whether recent life stress predicted worse working memory through impaired capacity or precision in a sample of 260 young adults. We expected to replicate prior research showing that recent life stress is associated with worse working memory. Moreover, we expected that this association would hold while controlling for important covariates, such as current negative affect and cumulative lifetime stress exposure. However, given the lack of data linking stress to capacity or precision, we did not develop *a priori* hypotheses regarding precision versus capacity.

Method

Participants

Participants were 260 healthy young adults (194 females; $M_{age} = 19.95$, $SD_{age} = 2.18$, range = 18–33 years) attending a large public university. This sample size provided 92.5% power to detect a correlation of $r = -.19$, which is the correlation we obtained in a prior, independent study of recent life stress and working memory (Shields, Doty, et al., 2017).

Materials

Recent life stress exposure

Participants reported their recent life stress exposure using the Stress and Adversity Inventory for Daily Stress (Daily STRAIN), which has been shown to predict worse mental and physical health, poor long-term memory, and poor working memory (Shields, Doty, et al., 2017). The Daily STRAIN assesses the frequency of 17 stressors that are likely to occur over a two-week period. Example items include, "Over the past two weeks, how many times were you criticized, insulted, or made fun of by someone you care about?" and, "Over the past two weeks, how many times did an important friendship or romantic relationship end with you and someone else?" Participants responded using a scale of 0–5+ times. The frequency of each stressor (0–5) was summed to create a total recent life stress score, with higher scores indicating more recent life stress.

Working memory

Participants completed the color wheel task (Zhang & Luck, 2008) to assess working memory (see Figure 1). Each trial began with a fixation cross in the center of the screen for 1000 ms. When the fixation cross disappeared, participants saw four colored squares with randomly selected non-overlapping colors, equal in saturation and value but differing in hue, randomly distributed in a non-overlapping layout in a 400 400 pixel area. Squares were displayed for 400 ms and then a blank screen was shown for 1000 ms. Next, four black borders appeared where the squares had been, and one of them was cued with a thicker border. During this second presentation, boxes were surrounded by a color wheel, depicting all colors of each hue (360 totals) at the same level of saturation and value (100% each). Participants indicated the color of the cued box by clicking on the color wheel. Feedback on the correctness of responses was provided in the form of the correct color being shown in the cued box for 1000 ms. After reading the instructions, participants completed 10 practice trials before completing 5 blocks of 30 trials each, for a total of 150 analyzed (i.e., non-practice) trials.

Following standard practice for the color wheel task (Zhang & Luck, 2008), we fit the data to a mixture model, which provides estimates of both precision and capacity. Additional information on fitting the model is presented in the Supplemental Material.

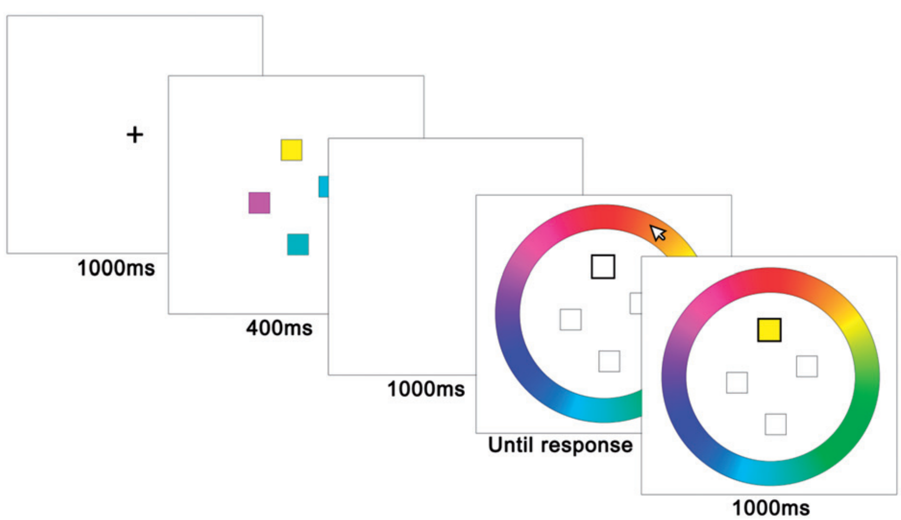

Figure 1. Schematic illustration of a color wheel task trial. Each trial began with a fixation cross in the center of the screen for 1000 ms. When the fixation cross disappeared, participants saw four non-overlapping colored squares. Squares were displayed for 400 ms and then a blank screen was shown for 1000 ms. Next, participants indicated the color of square highlighted by a thick black border. During this second presentation, boxes were surrounded by a color wheel, depicting all colors possible. Participants indicated the color of the cued box by clicking on the color wheel. Feedback on the correctness of responses was provided in the form of the correct color being shown in the cued box for 1000 ms.

Table 1. Descriptive statistics and correlations for the main study variables.

Variable	%	*M* (*SD*)	Range	1	2	3	4	5	6
1. Recent life stress exposure		17.58 (10.61)	0–63						
2. Probability of memory (Capacity)		0.74 (0.14)	0.13–0.97	.19					
3. *SD* of memory distribution (Imprecision)		19.66 (7.43)	8.9–111.2	.08	.35				
4. Age		19.95 (2.18)	18–33	.06	.07	.01			
5. Negative affect		22.25 (7.31)	10–50	.41	.14	.10	.03		
6. Cumulative lifetime stress exposure		17.08 (11.94)	0–69	.35	.05	.05	.12	.11	
7. Socioeconomic status		0.03 (0.88)	1.8–1.6	.05	.21	.07	.08	.01	.12
Gender									
Male	25.0								
Female	74.6								
Transgender	0.4								
Race/Ethnicity									
American Indian/Alaska Native	1.2								
Asian/Asian American	47.7								
Black/African American	1.2								
White	19.2								
Hispanic	22.7								
Mixed/Biracial	5.8								
Decline to State	2.3								

Note: $p < .05$; $p < .01$; $p < .001$.
M and *SD* represent mean and standard deviation, respectively. Socioeconomic status was calculated by standardizing then averaging self-reported household income (listed in IRS percentiles) and mother's highest education level achieved.

Negative affect (PANAS)

Participants completed the Positive and Negative Affect Schedule (PANAS) (Watson, Clark, & Tellegen, 1988) to assess current affect. Participants were instructed to report the extent to which they "currently feel (i.e., at this moment)" several positive and negative affective states using a scale from 1 (*very slightly or not at all*) to 5 (*extremely*). Because we were interested in controlling for negative affect in analyses, we used these responses to create an overall PANAS negative affect score for each participant by averaging together the respective affective states. Higher scores thus indicated greater negative affect. Internal consistency of the negative affect items was good, $\alpha = .86$.

Cumulative lifetime stress exposure

Cumulative lifetime stress exposure was assessed with the Stress and Adversity Inventory for Adults (Adult STRAIN) (Slavich & Shields, 2018). The Adult STRAIN asks respondents about 55 different types of acute life events and chronic difficulties that they could have experienced over the lifespan. The STRAIN has excellent test–retest reliability (*rs* = .904–.919) and predictive validity in relation to several different health outcomes (Slavich & Shields, 2018).

Procedure

Data presented in this manuscript were collected as part of a larger project with several independent research aims. In this study, we sought to replicate and extend our prior work showing that recent life stress predicts worse working memory (Shields, Doty, et al., 2017) by examining *a priori* hypotheses regarding associations between recent life stress, working memory capacity, and working memory precision. As such, although participants completed various measures unrelated to the present manuscript (e.g., diet assessments), all measures that were included within the larger project for the purposes of this study have been analyzed and reported in the manuscript.

Participants came to the lab and first provided informed consent. After measures unrelated to this study, participants completed the working memory task. Participants then completed two brief filler measures before completing the negative affect assessment. Next, participants provided demographic information before completing the recent life stress questionnaire. After completing additional measures unrelated to this study, participants completed the cumulative lifetime stress assessment and were then debriefed and dismissed. All study materials and procedures were approved by the Institutional Review Board at the University of California, Davis.

Data analysis

Our analyses were standard correlations, regressions, and tests of slope differences. Data were inspected for normality using the adjusted Fisher–Pearson coefficient of skewness and by manual inspection. Variables of interest were skewed due to outliers, which were defined as values greater than three standard deviations from the mean; as such, analyses are presented both with and without including outliers. In presentation of results, the standard deviation of the von Mises distribution was reversed so that higher scores entail greater precision for ease of conceptual understanding. We set α at the standard .05 level.

We included age, sex, race, socioeconomic status, and current negative affect as covariates in models incorporating covariates due to their associations with working memory and self-reported stress, and to parallel the analytic plan in our prior work examining recent life stress and working memory (Shields, Doty, et al., 2017). In addition, to ensure that associations between recent life stress and working

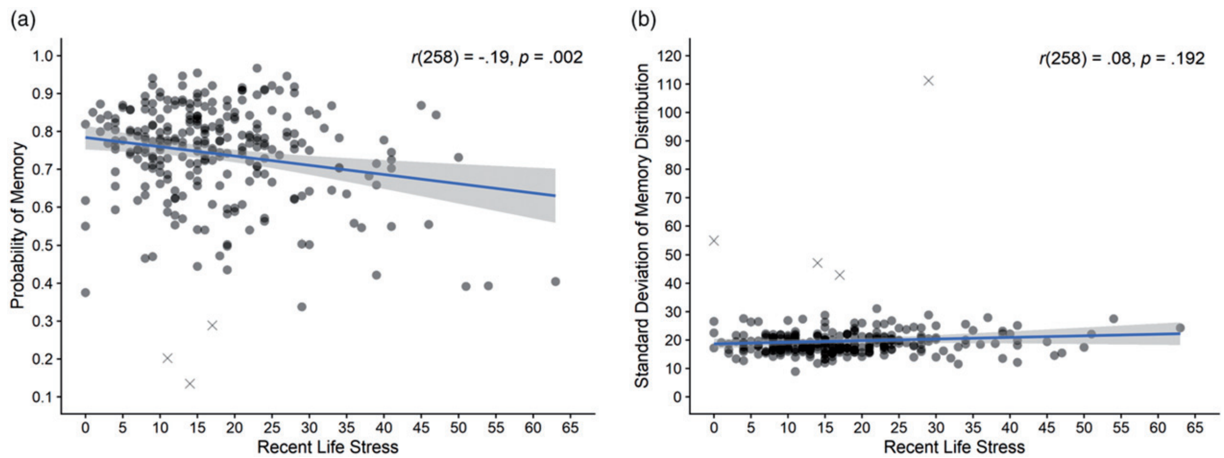

Figure 2. (a) Associations between recent life stress exposure and probability of memory (i.e., capacity) with outliers marked with an X. Likewise (b) associations between recent life stress exposure and the standard deviation of the von Mises distribution (i.e., imprecision) with outliers marked with an X. Associations described on figures were associations prior to removing outliers. Recent life stress was more strongly related to poor working memory capacity (i.e., lower probability of memory) than it was related to imprecision of items in working memory.

Table 2. Adjusted associations with recent life stress exposure.

Predictor	β
Capacity	.22
Precision	.07
Age	.09
Gender (Female)	.10
Gender (Transgender)	.06
Race (Native American)	.04
Race (Asian)	.14
Race (Black/African American)	.11
Race (Hispanic)	.07
Race (Mixed/Biracial)	.05
Race (Decline to State)	.04
Socioeconomic status	.06
Current negative affect	.31
Cumulative lifetime stress exposure	.34

$p < .05$; $p < .01$; $p < .001$.

Note: Outliers were removed in this analysis. White served as the reference group for race, and male served as the reference group for gender.

memory were not artifacts of people with more recent life stress simply having experienced more stress over their entire lives, we controlled for cumulative lifetime stress exposure in models including covariates. Results were virtually identical without controlling for lifetime stress exposure.

Results

Table 1 presents descriptive statistics for all variables of interest. Before examining associations with recent life stress, we assessed how well the mixture model fit the data. We found that the mixture model – fitting both uniform and von Mises distributions to the data (i.e., estimating precision and capacity) – was an excellent fit, $R^2 = .97$, and it fit significantly better than a reduced model fitting only a von Mises distribution to the data (i.e., estimating precision alone), $R^2 = .67$, $p < .001$.

Next, we examined whether recent life stress exposure was associated with working memory capacity and precision. We found that greater recent life stress exposure was, in fact, significantly related to worse working memory capacity, $r(258) = -.19$, $p = .002$ (Figure 2a). Removing outliers in capacity only strengthened this association, $r(255) = -.23$, $p < .001$. In contrast, we found that recent life stress exposure was not associated with working memory precision, $r(258) = -.08$, $p = .192$ (Figure 2b). However, after removing outliers in precision, recent life stress became significantly associated with precision in working memory, $r(254) = -.14$, $p = .025$.

Controlling for age, sex, race, socioeconomic status, current negative affect, and cumulative lifetime stress exposure did not alter the association between recent life stress and capacity (Table 2). In particular, recent life stress remained a significant predictor of lower capacity both before removing outliers, $\beta = -.18$, $t(245) = 3.03$, $p = .003$, and after removing outliers, $\beta = -.22$, $t(240) = 3.79$, $p < .001$. However, controlling for covariates weakened the association between recent life stress and precision: in adjusted analyses, recent life stress remained unrelated to precision before removing outliers, $\beta = .00$, $t(245) = 0.06$, $p = .951$, and it was no longer associated with precision after removing outliers, $\beta = -.07$, $t(240) = -1.31$, and $p = .192$.

Finally, we compared the relative strength of associations of capacity and precision with recent life stress in the above analyses (adjusted for covariates). We found that the inverse association between recent life stress and capacity was significantly greater than the inverse association between recent life stress and working memory precision, both before removing outliers, $t(245) = 2.66$, $p = .008$, and after removing outliers, $t(240) = 1.98$, $p = .049$. Therefore, recent life stress exposure predicted lower capacity to a significantly greater extent than it predicted poorer precision.

Additional analyses are presented in the Supplemental Material.

Discussion

Despite an abundance of existing research on life stress and memory, it remains unclear how recent life stress exposure modulates working memory capacity and precision. We addressed this important issue in this study, which first replicated prior results showing that recent life stress is associated with poorer working memory (Shields, Doty, et al., 2017). The present findings extend this body of work by showing that stress-related impairment is primarily due to lower working memory capacity, not imprecise representations of items held within working memory. Moreover, we found that this association between recent life stress and poor working memory capacity was robust while adjusting for several covariates and not simply due to individuals experiencing greater cumulative lifetime stress exposure. Therefore, recent life stress exposure is associated with worse working memory primarily through diminished capacity.

These results suggest that recent life stress may be associated with impaired working memory through some of the same mechanisms seen in schizophrenia, such as attentional narrowing, as schizophrenia also preferentially impairs capacity (Evans & Schamberg, 2010; Luck & Vogel, 2013). However, individuals with schizophrenia show normal precision, whereas after excluding outliers, recent life stress was somewhat associated with lower precision – though not to the same extent as capacity. As such, although recent life stress may be associated with attentional narrowing, it may also be associated with impairments in hippocampal function (Diamond & Rose, 1994), thereby manifesting in worse working memory precision (Yonelinas, 2013). Future research aimed at examining the neural bases of these associations, therefore, appears warranted.

These results may have implications for developing interventions aimed at improving performance in situations requiring working memory for individuals who have undergone recent stress. For example, if stress had primarily acted through precision to impair working memory, then extending presentation time – which improves precision (Peich, Husain, & Bays, 2013) – would be the intervention of choice for enhancing overall working memory performance. However, because stress primarily acted through capacity, reducing the number of items maintained in working memory at any given time will increase the likelihood that each new item makes it into working memory (Zhang & Luck, 2008). Therefore, our results suggest that interventions aimed at stress-related working memory impairments should primarily focus on reducing set sizes for actively maintained items – for example, during the introduction of concepts in a lecture.

This study has limitations that should be noted. First, as with any cross-sectional study, we cannot address cause. The fact that the associations observed were robust while controlling for negative affect suggests that these associations were not driven by trait-like factors that could bias individuals' reporting of their stress levels or state fluctuation in mood that could affect performance. However, it is also possible that lower working memory capacity contributed to greater stress exposure; interested readers are referred to the Supplemental Material for additional analyses addressing this possibility. Nevertheless, future studies aimed at understanding these associations could experimentally expose individuals to repeated stress to evaluate potential causal effects. Second, the association between recent life stress and working memory capacity was small by conventional standards. As such, future work should establish the relevance of this association to real-world outcomes, such as educational achievement. Finally, this study included a young adult sample, which limits its generalizability to other populations.

In conclusion, we found that recent life stress exposure was associated with lower working memory capacity, and that this association was significantly stronger than the association between recent life stress and working memory precision. These results suggest that stress may influence working memory through both frontal and hippocampal mechanisms, rather than through the hippocampus alone – though future studies are needed to examine the neural basis of these associations. In sum, recent life stress is associated with an impaired ability to hold things in mind more than it is associated with how well those things in mind are remembered.

Disclosure statement

No conflicts of interest were reported by the authors.

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