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Paying attention: cost of cumulative life stress is for older adults only

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ABSTRACT

Experimental evidence consistently demonstrates older adults often perform worse than younger adults across various cognitive domains. Prior studies reported that older adults with high lifetime stress perform worse on working memory and inhibitory tasks than both younger individuals and older adults with low stress. Notably, low-stress older adults performas well as younger adults, indicating that life-time cumulative stress, rather than age alone, may drive some cognitive decline during aging. However, this stress-age affect on attention, the underlying process of both working memory and inhibition is yet to be investigated. In this within-subjects cross-sectional online study 141 participants (n = 85 under 30 and n = 56 over 60) identified two target words in an Attentional Blink task. Participants also reported their lifetime and perceived stress and their state anxiety. Using linear mixed models and Bayes Factors, we provide evidence that age and lifetime stress predict overall attentional performance on the Attentional Blink task. This supports the hypothesis that older high life-time stress participants would score lower on the attentional task compared to older low-stress participants and younger participants. Due to the interconnected nature of attention, these results suggest the stress-age interaction could be a factor in other cognitive domains that are susceptible to age-related decline. On a positive note, the results also suggest that attentional decline during aging, like impairments in working memory and inhibition, may be exacerbated by factors outside of simply getting older (here, elevated lifetime exposure to stress) and may therefore, not be inevitable.

PUBLIC SIGNIFICANCE STATEMENT

Previous work demonstrated that older adults with low cumulative life stress perform as well on some cognitive tasks as their younger and more stressed peers. This study provides evidence for this same pattern during an attentional task, high stress older adults performed worse than older low stress adults and younger adults. These findings suggest that cumulative long-term stress, not aging alone, may drive cognitive decline during aging, highlighting the importance of managing stress across the lifespan.

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Introduction

Aging is associated with various aspects of cognitive decline, with studies supporting this observation reporting cognitive decline during aging for attentional, memory, language, and perceptual performances (e.g., Colsher & Wallace, 1991; Evans et al., 1993; Kausler, 1994; Sweeney et al., 2001), and replicated across cultures (Yu et al., 1989). While often attributed to the aging process itself, research indicates that this may not always be the case. One longitudinal study found that when unaffected by Alzheimer's disease (AD), advancing age was not associated with cognitive decline (Wilson et al., 1999). More recently, a study reported that neuropathology accounts for 43% of the variation in cognitive decline during aging, with AD accounting for ~33% of the variance (Boyle et al., 2021). This suggests cognitive decline during aging is not a result of merely aging; neuropathology, in part, drives cognitive decline associated with aging. The pathogenesis of AD and other related neuropathologies is not always clear but neuroinflammation seems to play a key role (Ghosh et al., 2020; Heneka et al., 2013). Neuroinflammation in turn is associated with stress (Sorrells et al., 2009). Furthermore, Justice (2018) asserts that stress exacerbates neuropathology in what they call the "Vicious Cycle of Stress."

By itself, stress is an adaptive process preparing the body for action when faced with a threat. To do this, stress alters the operational states of different bodily systems to allow for the reallocation of energy from one system to another. For example, suppressing the immune system to reallocate that energy to the cardiovascular system, thereby increasing heart rate at the cost of decreased immune function (Allen et al., 1946; Khansari et al., 1990). This altered state, known as allostasis (McEwen & Stellar, 1993), increases physiological and cognitive performance in order to deal with immediate threat and avoid death or harm. However, such an allostatic state is not sustainable in long term as it trades long-term survival for short-term survival: continued and repeated exposure to allostasis leads to allostatic load, which is the accumulation of general wear and tear on the body from allostasis (McEwen, 2004). Indeed, chronic cumulative stress is associated with many long-term health and physiological impairments, including dendritic and synaptic atrophy in the frontal cortex and hippocampus (Pavlides et al., 2002; Sotiropoulos et al., 2011) as a consequence of increased cortisol exposure (Lupien et al., 2009) exacerbating cognitive decline during aging.

With these links between cumulative stress, aging and cognitive decline in mind, a series of studies investigated the interaction of cumulative life stress and aging on spatial memory (Marshall et al., 2016b, 2018), inhibition (Marshall et al., 2016a) and working memory (Marshall et al., 2015; but see; Wallace et al., 2023 for contrasting results). They consistently reported that older high cumulative stress participants performed worse than their low-stress counterparts. Furthermore, older low-stress participants performed as well as younger participants, regardless of younger participant cumulative stress, which reflects the results of Wilson et al. (1999) and Boyle et al. (2021), that aging itself may not be solely responsible for cognitive decline or the rate of cognitive decline. The authors attributed this cumulative stress-age interaction effect to the deleterious consequences of prolonged cortisol exposure on the prefrontal cortex (PFC; McEwen, 2004; Sotiropoulos et al., 2011) and hippocampus (Gould et al., 1998; McEwen, 1999; Pavlides et al., 2002; Sapolsky et al., 1990; Woolley et al., 1990). That high cumulative stress only affects older participants suggests that the negative cognitive consequences of allostatic load only begin to manifest over a prolonged period (i.e., advanced aging). Furthermore, high cumulative stress can increase the aging process, furthering the cognitive decline seen in older high-stress participants (Yegorov et al., 2020); suggesting this is a mechanism leading to accelerated cognitive decline during aging. Given this and the overlap in brain areas associated with different cognitive processes, such as the frontal cortex, it suggests that increased exposure to stress over ones lifetime may also link to the attentional decline, also observed during advanced aging (Greenwood et al., 1997; Sweeney et al., 2001) but which has yet to be formally tested.

In the current study, we attempt to test this proposed stress-age interaction on attention using the attentional blink (AB) task. In the AB task, participants recall two target stimuli, usually words or pictures, which are embedded in a rapid (~100 ms per stimulus) stream of distractor stimuli, other non-related words or pictures. AB is a phenomenon whereby the recall accuracy of the second (T2) of two target stimuli is significantly lower if presented within a 500 ms window of the first target (T1) when embedded in a rapid serial visual presentation (RSVP; Raymond et al., 1992). The AB represents temporarily disrupted attentional engagement just after T2 perception (not T1 as intuition would suggest), weakening its subsequent processing and preventing working memory consolidation for T2 (Olivers & Meeter, 2008). There are many conflicting theories to explain the AB. Bottleneck theories suggest access to working memory is disrupted (Chun & Potter, 1995), while, what refer to as the disrupted-engagement account suggests disruption occurs earlier in the attentional process either from attentional suppression (Raymond et al., 1992) or slowed attention (Olivers & Meeter, 2008). Regardless, these theories converge regarding attentional allocation as the limiting factor. In particular, the AB has been linked to disruptions in the ability to sustain attention over time. In support of this, studies examining the effects of mindfulness meditation on AB performance have shown that increased mindfulness is associated with improved T2 detection and a decrease in AB magnitude, an effect attributed to enhanced sustained attentional capacity (MacLean et al., 2010; van Leeuwen et al., 2009). Together, this evidence supports the interpretation of AB performance as a reflection of sustained attentional engagement, making the task well suited for the present investigation.

Older participants perform significantly worse than younger participants on the AB task (Lahar et al., 2001; van Leeuwen et al., 2009) reflecting a larger AB magnitude (or an increased time window in which the AB occurs) than younger participants. This larger AB window suggested attentional engagement is disrupted for longer in older compared to younger participants. van Leeuwen et al. (2009) suggested this detrimental effect of age on attention is caused by decreased ability to sustain attention due to the altered PFC activation, which accompanies aging (Chao & Knight, 1997). A network that includes the PFC is responsible for processing sustained attention (Eck et al., 2020; Rosenberg et al., 2016). Indeed, activity in the lateral frontal cortex (Kranczioch et al., 2005; Marois et al., 2000) is associated with AB task performance, and as mentioned earlier the PFC is susceptible to allostatic load. Given the detrimental effects of cortisol on the PFC and the stress-age interaction described above, cumulative stress exposure may similarly moderate the age effect reported for the AB by cumulatively damaging this attentional network and disrupting sustained attention. An alternative (or complementary) explanation for the robust effect of age is that during the aging process older persons switch from specific to generalized processing as cognitive load increases (Li et al., 2013; Smith et al., 2001), sacrificing processing speed for processing accuracy. Given the rapid nature of the AB task (i.e., 100 ms per stimulus) this generalization of cognitive processing may account for poorer AB task performance in older participants and is an important factor to consider. The AB magnitude is calculated by subtracting experimental trials (i.e., trails where T2 appears at or within 300 ms of T1) from baseline trials (i.e., when T2 appears 800 ms after T1). In this way, we can control for individual differences and control for the robust effect of age on AB task performance and focus on the external effects, in this case cumulative life stress, in an attempt to measure the cumulative stress-age interaction effect on attention. This all makes the AB task particularly well-suited for examining the effects of cumulative stress and aging on attention per se.

Despite extensive evidence for age-related changes in attentional blink performance, little is known about how cumulative lifetime stress shapes age-related differences in attention. Furthermore, prior work examining stress and aging has focused primarily on memory and inhibitory control, leaving attentional processes relatively underexplored. The present study addresses these gaps by examining whether cumulative lifetime stress moderates age-related differences in attentional blink magnitude. By demonstrating a robust stress-age interaction in attentional performance, this work would extend existing stress-aging frameworks to the domain of sustained attention.

The aim of the present study was to test whether lifetime stress exposure interacts with aging to impair attentional function. To investigate this, participants completed an AB task, with a combination of aversive and neutral target words (in both T1 and T2 positions) and provided cumulative life stress scores. In line with previous work, we hypothesized worse performance for older participants even though the calculation of the AB magnitude accounts for this, because age has such a strong effect on AB performance in general. Crucially, though, we expect this effect of age to be moderated by cumulative life stress such that older high-stress participants would perform worse than younger participants and their older low-stress counterparts as this pattern of results was reported for previous cognitive tasks such as memory (Marshall et al., 2015) and inhibition (Marshall et al., 2016a).

Methods

Transparency and openness

The present study was not preregistered. The data and task stimuli (additionally see appendices) are all publicly available on the Open Science Framework (https://osf.io/aev6k/?view_only=e59bb2a663a94f548e65e2e8e49045d9). All figures were created in R using the tidyverse (Version 1.2.1; Wickham, 2017). Data cleaning was conducted in IBM SPSS Statistics (Version 28) and Microsoft Excel. Descriptive statistics were analyzed in IBM SPSS Statistics (Version 28). We report how we determined our sample sizes, all data exclusions, all manipulations, all measures, as well as all analyses throughout the present study.

Participants and design

We recruited 146 participants who completed both the questionnaires and AB task. Of these, 133 were analyzed. One participant was removed for failing Cook's (1977) and Leverage's (Belsley et al., 2005) distance checks; a further four entered the incorrect ID number when starting the AB task and could not be matched to their questionnaire; finally, 8 participants had an overall T1 accuracy score lower than 25% (chance performance per trial is 25%) and so were excluded. Overall, mean T1 accuracy was 84% (SD = 18.65). Participants were recruited from the University of Essex (where students complete studies for course credit) and online via social media (nextdoor.com and facebook.com) Colchester, located in the southeast region of the United Kingdom and considered an urban area with a mix of residential, academic, and commercial environments. In line with Marshall and colleagues' approach (Marshall et al., 2015, 2016a, 2016b, 2018), we sought to test at least 30 young adults (18 – 30 years) and 30 older adults (over 60 years old). Foreseeing trouble recruiting older participants[1] we left the posts advertising the study online for two months and allowed all those that were eligible to take part. The young participants (n = 78; females: 81%) mean age was 21.11 (*SD* = 2.94), white (60%; 22% Asian; 13% black) with most achieving an A-level or equivalent qualification or higher (95%). The older participants' (n = 55; females: 56%) mean age was 65.25 (*SD* = 5.55), they were also predominantly white (98%; 2% prefer not to say) with 58% achieving an A-level or equivalent qualification or higher. Overall, participants were 70% women, 76% white (13% Asian and 8% black) with 79% having achieved an A-level qualification or higher. Please see Table 1 for a demographic breakdown of each group (young low-stress, young high-stress, old low-stress and old high-stress).

We used a within participant design, and the study was completed online. The questionnaire was completed first on Qualtrics (2021) and the AB task was then completed on

Table 1. Socio-demographic information per experimental group (younger low stress [YLS], younger high stress [YHS], older low stress [OLS], older high stress [OHS]).

	Gender	Age	Ethnicity	Education
YLS n = 39	28 Female 10 Male 1 Other	20 (2.54)	19 White 11 Asian (British/Other) 6 Black (British/Other) 2 Other 1 Prefer not to say	2 GCSE 24 A-level 11 Bachelor's 1 Master's 1 Other
YHS n = 39	35 Female 4 Male	21 (3.29)	28 White 6 Asian (British/Other) 4 Black (British/Other) 1 Other	2 GCSE 25 A-level 7 Bachelor's 5 Master's
OLS n = 28	14 Female 14 Male	62 (3.71)	28 White	16 GCSE 9 A-level 1 Bachelor's 1 Master's 1 Other
OHS n = 27	10 Female 17 Male	67 (6.08)	26 White 1 Prefer not to say	2 no qualifications 8 GCSE 4 A-level 3 Bachelor's 1 Master's 1 Doctoral 2 Other

Inquisit 5 (Millisecond Software, 2016). The dependent variable is attentional performance represented by the blink magnitude (see below for calculation). The independent (predictor) variables were cumulative life stress and age. Finally, we controlled for perceived stress, gender, state distress and AB stimulus valence. Although valence was not a primary variable of interest, the inclusion of aversive stimuli served to increase the ecological validity of the AB task. Real-world attentional demands often involve emotionally salient information, and prior research suggests that such stimuli can modulate attentional dynamics (Kan et al., 2019, 2021; Schwabe & Wolf, 2010). Including valenced targets ensured that the task captured a wider range of attentional responses, while controlling for valence statistically allowed us to isolate the effects of age and cumulative stress. The University of Essex, Ethics Sub Committee 3 (ETH2122-0852), granted ethical approval. Data collection occurred between June and November 2021.

Materials

Questionnaires

Questionnaires were used to ascertain the cumulative life stress of participants, their perceived stress and state distress.

We were interested in the detrimental effects of accumulated lifetime stress on attentional performance but as noted by Marshall et al. (2015), older participants are more likely to have encountered more stressful events as a natural consequence of being alive longer than younger participants have. Furthermore, the nature of these stressors likely differs between the two age groups. To ensure an accurate assessment of cumulative life stress exposure for each group, age-appropriate items are necessary, especially to make the argument that long-term cumulative stress is associated with cognitive decline and not high amounts of acute stress. For this reason, we captured cumulative life stress using two respective scales for younger and older participants. The Life Event Scale for Students (LESS: Clements & Turpin, 1996) and the Social Readjustment Social Scale (SRSS: Holmes & Rahe, 1967). Due to their analogous nature, they have been used in conjunction previously with robust results (Marshall & Cooper, 2017; Marshall et al., 2015, 2016a, 2016b, 2018). Scores from both are standardized before analysis to allow for comparison. It is not always best practice to equate scores from distinct questionnaires, but it is unavoidable in this case as older participants have inevitably experienced more life stress than younger participants.

Each scale contains a set of weighted statements representing an empirically derived list of life events (e.g., "The death of a spouse" or "The death of a parent"). Participants indicate if they have experienced any of the life events over their lifetime. A cumulative stress score is calculated by summing the weights of all events the participants indicated they experienced. The frequency of each event is not taken into account as this does not increase the predictive power of either questionnaire (Wilker et al., 2015). The SRSS comprises 43 items (total scores range from 0 to 1466), while the LESS comprises 36 (total scores range from 0 to 1849).

We used the Perceived Stress Scale-10 (PSS-10; Cohen et al., 1983) to capture participant stress tolerance and control for the subjective feeling of stress. Arguably, if there is an effect of cumulative stress and age regardless of perceived stress then the effect may be more objective than subjective in nature because the effect is thought to be due to the structural changes to the brain caused by cumulative stress (Marshal *et al.*, 2016a; Sapolsky et al., 1990). The PSS asks participants to rate their dis/agreement to various statements (e.g., "In the last month, how often have you felt nervous and 'stressed?'") on a 4-point Likert scale ranging from 1 ("Never") to 4 ("Very often"). The 10-item PSS has the highest validity and reliability and was the version used here (Lee, 2012) and had high internal consistency here (α = .88). Scores from items are added together (items 4, 5, 7 and 8 are reversed scored). Higher scores indicate more stressful appraisals than a lower score (total score range: 10 – 40).

To further control for acute distress, we used the State half of the State/Trait Anxiety Scale (STAI-S; Spielberger, *et al*., 1971). As acute distress may increase bottom-up attentional focus toward negative stimuli and decrease top-down control (Arnell et al., 2007; Most, *et al*., 2007; for an overview see McHugo, *et al*., 2013). The STAI-S comprises a 20-item questionnaire. Participants rate their (dis)agreement to a presented statement (e.g., "I feel calm" or "I feel nervous") on a 4-point Likert scale ranging from 1 ("Not at all") to 4 ("Very much"). Higher scores indicate higher levels of trait anxiety (total score range for each: 20– 80). The STAI has been validated for university students (Thomas & Cassady, 2021) and had high internal consistency here (α = .90). Scores from items are added together (items 5, 7, 9, 11, 13, 14, 19 and 20 are reversed scored). Higher scores indicate more stressful appraisals than a lower score (total score range: 20 – 80).

Attentional blink task

Eighteen items were presented in a rapid serial visual presentation (RSVP) stream, whereby T1 could appear as item 5 or item 8 and T2 was either 3 or 8 items later (lag 3 (300 ms) and lag 8 (800 ms) respectively. Referring to Figure 1, items were presented for 100 ms; therefore, a stream lasted 1.8 seconds. Words were in Arial font, set to be 10% of the screen height to account for varying screen sizes. Similar to Schwabe and Wolf (2010), target words were in red and all distractor words were neutral and in white. All stimuli (words) were centered on a black screen.

After each stream, participants recalled T1, followed by T2 using a multiple-choice question format, consisting of the target word and three distractor (incorrect) words. Target words were length matched and substantially shorter (3 – 4 letters) in length than distractor words (6 – 12 letters) ensuring that targets were forward and backward masked (MacLean & Arnell, 2012; Schwabe & Wolf, 2010). Words were sourced from several previous studies and already validated (Arnell et al., 2007; Bradley, 1999; Schwabe & Wolf, 2010) leading to a total of 36 target words: 18 aversive-target (e.g., "war," "cut"); 18 neutral-target (e.g., "fish," "gel"); and 18 neutral distractor words (a full list is given in supplementary materials).

There were 16 conditions: 2 (T1 position: 3 or 5) ×2 (T2 lag: 3 or 8) ×2 (T1 valence: neutral or aversive) ×2 (T2 valence: neutral or aversive). Participants completed 16 practice trials, one for each condition. After the practice, we presented each condition 18 times totaling 288 trials. We divided each T1/T2 word combination into 4 blocks of 72 trials and presented each of these blocks in random order. Participants were offered a break between each block. After each trial, participants were asked "What was the first red word in the list?" and were presented with a forced choice with 1 correct and 3

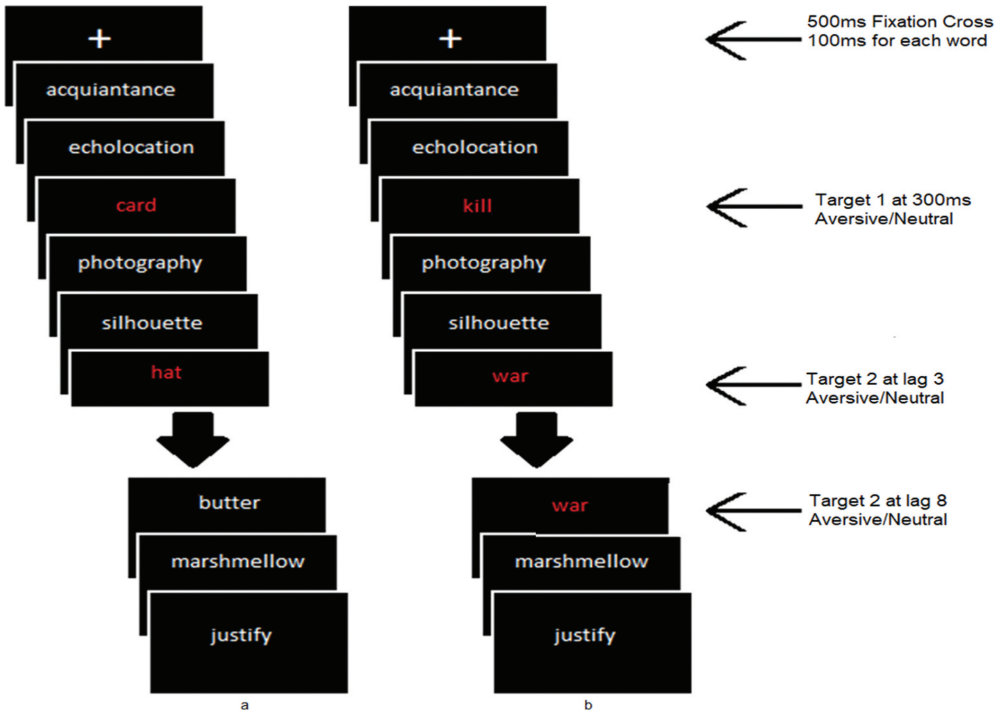

Figure 1. Example of an RSVP stream. Participants are asked to watch the fixation cross for 500 ms. Each word is shown for 100 ms, with T1 appearing at the third (but can appear also appear in the fifth position). T2 could appear either 300 ms, see Figure 1a or 800 ms after T1, see Figure 1b, meaning T2 could appear in position 6, 8, 11 or 13 in the stream.

incorrect options (which were taken from the same pool of words the target word belonged to). Participants responded by selecting their choice using the number keys (1 – 4). Following this, on a new screen, participants were asked, "What was the second red word in the list?" and responded in the same way as before.

We used accuracy rates of T2 at lag 3 and accuracy rates of T2 at lag 8 to calculate the AB magnitude (see below) whereby lag 8 represents baseline performance and lag 3 is the experimental trials. Trials with an incorrect T1 were removed from analysis (otherwise, it is unclear if AB has occurred) and participants with an overall T1 accuracy at chance (25%) or lower accuracy were also removed. Accuracy was calculated from the remaining correct T2 trials. Accuracy was simply the number of correct answers for T2 for each condition. As in previous AB studies, we calculated the magnitude of the AB by subtracting the accuracy of T2 at lag 3 from accuracy of T2 at lag 8 (score range: 0 - 36 for lag 3, lag 8 and magnitude scores for each T1/T2 condition). For the overall magnitude, we subtracted the average T2 accuracy at lag 3 from the average T2 accuracy at lag 8 (score range: 0 – 36). This is to account for general ability to detect targets in an RSVP (Arnell & Stubitz, 2010; MacLean & Arnell, 2012) and to address the speed for accuracy trade off seen in older adults (Draheim et al., 2019). A larger positive AB magnitude indicates worse performance at lag 3 than lag 8, indicating a bigger AB effect. A negative number indicates better performance at lag 3 than at lag 8.

Procedure

After participants read the study information and provided informed consent in the form of a check box, they then completed all questionnaires, starting with sociodemographic, followed by the questionnaires which were presented in random order. Following this, they completed the AB task.

Data preparation and analysis

We used a linear mixed-effect model using the lme4 R package (Bates, 2014) to analyze the overall AB magnitude. Overall, the AB magnitude was the dependent variable in the model while cumulative stress, age and their interaction were fixed effects as the predictors. Age was dummy coded as 1 (participants under 30) and 2 (participants over 60) thereby making age a dichotomous variable and used as such throughout for all analyses. We controlled for perceived stress, acute distress, gender and T1/T2 word combinations as fixed effects. Finally, participants were included as random effects in the model. We used simple slopes to follow-up the interaction effect. We also calculated Bayes factors (BFs) alongside all the analyses described above including any potential slopes analyses using the web version of the "bayesplay" R package (Colling, 2021). BFs can provide evidence for null hypothesis (in this case there is no effect of age, cumulative stress and no stress-age interaction) as well as lend support for the alternative hypotheses (stated above), instead of just failing to reject the null hypothesis as is the case with frequentist statistics (Rouder et al., 2017). We specified the likelihood model (i.e., the actual data) as normally distributed and used the standardized beta coefficients and SEs produced by each model specified above. We used a uniform distribution from 0 to 1 (all possible values for beta coefficients) for the alternative hypothesis and a single point of 0 (representing no association with predictor and out-come variable) for the null hypothesis. We report all the standardized beta coefficient estimates, standard error, *t*-value, *p*-values and confidence intervals (Baayen et al., 2008) as well as the BFs.

Results

Before standardizing the cumulative stress scores, older participants had an average cumulative stress score of 689.87 ($SD = 123.87$) indicating scores in the middle of the total range for the SRSS. Younger participants had an average cumulative stress score of 651.28 ($SD = 277.09$) indicating younger participants had experienced slightly less than the middle of the total range (total stress score could be 1849). For younger participants the average perceived stress score was 26.38 ($SD = 5.58$) while older participants had an average perceived stress score of 20.31 ($SD = 4.51$). For state anxiety younger participants had an average score of 45.88 (11.62) and older participants had an average score of 36.81 (7.69). These scores indicate that overall younger participants perceived more stress and had higher state anxiety than the older participants. See Table 2 for the unstandardized T1, T2 (lag 8), T2 (lag 3) magnitude scores for each age group, stress group and each age by stress group (young low stress, young high stress, old low stress, old high stress) and Table 3 for the overall

Table 2. Mean (standard deviation) for the unstandardized scores at target 1 (288 total), at T2 at lag 8 (144 total), at T2 for lag 3 (144 total) and magnitude scores (T2 lag 8 – T2 lag 3) across age groups (young and old), stress groups (low and high) and for the age by stress groups (younger low stress [YLS], younger high stress [YHS], older low stress [OLS], older high stress [OHS]).

	T1	T2 (lag 8)	T2 (lag 3)	Magnitude
Younger n = 78	259.56 (44.26)	132.53 (19.85)	116.06 (25.44)	16.46 (15.81)
Older n = 55	218.32 (56.84)	124.38 (19.71)	98.76 (21.09)	25.61 (19.79)
Low Stress n = 67	236.99 (51.38)	128.04 (18.07)	110.31 (24.49)	17.73 (15.59)
High Stress n = 66	248.12 (55.71)	130.28 (22.08)	107.48 (25.91)	22.81 (20.07)
YLS n = 39	260.11 (42.14)	133.05 (16.58)	117.82 (23.49)	15.233 (14.22)
YHS n = 39	259.03 (46.83)	132.01 (22.86)	114.31 (27.44)	17.69 (17.35)
OLS n = 28	204.79 (45.92)	121.07 (19.69)	99.86 (22.29)	21.21 (16.98)
OHS n = 27	232.37 (64.17)	127.81 (21.08)	97.63 (20.18)	30.18 (21.71)

Table 3. Mean (standard deviation) for the AB magnitude, cumulative stress, state anxiety and perceived stress for each age group (younger and older), for each stress group (low and high stress) and for the age by stress groups (younger low stress [YLS], younger high stress [YHS], older low stress [OLS], older high stress [OHS]). Performance scores are standardized so 0 is the average (1 is 1 SD). Negative scores indicate better performance and positive scores indicate worse performance for AB task.

		Overall AB Magnitude	Cumulative Stress	State Anxiety	Perceived Stress
Age	Younger n = 78	−.147 (.84)	.065 (1.04)	.347 (1.03)	.421 (.94)
	Older n = 55	.208 (1.16)	−.092 (.94)	−.492 (.71)	−.598 (.76)
Stress Groups	Low Stress n = 67	−.158 (.81)	−.733 (.36)	−.227 (.69)	−.199 (.81)
	High Stress n = 66	.161 (1.15)	.744 (.88)	.231 (1.19)	.201 (1.13)
Age by Stress	YLS n = 39	−.217 (.76)	−.753 (.39)	−.007 (.79)	.086 (.91)
	YHS n = 39	−.076 (.92)	.883 (.82)	.701 (1.12)	.757 (.85)
	OLS n = 28	−.076 (87)	−.705 (.31)	−.533 (.37)	−.596 (.41)
	OHS n = 27	.503 (1.36)	.543 (.95)	−.451 (.95)	−.599 (1.01)

descriptive statistics for standardized magnitude scores and various stress scores for each group described above.

Manipulation check

To test whether the AB was successfully manipulated, a paired samples t-test was conducted between accuracy rates of T2 at a latency of 800 ms (lag 8; $M = 28.14$, $SD = 8.89$) and a latency of 300 ms (lag 3; $M = 23.49$, $SD = 8.74$) and found to be significant $t(132) = 11.09$, $p < .001$, $d = 1.03$.

Overall magnitude

Linear mixed-effects model for overall AB magnitude

The main predictors of AB magnitude, cumulative stress, age and their interaction were input as fixed effects. The control variables (perceived stress, acute distress (state anxiety) and gender) and the individual T1/T2 word combinations were also input as fixed effects. Individual participants were included as random effects. All variables were standardized prior to analyses so that beta coefficients could be accurately interpreted and along with SE, the BF, the *t*-value, *p*-value and confidence intervals are displayed in Table 4. There was a main effect of age, where increases in age were associated with decreased performance and an effect of cumulative stress where an increase in cumulative stress was associated with a decrease in performance. BF provides moderate support for age and very strong support for cumulative stress. There was no association between perceived stress, state anxiety (a stand in for acute distress), gender or T1/T2 word combination on performance and BFs provide moderate to strong evidence for the null for all four factors. Importantly, the mixed model showed an interaction effect between cumulative stress and age with BFs providing extreme evidence for this finding. Follow-up simple slopes analyses revealed no effect of cumulative stress on young participants ($\beta = .025$, SE = .086, $t = .30$, $p = .765$, 97.5 CI [−.14, .19]), with the Bayesian test providing moderate support for the null ($BF_{10} = .14$). There was an effect of cumulative stress on older participants ($\beta = .521$, SE =.111 t =4.69, $p < .001$, 97.5 CI [.31, .74]), with BFs provided extreme evidence for this finding ($BF_{10} > 100$). There was a similar pattern for age at different levels of cumulative stress.

There was no effect of age when cumulative stress was low ($\beta = -.031$, SE = .100 t = .31, $p = .762$, 97.5 CI [−.23, .17]) with BFs providing moderate evidence for the null ($BF_{10} = .1$). There was an effect of age when cumulative stress was high ($\beta = .459$, SE =.106 t =4.31, $p < .001$, 97.5 CI [.25, .67]) with BFs providing extreme evidence for this finding ($BF_{10} > 100$). These results indicate that older high cumulative stress participants performed worse than younger participants and their older low cumulative stress counterparts did (see Figure 2). Overall, we report evidence that older high cumulative stress participants perform worse than younger participants perform and worse than older low cumulative stress participants did, supporting our main

Table 4. Results of mixed-effects model for predicting overall attentional blink magnitude. T1/T2 word combinations are displayed as NN (T1 neutral, T2 neutral), NE (T1 neutral, T2 aversive), NN (T1 aversive, T2 neutral), NN (T1 aversive, T2 aversive).

	β	SE	*t*-value	*p*-value	BF_{10}	97.5 CI
Age	**.212**	**.079**	**2.72**	**.007**	**7.23**	**.06; .36**
Cumulative Stress	**.229**	**.071**	**3.25**	**.001**	**32.29**	**.09; .36**
Age ×Cumulative Stress	**.243**	**.068**	**3.58**	**<.001**	**101.05**	**.11; .37**
Perceived Stress	.015	.111	.14	.893	.16	−.20; .23
State Anxiety	.029	.104	.28	.783	.17	−.17; .23
Gender	.147	.148	.99	.322	.51	−.14; .43
NN	−.042	.104	−.41	.684	.1	−.25; .16
NA	.024	.103	.24	.814	.16	−.18; .22
AN	.117	.103	1.14	.254	.43	−.08; .32
AA	−.263	.271	−.97	.331	.18	−.78; .26

Significant main effects and interactions are in bold.

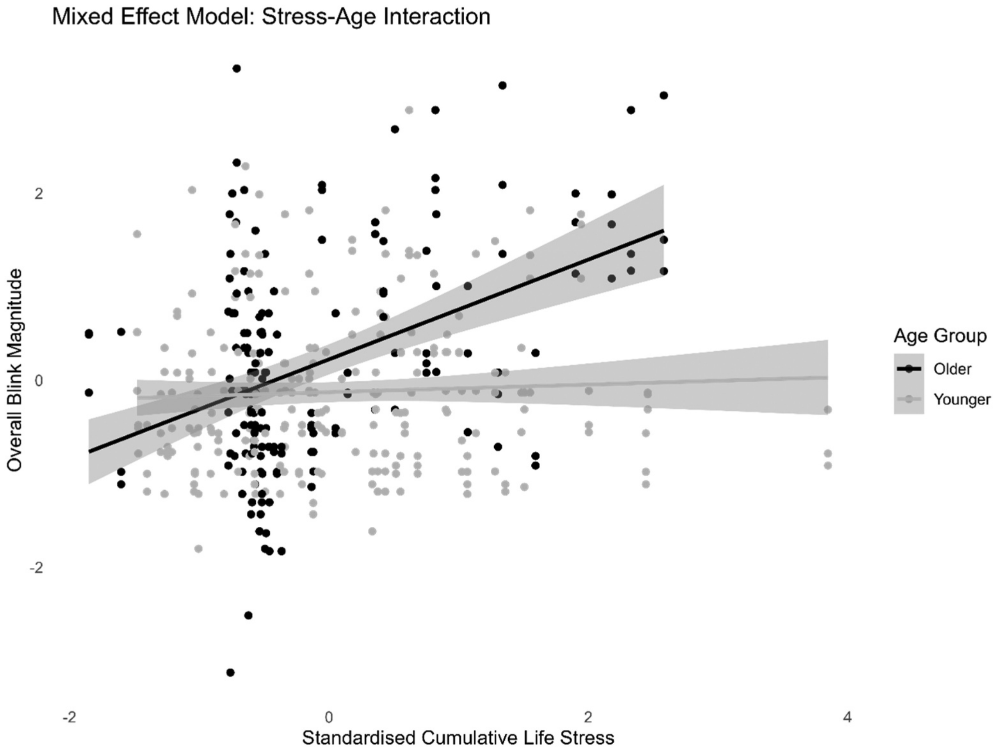

Figure 2. Overall AB magnitude scores (higher scores indicate worse performance). From the linear mixed-effects model.

hypothesis; older participants performed worse than younger participants did and this age effect was moderated by cumulative life-time stress such that older high cumulative stress participants performed the worst.

Discussion

We investigated whether cumulative life stress moderates the effect of age on sustained attention: such that high levels of cumulative life stress would lead to decreased attentional performance for older participants compared to younger participants and older, low-stress participants. We report that overall, older participants performed generally worse than younger participants. In line with predictions, we found this age effect was moderated by lifetime stress exposure. Specifically, older high cumulative stress participants performed worse than older, low cumulative stress participants and younger participants (high or low cumulative stress). This pattern of results is consistent with previous work examining the interaction between cumulative stress and aging across other cognitive domains (memory and inhibitory control) and supports our original hypotheses. To our knowledge, this investigation is the first to report the interaction effect of cumulative stress and age on sustained attentional processing associated with the AB. We therefore extend the literature by reporting the moderating effects of cumulative life stress on age for sustained attention.

The negative effect of age on the AB magnitude is a robust and highly replicable finding (Georgiou-Karistianis et al., 2007; Maciokas & Crognale, 2003; van Leeuwen et al., 2009) and therefore our data overall compliments well-established literature. Age-related deficits in the AB task have been hypothesized to reflect reduced efficiency of attentional engagement (specific vs global processing; Li et al., 2013; Smith et al., 2001) or a decline in sustained attention during rapid cognitive tasks (Chao & Knight, 1997). Notably, this effect was observed even though the AB magnitude was calculated in a way that controls for general performance, highlighting the large impact aging has on attentional processes.

Here we expand on both cognitive aging and the cumulative stress-age literature by providing evidence that age-related deficits in attention are moderated by cumulative life time stress and that therefore the stress-age interaction extends to attention. Older participants with high lifetime cumulative stress showed a larger AB magnitude than their low cumulative stress counterparts, and younger participants with high cumulative stress performed as well as younger low cumulative stress participants. This indicates that the negative effect of cumulative stress takes years to manifest. This pattern of results mirrors findings reported by Marshall and colleagues across other cognitive domains including working memory (Marshall et al., 2015), inhibition (Marshall et al., 2016a), and spatial memory (Marshall et al., 2016b, 2018). Together, these findings suggest that cumulative stress may act as a general factor that exacerbates cognitive decline during aging, rather than producing uniform deficits across the lifespan.

One potential explanation for the changes in PFC functioning that lead to this decrease in efficiency may lie in elevated cortisol exposure across the lifespan caused by higher cumulative stress. Sustained attention and AB performance have been linked to activity within frontal attentional networks (Kranczioch et al., 2005; Marois et al., 2000), and age-related changes in PFC functioning have been previously reported (Chao & Knight, 1997). Chronic stress and elevated cortisol exposure are known to negatively affect the PFC over time (McEwen, 2004; Sotiropoulos et al., 2011), suggesting that cumulative stress may gradually compromise attentional networks, with behavioral consequences becoming apparent in later adulthood. The absence of a cumulative stress effect in younger participants supports the idea that these negative consequences only emerge after prolonged exposure. This is consistent with allostatic load and accelerated cognitive aging.

Here, and reported by Marshall and colleagues, there was no impact of perceived stress or acute distress (as measured by state anxiety) indicating that it is the cumulative effects of a lifetime of stressful events, and not subjective feeling, that contributes to cognitive decline during aging – the consequences of a long-term allostatic state. This dissociation supports theoretical accounts that propose long-term physiological wear and tear (allostatic load) that lead to structural and functional neural changes is a consequence of long-term cumulative stress rather than subjective stress appraisal or acute stress interference (Justice, 2018; Lupien et al., 2009). Arguably, these neurological changes brought about by allostasis seem to contribute to attentional deficits during aging.

Aside from attention, decline in other cognitive domains such as language and sensory processing has also been observed in aging adults (Colsher & Wallace, 1991; Evans et al., 1993; Kausler, 1994; Sweeney et al., 2001). Given the link between attention and these domains, the stress-age interaction may also be a factor in the observed decline, making the detrimental effects of cumulative stress wide reaching. With that said, attention is a multifaceted cognitive domain and here we focused on sustained attention. Future work should examine the stress-age effect on different aspects of attention such as selective attention (e.g., using a Stroop task) or divided attention (e.g., using a dual-task setup) and whether these are linked to other cognitive domains observed to decline during aging.

Constraints on generality

As noted above, one potential issue in this study was the use of two separate cumulative stress measures for young and older participants, and particularly the use of the SRSS. For the SRSS, the weights of each item were standardized across an adult sample ranging 18 years and older. However, this does not take into account whether the items are normative or not. For example, while all the items are stressful, some are normal at certain points in life and can be expected. This could mean that for different age groups the weights should naturally differ, but they do not in the SRSS. In this study, we are not so much interested in the relative amount of stress each item produces; we were interested in the cumulative effects of experiencing more or less stressful life events. Importantly, this approach has been used before with similar behavioral results (Marshall & Cooper, 2017; Marshall et al., 2015, 2016a, 2016b, 2018), and where the measures were paired with physiological data taken from EEG recordings. Throughout those studies, there was a clear association between the questionnaire responses and the EEG data. For this reason, their inclusion here is valid especially given the congruence of data between those and this study.

Another two issues pertaining to potential study limitations are related to the sample characteristics. The first is the difference between the younger and the older groups. The younger group was predominantly female, racially diverse and achieved higher education compared to the older group who were a mix of male and female and predominantly white. There is no evidence that education or race effects performance on the AB task, so we do not expect either to factor into this analysis or the subsequent results. There is some evidence for differences in AB task performance between males and females, where one study found an effect of a negative T1 for women (Kan et al., 2019) but not for males (Schwabe & Wolf, 2010). However, here we controlled for both gender and T1/T2 valance and there was no effect. It is therefore unlikely the sample characteristics in each group drove the current results. The seemingly second issue is the overrepresentation of affluent, educated and resilient individuals in older samples suggesting a generalization problem. The potential issue is that not only do these traits intuitively buffer against cognitive decline during aging but also against the effects of cumulative stress per se. However, this potentially increases the importance of our results given that we report the stress-age effect even in this relatively advantaged older sample, especially given that restrictive sampling range attenuates effect sizes (Sackett & Yang, 2000). In a more representative sample that included older people without these buffers, the results may have been more pronounced. However, it is more than likely affluence and education does not make a difference. There is mixed evidence that education, occupation and income buffer against age-related cognitive decline (Carmelli et al., 1997; Colsher & Wallace, 1991; Evans et al., 1993; Hultsch, *et al.*, 1998). In general, older adults are more resilient to stress in general and happier than younger adults (Charles & Piazza, 2009), which has been reported worldwide (Blanchflower, 2021), with little evidence that this is due to different life needs between different groups of people (Buijs et al., 2021). Indeed, factors other than affluence seem to act as larger buffers for cognitive decline and stress. For example, happiness in all ages is associated with social fulfillment (Buijs et al., 2021) and a large social network is associated with a slower rate of cognitive decline (Clarke et al., 2015). Social connectedness also acts as a natural buffer to stress (Roth, 2022). As evidence suggests, social economic status is not associated with the number of close individuals within a social network (Ajrouch et al., 2005) and social fulfillment may be one such buffer. Another factor to consider is physical exercise. One large meta-analysis reported that physical exercise reduced cognitive decline (Law et al., 2020) while another meta-analysis reported that exercise reduces the stress symptoms (Stubbs et al., 2017). It is not only affluence that determines how much one exercises, although it is factor, but other factors that count also include whether one has children, are married (Brown & Roberts, 2011) and levels of self-efficacy and social-support (Cerin & Leslie, 2008). Taken together this suggests factors other than affluence may act as a buffer to the effects of cumulative stress and cognitive decline seen in aging making our results more generalizable than would appear at first glance.

Future work

Having established the stress-age effect on attention, a potentially useful, new line of inquiry would be to test other potential moderators such as a stress mind-set. A stress mind-set is the subjective belief that stress can be either debilitating or enhancing (Crum et al., 2013). Crum et al. (2013) argue that, in certain circumstances, stress can actually improve biological function, even chronic stress and therefore, one's mind-set, while a mental shortcut, can have real world consequences for individual judgments, health and behavior. Crum and colleagues have produced theoretical and experimental evidence that the stress mind-set is an independent influence on the stress response and that it is a meaningful influence (Crum et al., 2013, 2017). Further, evidence suggests a stress-is-enhancing mind-set reduces the development of depression and anxiety in high-stress individuals (Huebschmann & Sheets, 2020) and mitigates the deleterious effects of allostatic load, as well as promoting wellbeing (e.g., in police officers; Keech et al., 2020). Given our findings on how long-term stress affects cognition as we age, it would be useful to explore how differences in stress mind-set may alleviate or exacerbate this process. This could pave the way for future possible interventions to support cognition during aging.

Conclusions

Overall, this study investigated the long-term effects of cumulative stress on attention. We found that older high cumulative stress participants performed worst on the attentional task, whereas older low cumulative stress participants performed as well as younger participants, and younger high-stress participants performed as well as low-stress participants. Taken together, these findings suggest that cognitive deficits commonly attributed to aging may be exacerbated by the cumulative effects of lifetime stress, rather than the aging process itself. We suggest this may be due, amongst other factors, to prolonged exposure to cortisol, which slowly produces wear and tear on the body that manifest as cognitive decline during advanced aging. As such, this study builds on similar studies that previously investigated the effects of cumulative stress and aging on memory and inhibitory control and expands the literature by demonstrating a similar pattern for attention. More broadly these results highlight cumulative lifetime stress as a factor affecting individual differences in cognitive aging, suggesting cognitive decline during aging is not necessarily as inevitable as once believed.

Note

1. 121 older people completed the questionnaires but only 57 completed the AB task. Many elderly participants expressed apprehension or confusion when using Inquisit somewhat justifying this decision. We also planned to recruit from the University of the 3rd Age (u3a). A UK-wide movement that aims to bring people no longer in full-time work together to promote non-formal learning. Marshall and colleagues recruited their older participants from u3a, however due to COVID they did not want to be involved.

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Disclosure statement

No potential conflict of interest was reported by the author(s).

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