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Does older adults' cognition particularly suffer from stress? A systematic review of acute stress effects on cognition in older age

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ABSTRACT

This literature review provides the first comprehensive qualitative and quantitative systematic synthesis of acute laboratory stress effects on older adults' cognition by specifying the direction and magnitude of those effects both overall and for different cognitive processes separately. A systematic literature search was performed, and effect sizes estimated whenever possible. We found meta-analytical evidence that stress has negative effects on older adults' verbal fluency ($g_{adj} = -0.53$, 95 % CI [−2.70, 1.63]), null-to-negative effects on episodic memory ($g_{adj} = -0.26$, 95 % CI [−0.44, −0.08]), null effects on executive functions ($g_{adj} = 0.07$, 95 % CI [−0.31, 0.46]), and enhancing effects on working memory ($g_{adj} = 0.16$, 95 % CI [−0.01, 0.33]). Relating these findings to those in young adults, notable differences emerged for some cognitive functions, such as opposing effects on working memory between age groups. Our review further reveals that stress effects on older adults' memory retention, associative memory, prospective memory, interference control or cognitive flexibility are heavily understudied. We provide a conceptual and methodological framework for future studies in older adults.

1. Introduction

The relationship between stress and aging is complex and appears somewhat paradoxical. It has been argued that stress can either diminish or exacerbate the aging process just as the aging process can worsen or counter the effects of stress (Pardon, 2007). For example, perceived stress is related to subsequent cognitive decline in older adults (Aggarwal et al., 2014; Ihle et al., 2020), yet older adults generally report less perceived stress and related negative affect compared to young adults (Scott et al., 2017; Young et al., 2021).

Stress, like aging, is capable of affecting cognitive functioning and is an important factor to consider for cognitive health given that stress, unlike aging, can be directly targeted and prevented in the long term through interventions (Gamaiunova et al., 2019; Kremen et al., 2012). What is known about the relation of stress and cognition in older age? It has been established that sustained activation of the stress system (i.e., chronic stress) has cumulative negative effects on the brain (Lupien et al., 2018) and cognition (Marshall et al., 2016). However, on a more fundamental level, much less is known about the effects that a single exposure to a stressful situation (i.e., acute stress) has on older adults' cognition.

In experimental research, acute stress is usually induced in the laboratory through validated stress protocols such as the Cold Pressor Test (CPT, Lovallo, 1975), a physical stressor, and the Trier Social Stress Test (TSST, Kirschbaum et al., 1993) a psychological stressor. Of special interest for this review, the TSST consists of three five-minute phases comprising the preparation of an oral speech, the delivery of an oral speech (i.e., simulation of a job interview), and an oral mental arithmetic task (e.g., 1022 - 13 - 13 - …). Importantly, the last two phases take place in front of a panel of two experimenters wearing lab coats and presenting a strictly neutral demeanor towards the participant. The TSST is considered the gold standard for inducing psychological stress and evoking a cortisol stress response in laboratory settings (for detailed reviews, see Allen et al., 2017; Dickerson and Kemeny, 2004; Goodman

Abbreviations: TSST, Trier Social Stress Test; SNS, Sympathetic nervous system; HPA, Hypothalamic–pituitary–adrenal axis; PFC, Prefrontal cortex; WM, Working memory; EF, Executive functions.

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et al., 2017).

Many studies examined either the effects of aging (Cansino et al., 2020; Lehert et al., 2015) or acute stress (mostly in young adults, e.g., Shields et al., 2017, 2016a; Starcke and Brand, 2016) on cognition. Surprisingly, however, considerably less attention has been given to the *combined* effects of stress and aging by testing effects of acute stress on older adults' cognition. It is generally predicted that exposure to acute stress in older adults will exacerbate age-related cognitive impairments (e.g., Crosswell et al., 2021; Luers et al., 2020; Pulopulos et al., 2013). Yet, empirical evidence in support of this hypothesis is scarce (Hidalgo et al., 2019; Pulopulos et al., 2015, 2013). This review aims at systematically summarizing the literature regarding effects of acute stress on older adults' cognition, considering the various types of cognition.

1.1. Acute stress and cognition

The neurobiology of the acute stress response, comprising the sympathetic nervous system (SNS) and the hypothalamic-pituitary-adrenocortical (HPA) activation, has been extensively described and reviewed in the literature (de Kloet et al., 2005; Herman et al., 2003). In short, in a first stress response wave of the SNS ("fight-flight" response) catecholamines are released into the bloodstream (Murison, 2016). In a second, slower, response wave, activation of the HPA results in the release of the glucocorticoid hormone cortisol into the bloodstream (Dedovic et al., 2009). Importantly, cortisol can cross the blood-brain barrier and enter the brain, where it binds to glucocorticoid receptors located in the prefrontal cortex (PFC), the hippocampus, and the amygdala (Lovallo and Buchanan, 2016). These three brain regions are crucial for working memory (WM) and cognitive control (PFC, respectively, D'Esposito and Postle, 2015; Koechlin, 2003), episodic memory (hippocampus; Bird and Burgess, 2008), and processing of novel and/or emotional stimuli (amygdala; Blackford et al., 2010; Sergerie et al., 2008). Moreover, the blood-brain barrier as well as these three brain regions are susceptible to age-related changes, either with or without related cognitive decline (Banks et al., 2021; Fjell et al., 2014; Zanchi et al., 2017). Thus, cortisol acts on the central nervous system affecting cognition and cognitive aging.

How exactly do stress-induced cortisol increases relate to cognition? Results on that question are mixed. For example, Sazma et al. (2019) found that over half of the reviewed studies on post-encoding stress showed a correlation between stress-related increases in cortisol and memory performance in young adults, but this correlation was not confirmed when tested on a meta-analytical level (Shields et al., 2017). The relationship between cortisol levels and cognitive performance is not linear but rather appears to follow an inverted U-shaped function (Lupien and McEwen, 1997). This means that having both too low and too high levels of glucocorticoids (extremes of the inverted U) typically impairs cognitive performance, and that an optimal level of circulating glucocorticoids is required for efficient cognitive function (Herbert et al., 2006; McCullough et al., 2015; Rimmele et al., 2010). In line with that, higher cortisol reactivity to a laboratory stressor has been shown to increase the risk of being diagnosed with Cognitive Impairment with no Dementia five years later in older adults (de Souza-Talarico et al., 2020). However, how cognition is affected *in direct response* to a laboratory stressor in normal aging is yet to be established.

1.2. The role of age in determining stress effects

The present review focuses specifically on the role that age has in the relationship between stress and cognition. Age is crucial when addressing individual differences in cognition in general. Most commonly, healthy older adults show lower performances in cognitive abilities like episodic memory and processing speed compared to young adults (Dumas, 2015; Verhaeghen, 2017; Verhaeghen et al., 1993) while maintaining, or improving, other functions such as world knowledge or wisdom (Grossmann et al., 2010; Park et al., 2002). Given that most of the research addressing stress effects on cognition has been conducted in young adults, the role that age, and its interaction with age-related cognitive decline, remains to be elucidated in the stress-cognition relation.

Nonetheless, age is considered an important factor in determining the direction of acute stress effects on different types of cognition (Hidalgo et al., 2019). In fact, older age and male sex have been identified as the strongest predictors of larger cortisol responses to stress (Miller and Kirschbaum, 2019; Otte et al., 2005). Interestingly, in three meta-analyses, age has been found to moderate stress effects on cortisol, but neither stress effects on memory (Shields et al., 2017), nor executive functions (Shields et al., 2016a), nor decision-making (Starcke and Brand, 2016). However, these meta-analyses only included a total of five studies on older adults, thus greatly limiting power to detect potential age effects.

A more recent (descriptive) review focusing on effects of stress on different memory types and memory phases in young and older people specifically, concluded that acute stress neither seems to affect long-term memory retrieval nor WM in older people (Hidalgo et al., 2019). This is in contrast with results in young adults showing impairing effects of stress on both memory retrieval and WM (see below).

1.3. Underlying mechanisms of stress effects on cognition

It is by now established that, depending on the type of cognition, acute stress can both impair or enhance cognitive performance in young adults (see Shields, 2020). Acute stress exerts differential effects on memory according to the targeted memory phase (Schwabe, 2017). Stress can either enhance or impair encoding, depending on the timing of the stressor and the relevance of the study materials (Shields et al., 2017), and it usually enhances memory consolidation while impairing memory retrieval (Schwabe, 2017). Several theories have been proposed to account for the effects of stress on memory (see in Shields et al., 2017) and the main idea behind these theories is that if stress is experienced shortly after encoding, it will aid in consolidating memory for recent (i.e. stressful) information which enables the organism to effectively encode the experiences made under stress (see "dual-mode" theory by Schwabe et al., 2012).

Furthermore, considering executive functions, acute stress has been found to mostly impair WM via catecholamine modulation of PFC function (Arnsten, 2015, 2009). Although catecholamines do not cross the blood-brain barrier, they can influence the central nervous system indirectly through the vagus nerve (McGaugh and Roozendaal, 2002). Thus, the reported absence of acute stress effects on memory and WM in older adults is rather puzzling (Hidalgo et al., 2019, 2015; Pulopulos et al., 2015) and challenges the assumption that aging might further exacerbate effects of stress on brain and cognition in older adults (de Souza-Talarico et al., 2011; Pardon and Rattray, 2008; Wilson et al., 2011, 2005).

Pulopulos et al. (2013) proposed that age-related changes in the central nervous system, such as reduced density and sensitivity of glucocorticoid receptors in the aging brain (Heffelfinger and Newcomer, 2001), could underlie the apparent decrease in stress-induced cortisol effects on memory retrieval in older people. However, at the current state, alternative explanations involving other age-related changes such as changes in HPA activity or reactivity (Wolf, 2015) or reductions of functional connectivity between the amygdala and the hippocampus (St. Jacques et al., 2009) are just as valid.

Moreover, potential age differences in emotion regulation and/or stress appraisal could also influence the outcome of the stress effects in young and older adults. In gerontology, there is a solid body of literature indicating better emotion regulation and higher emotional well-being in older compared to young adults (see e.g., Carstensen et al., 2011; Luong et al., 2018; Young et al., 2021). Recent research also shows that resilience was positively related to active coping, and that more active coping led to lower cortisol reactivity to a TSST in a sample of healthy

older adults (Zapater-Fajarí et al., 2021). This suggests that coping strategies could explain, at least in part, individual differences in the cortisol response to a psychosocial laboratory stressor in older adults (Kudielka et al., 2009; Zänkert et al., 2018; Zapater-Fajarí et al., 2021).

1.4. Current review's aims

Intending to improve understanding and encourage new research in this field, here we provide a systematic qualitative *and* quantitative synthesis of stress effects on cognitive performance in older adults. In doing so, all cognitive processes that have been investigated in relation to acute stress in older adults will be summarized, therefore critically going beyond the previous review that only focused on memory (Hidalgo et al., 2019). This previous literature review presents an important overview of the last few decades of research on the effects of acute stress on memory encoding, retention, and retrieval considering the moderating effects of sex and age. Yet, this previous review presents with some limitations as, first, it does not seem a systematic review which would require specific criteria for study selection, and only seven studies (out 59 studies considered in their summary) reported data in older adults. Here, we systematically assessed the number of available studies on acute stress and cognition in older adults to foster our understanding of stress effects on cognition in older age. Second, the authors only presented a qualitative integration of the studies reviewed and, to the best of our knowledge, the present study is the first to estimate the magnitude of stress effects on cognition in aging applying a quantitative meta-analytic approach.

Taken together, the research goals of the present review are to (a) identify which cognitive domains have been investigated in older adults in relation to acute stress, as well as the understudied areas of this field; (b) disentangle effects of stress on different cognitive processes in terms of impairing, enhancing or null effects through a qualitative summary of the literature; (c) where possible, conduct quantitative analyses to estimate the magnitude of the effects of stress in older age; (d) provide a starting point for future studies and methodological recommendations to encourage research in this field.

2. Methods

2.1. Search strategy

The present review followed the PRISMA protocol for conducting systematic reviews (Moher et al., 2009). The string of keywords used in electronic databases can be found in the Supplementary material (S1). Variations of keywords belonging to the fields of "stress", "cognitive performance" and "older age" were combined and searched in Web Of Science, PubMed, and PsycINFO databases. Besides, a restriction specific to the title of the studies was applied. The title had to include the word stress AND another age-related word like "older adults" or "ag(e)ing". This search yielded a total of 392 potential publications as of February 4, 2021. No a priori restrictions regarding the year of publication or language of the study were applied. Reference lists from relevant articles were reviewed, as well as the studies that cited selected articles, to detect potential additional studies. Whenever an article had the potential of including an acute stressor, the full-text article was reviewed. Fig. 1 illustrates the review and selection process using the PRISMA flow diagram.

2.2. Inclusion/exclusion criteria

There were four main inclusion criteria for the qualitative synthesis: (i) participants of included studies had a mean age of 60 years or older and were healthy community-dwelling older adults. For clinical studies including patients or pharmacological manipulation, only the values from the control or placebo groups were considered. (ii) To ensure that acute stress, rather than arousal or mood, was manipulated, the stressor had to either be validated for endogenous cortisol elevation (e.g., TSST, Kirschbaum et al., 1993) or to include cortisol measurements demonstrating effective cortisol elevation. Inclusion of parameters such as heart rate activity alone was not sufficient as it is sensitive to the effects of emotional arousal without stress (e.g., Brosschot and Thayer, 2003). Studies using exogenous methods for cortisol elevation (i.e., pharmacological administrations) were excluded. (iii) The selected studies provided a control comparison either within-subject by administering parallel versions of the same cognitive task to the same participants in stressful and non-stressful conditions or between-subject by randomizing participants in a stress versus a control group. (iv) A final major criterion for inclusion was the administration of a cognitive task post-stress induction within temporal proximity to the stressor or control task. Therefore, studies that used a cognitive task both as a stressor and as a cognitive function assessment (e.g., using the Stroop task to induce stress and evaluate performance on Stroop itself) were excluded.

The selection criteria are summarized in Table 1 using the PICO reporting system endorsed by the Cochrane Collaboration (Cochrane Collaboration, 2020). The final selection from the search results has been executed by the first author given that the established inclusion and exclusion criteria were clearly defined in advance. However, whenever a full-text review of an article did not result in a clear verdict, the decision on in- or exclusion was made by mutual agreement of the second and last author.

Beyond study selection for the qualitative reporting, it was decided that sufficient quantitative data on stress effects on the cognitive dimension of interest would be needed to combine effect sizes. Therefore, a minimum of two studies providing means, standard deviations, and sample sizes were required for a given cognitive process to be considered in the meta-analyses. Corresponding authors were contacted to obtain the necessary statistics in case they were not fully reported.

2.3. Study selection

Out of the 397 search results, study inclusion criteria led to the selection of 22 studies (Fig. 1), 19 of which were published in 17 peer-reviewed papers (two papers reported results for two independent studies: Pulopulos et al., 2015; Schmank and James, 2020), and three were unpublished studies from doctoral theses (Lighthall, 2012, Experiment 3; McMullin, 2020; Moreno, 2015, Experiment 1). Twelve[1] independent studies were further selected to be included in the quantitative analyses, while the remaining studies were only reported qualitatively. Five studies were excluded from quantitative analyses because raw data were not available (Lighthall, 2012, Experiment 3; Lupien et al., 1997; McMullin, 2020; Moreno, 2015, Experiment 1; Wolf et al., 1998). Two studies presented results on older adults published in previous articles (Hidalgo et al., 2015, 2014). Two other studies used outcome variables that were not comparable meaning that their effect sizes could not be aggregated. Namely, Lighthall et al. (2013) investigated reinforcement learning, whereas Mather et al. (2009) investigated risky decisions (for a categorization see Starcke and Brand, 2016).

2.4. Analytic strategy

Most studies reported data on more than one outcome (cf. Table 2), or used a pre-post design, with the result that different outcomes and/or assessment points are based on the same participants. Thus, the information for the different effects was not independent and this was accounted for in the analysis (Scammacca et al., 2014): we aggregated non-independent effect sizes in a synthetic within-study effect size and

[1] Originally, 13 studies were selected for quantitative analyses but the sample from Pulopulos et al. (2013) is the same as in Pulopulos et al. (2015, Experiment 2). Data from these two studies were treated as if they were coming from the same study, thus leaving 12 independent studies.

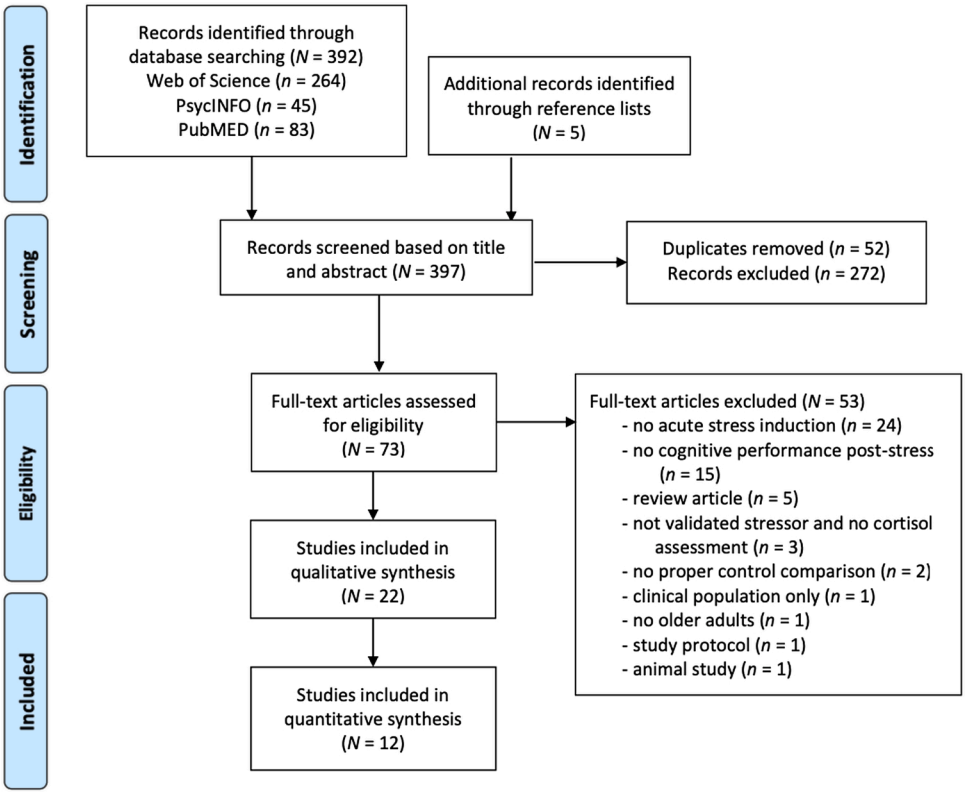


Fig. 1. Selection of studies for inclusion in qualitative and quantitative review using preferred reporting items for systematic reviews and meta-analysis (PRISMA) flow diagram.

Table 1
Selection criteria according to the PICO framework.

PICO element	Description
Population	Healthy older adults with a mean age of at least ≥ 60 years, with no major cognitive impairments
Intervention	Acute laboratory stress induction
Comparison	Control group or pre-post comparison
Outcome	Cognitive performance in any of the major cognitive domains

then summarized the (independent) synthetic effect sizes across studies (Borenstein et al., 2009, chap. 24). We then performed a random-effects model meta-analysis using *Meta-Essentials* (Suurmond et al., 2017) to compute a summary effect for overall cognitive performance across studies, as well as separate analyses for episodic memory, working memory, executive functions (i.e., combining cognitive control, cognitive flexibility, problem-solving and response inhibition), and verbal fluency. Accuracy outcomes were separated from reaction time outcomes and tested separately. In addition, in the cases where cortisol data was available, we also tested for the potential moderating effect of age on the relationship between stress and cortisol (i.e., a weighted linear regression).

To assess the heterogeneity of studies, we used the *Q-statistic* to examine the null hypothesis that all studies estimated the same effect (Borenstein et al., 2009, chap. 16). *Meta-Essentials* provides I^2 to estimate the ratio of true heterogeneity to total observed variation, and Tau^2 (T^2) to estimate between-study variance (Borenstein et al., 2009, chap. 16). Publication bias was examined by means of funnel plots, with Egger regression and trim-and-fill analysis for estimation of the adjusted effect size and missing studies (Borenstein et al., 2009, chap. 30). We also performed a p-curve analysis using the online app http://p-curve.com/ as an alternative tool to investigate potential publication bias and to assess the evidential value of our set of findings (Simonsohn et al., 2014). The p-curve disclosure table is provided in Supplementary Materials S2.

3. Results

3.1. Publication bias

Fig. 2 illustrates the funnel plots for estimating publication bias in the overall study set (Fig. 2A), and on scores of memory (Fig. 2B), working memory (Fig. 2C), executive functions (Fig. 2D), and verbal fluency (Fig. 2E). Since there were no imputed data points (based on the Trim-and-Fill method, see Fig. 2), the funnel plots indicated there was no asymmetry in the distribution of the effect sizes. Egger statistic was not significant for the overall study set (intercept = 0.58, 95 % CI [−1.31, 2.48]; $t = 0.64$, $p = .532$); memory (intercept = 4.00, 95 % CI [−6.04, 14.05]; $t = 1.02$, $p = .364$), working memory (intercept = 2.47, 95 % CI [−2.81, 7.75]; $t = 1.15$, $p = .304$), executive functions (intercept = −0.05, 95 % CI [−3.80, 3.70]; $t = -0.03$, $p = .975$), and verbal fluency (intercept = −0.46, 95 % CI [−1.46, 0.54]; $t = -1.18$, $p = .303$).[2]

Moreover, one can infer whether these findings contain evidential value (i.e., a true effect not biased by selective reporting of studies) by examining p-value distributions, also known as p-curve analysis (Simonsohn et al., 2014). When a set of studies has a right-skewed p-curve (Fig. 3), we infer that the set has evidential value. If the half p-curve test is right-skewed with $p < .05$ or both the half and full test are right-skewed with $p < .1$, then p-curve analysis indicates the presence of evidential value. Here both conditions are met (full p-curve: $Z = -4.49$,

[2] The Egger regression for verbal fluency could not be calculated using the two independent synthetic effect sizes. Thus, the non-aggregated non-independent effect sizes ($n = 6$) of the original studies were used in this analysis. Although the confidence interval was narrower, the resulting adjusted combined effect size ($g_{adj} = 0.54$, 95 % CI [0.23, 0.84]) did not change from the one calculated using the synthetic effect sizes ($g_{adj} = 0.53$, 95 % CI [−1.63, 2.70]).

Table 2
Studies' Characteristics and Qualitative Summary of Stress Effects on Cognition in Older Adults.

Study	Participants (range, mean age)	Country of origin	Study design	Cognitive functions studied	Task(s) used	Stressor	Stress effects on cognition	Cortisol-cognition association	SNS measures
Lupien et al. (1997)	7 M (62–83; *M* = 73.3)	Canada	Within	Memory	Word lists recall	Public speaking task	↓ Stress impaired declarative memory	Cortisol "responders" presented poorer declarative memory pre and post stress vs. "non responders"	NO
	7 F (62–83; *M* = 71.3)			Nondeclarative memory	Word completion task		- No stress effects on nondeclarative memory		
Wolf et al. (1998)	38 M (*M* = 67.5; 59–81)	Germany	Within	Visual-verbal memory	Picture immediate recall	TSST	↓ Stress impaired visual-verbal memory	N.s. trends indicating that cortisol "responders" seemed to be more impaired than "non responders" on verbal memory performance	NO
	37 F (*M* = 67.4; 60–77)			Spatial memory	Mental rotation task		↑ Stress enhanced spatial memory		
				Attention	Selective attention task *d'*		↓ Stress impaired selective attention		
[a]Almela et al. (2011)	16 M (54–72; *M* = 60.5)	Spain	Within	Memory	RAVLT	TSST	- No stress effects on auditory-verbal memory (total learning, delayed recall and recognition)	In women only, cortisol reactivity to the TSST was negatively correlated with memory performance in the stress and control condition. Higher cortisol levels were negatively correlated with the impairing effect observed in trial 6, but were not correlated with the effect observed in trial 1. No significant association was found for men.	NO
	16 F (54–72; *M* = 63.7)						↑ Stress enhanced attention (trial 1) in women ↓ Stress impaired recall after interference (trial 6) in women		
[b,c]Pulopulos et al. (2013)	38 M (56–76; *M* = 64.6)	Spain	Between	Memory (Retrieval)	Picture recall	TSST	- No stress effects on the retrieval phase of visual, auditory, and verbal memory (free recall and recognition)	No significant association found	sAA
	38 F (56–76; *M* = 63.7)				Picture recognition RAVLT Rivermead stories				
[a]Hidalgo et al. (2014)	16 M + 16 F (53–78; *M* = 62.1)	Spain	Within	Memory	RAVLT	TSST	- No stress effects on auditory-verbal memory (total learning, delayed recall, and recognition) in both age groups	No significant association found between recall after interference (trial 6) and cortisol reactivity. However, older adults who had a predominance of sAA response over cortisol response (RAC) had poorer performance on trial 6	sAA
	18 M + 17 F (18–35; *M* = 21.1)						↓ Stress impaired recall after		

(*continued on next page*)

Table 2 (*continued*)

Study	Participants (range, mean age)	Country of origin	Study design	Cognitive functions studied	Task(s) used	Stressor	Stress effects on cognition	Cortisol-cognition association	SNS measures
							interference (trial 6 of RAVLT) in older adults only		
[b]Hidalgo et al. (2015)	27 M + 25 F (56–76)	Spain	Within	Memory (Retrieval)	Picture recall	TSST	- No stress effects in older adults on retrieval phase (free recall + recognition)	Young men's cortisol reactivity to the TSST was negatively correlated with recall of negative pictures	sAA
	26 M + 24 F (18–27)				Picture recognition		↓ Stress impaired free recall of pictures only in young men ↓ Stress impaired recognition of positive pictures in all participants (OA = YA)		
Smith et al. (2019)	15 M + 35 F (58–86; *M* = 71.9)	US	Between	Memory (Encoding)	Picture recall	TSST	- No stress effects on the encoding phase of visual memory, except for omission errors on a cued recall video synopsis	No significant relationship found	Heart rate
Deal et al. (2018)	34 M + F (*M* = 70.1)	US	Within	Memory	Video recall Paragraph recall	TSST	- No stress effects on visual-verbal memory	Cortisol reactivity to the TSST was negatively correlated with memory, but not cognitive control performance	Blood pressure and heart rate
					Word lists recall				
				Cognitive control	Consonant vowel odd even computerized test		- No stress effects on cognitive control		
Murphy et al. (2020)	7 M (61–86; *M* = 71.3)	Canada	Within	Memory	HVLT-R	TSST	↑ Stress enhanced immediate and delayed recall	Cortisol reactivity to the TSST was associated with enhanced immediate recall after the TSST compared to a previous session without TSST	NO
	9 F (61–86; *M* = 79.8)			Associative recognition	Face-name associative recognition test		- No stress effects on retention - No stress effects on associative recognition		
				Working memory	Spatial working memory task		- No stress effects on spatial working memory		
Crosswell et al. (2021)	45 M + F (60–79; *M* = 66)	US	Between	Memory	Wechsler Memory Scale delayed recall	TSST	↓ Stress impaired short-term memory in all participants (OA = YA)	No significant associations between poststressor cognitive scores and baseline cortisol, cortisol reactivity, or cortisol recovery speed	NO
	41 M + F (25–40; *M* = 31)			Cognitive flexibility	Card sorting task		- No stress effects on cognitive flexibility		
				Problem solving	Tower of London task		- No stress effects on problem solving		
Pulopulos et al. (2015, Experiment 1)	30 M + 33 F (55–77; *M* = 63.4)	Spain	Within	Working memory	Digit span forward and backward	TSST	↑ Stress enhanced performance of women only on the Digit-span forward task	Higher cortisol levels after the TSST improved memory span only in older women; however, they did not affect the	NO

(*continued on next page*)

Table 2 (*continued*)

Study	Participants (range, mean age)	Country of origin	Study design	Cognitive functions studied	Task(s) used	Stressor	Stress effects on cognition	Cortisol-cognition association	SNS measures
								executive component of WM in older men or women	
							- No stress effects on the Digit-span bBackward task		
[c]Pulopulos et al. (2015, Experiment 2)	38 M + 38 F (56–76; *M* = 64.3)	Spain	Between	Working memory	Letter-number sequencing	TSST	- No stress effects on Letter number sequencing task	No significant relationship found	sAA
Oei et al. (2018)	53 M + 51 F (55–77; *M* = 66)	Netherlands	Between	Working memory	Emotional Sternberg item-recognition task	TSST	- No stress effects on the emotional distraction task	Association not investigated	Blood pressure and heart rate
Luers et al. (2020)	32 M + 43 F (61–67; *M* = 64.1)	Germany	Within	Working memory	2-Back task	TSST	↑ Stress enhanced both accuracy and reaction time	Cortisol stress responses were negatively linked with accuracy in men. In women, cortisol responses were positively linked with accuracy instead. This relation was evident for accuracy, but not for reaction time	NO
Dierolf et al. (2018)	19 M (*M* = 67.3)	Germany	Between	Inhibition	Go/No-Go	TSST	↑ Stress enhanced response inhibition accuracy in compatible Go/No-Go trials in all participants (OA = YA)	Association not investigated	NO
	30 M (*M* = 24.3)								
Schmank and James (2020, Experiment 1)	25 M + 46 F (63–90; *M* = 72.79)	US	Between	Verbal fluency	Word retrieval task	TSST (modified)	↓ Stress impaired word retrieval measured by increased Tip-of-the-tongue states	Cortisol not investigated	NO
Schmank and James (2020, Experiment 2)	24 M + F (61–80; *M* = 69.13)	US	Between	Verbal fluency	Word retrieval task	TSST (modified)	↓ Stress impaired word retrieval measured by increased Tip-of-the-tongue states in all age groups	Cortisol not investigated	NO
	24 M + F (30–60; *M* = 40.50)								
	28 M + F (18–29; *M* = 21.71)								
Mather et al. (2009)	21 M + 19 F (65–89)	US	Between	Decision making	Computerized driving game	CPT	↓ Stress impaired risk taking in older adults	Association not investigated	NO
	22 M + 23 F (18–33)						- No stress effects in younger adults		
Moreno, 2015	32 M + F (65–93; *M* = 78.87)	US	Within	Decision making	Cups task	TSST	↓ Stress impaired risk taking (in gain trials only)	*Risk seeking* for advantageous loss trials, "non responders" showed an increase in risk-seeking whereas for disadvantageous gain trials, "responders" showed a decrease in risk-seeking	NO
					Ellsberg task		- No stress effects on decision under ambiguity	*Temporal discounting:* the change in temporal discounting for "responders" was specific to gain trials, and the change in temporal discounting for "nonresponders" was specific to loss trials.	

(*continued on next page*)

Table 2 (*continued*)

Study	Participants (range, mean age)	Country of origin	Study design	Cognitive functions studied	Task(s) used	Stressor	Stress effects on cognition	Cortisol-cognition association	SNS measures
					Intertemporal choice task		↑ Stress enhanced temporal discounting		
Lighthall et al. (2013)	23 M + 25 F (65–85; *M* = 72.58)	US	Between	Decision making	Probabilistic reinforcement-learning task	CPT	↓ Stress impaired sensitivity to recent feedback (OA = YA)	Older adults with greater increases in cortisol from baseline learned better from positive reinforcement	NO
	25 M + 23 F (18–34; *M* = 23.12)						↑ Stress enhanced learning of cues predicting positive outcomes (OA = YA)		
Lighthall et al. (2013, Experiment 3)	24 F (60–74; *M* = 64.4)	US	Between	Decision making	Probabilistic reinforcement-learning task	CPT	↑ Stress enhanced positive cue selection in young adults	Cortisol not investigated	NO
	27 F (18–34; *M* = 23.1)						- No stress effects in older adults		
McMullin, 2020	22 M + 39 F (45–81; *M* = 65.7)	US	Within	Decision making	Economic decision-making task	TSST	- No stress effects on decision making in the face of risk versus ambiguity	No significant relationship found	NO

M: mean; M: male; F: female; YA: Younger Adults; OA: Older Adults; SNS: Sympathetic Nervous System; RAVLT: Rey's Auditory Verbal Learning Test; HVLT-R: Hopkins Verbal Learning Test-Revised; TSST: Trier Social Stress Test; CPT: Cold Pressor Test; sAA: Salivary Alpha-Amylase.

[a] The older sample in Hidalgo et al. (2014) is the same as in Almela et al. (2011).

[b] The older sample in Hidalgo et al. (2015) is the same as in Pulopulos et al. (2013).

[c] The sample in Pulopulos et al. (2015, Experiment 2) is the same as in Pulopulos et al. (2013).

$p < .001$; half p-curve: $Z = -3.46$, $p = .003$) indicating evidential value. Similarly, p-curve analysis indicates that evidential value is inadequate or absent if the 33 % power test is $p < .05$ for the full p-curve or both the half p-curve and binomial 33 % power test are $p < .1$. Here neither condition is met; so p-curve does not indicate evidential value being inadequate or absent. Thus, we can rule out selective reporting as the sole explanation of these findings. Although together these parameters are not suggestive of publication bias, they are not diagnostic of absence of bias in these studies. Further discussion of publication bias is provided in the Limitations section.

3.2. Studies' characteristics

In total, 22 studies were selected for inclusion in the qualitative analysis (Table 2). Three different studies used non-independent samples[3] (Hidalgo et al., 2015, 2014; Pulopulos et al., 2015, Experiment 2), leaving 19 independent studies that investigated the impact of acute stress on cognition in a total of 848 older adults (55 % women). The mean age across all studies for the older age groups was 68.98 years (*SD* = 5.35, mean age range 60.5–79.8). Of note, eight studies included both young and older age groups in their sample: three studies on decision-making (Lighthall, 2012, Experiment 1; Lighthall et al., 2013; Mather et al., 2009), three on memory (Crosswell et al., 2021; Hidalgo et al., 2015, 2014), one on verbal fluency (Schmank and James, 2020, Experiment 2), one on inhibition (Dierolf et al., 2018).

Given the mixed results on the association between cortisol levels and cognitive performance in young adults, we also examined whether the studies included in our review reported correlations between stress-induced cortisol increases and cognitive performances (Table 2). Nineteen out of 22 studies assessed cortisol levels in their samples. Of these 19, 16 measured the relationship between stress-induced cortisol changes and cognitive performance. Nine studies found a significant association between cortisol concentrations and cognitive performance: five reported negative associations (Almela et al., 2011; Deal et al., 2018; Hidalgo et al., 2015; Lupien et al., 1997; Moreno, 2015, Experiment 1), three reported positive associations (Lighthall et al., 2013; Murphy et al., 2020; Pulopulos et al., 2015, Experiment 1), one study reporting both negative and positive associations (Luers et al., 2020). We describe these associations more in detail in relation to different cognition types in the sections below. Furthermore, we tested whether age moderated the effects of stress-induced increases on cortisol. The results of the meta-regression revealed that the effect sizes of stress-induced cortisol did not change according to the mean age (range: 63.4–75.5) of the participants ($B = 0.11$; 95 % CI [−0.12, 0.35]; $p = .255$; $R^2 = 2.75$ %).[4]

3.3. Overall cognitive performance

The cognitive domains that have been investigated are (by frequency) episodic memory, working memory, decision-making (i.e., risk-taking, temporal discounting, reinforcement learning), executive functions (i.e., cognitive control, cognitive flexibility, problem-solving, and response inhibition), and verbal fluency. The TSST (Kirschbaum et al., 1993) was the preferred stress induction method with 81 % of studies using this stressor. Of note, only 31 % of studies included some form of SNS activity assessment (heart rate/salivary alpha-amylase).

[3] Hidalgo et al. (2014, 2015) added a sample of young participants *a posteriori* to directly compare their performance with that of older adults coming from previously published studies from the same research group (Almela et al., 2011; Pulopulos et al., 2013). Thus, the older age sample in Hidalgo et al. (2014) and Almela et al. (2011), as well as in Hidalgo et al. (2015), and Pulopulos et al. (2013) respectively, are not independent. Only data coming from the original studies were included for the quantitative analyses.

[4] We also ran this analysis without an outlier effect size (Lighthall et al., 2013). Although the explained variance (R^2) increased, it did not affect the results of the meta-regression ($B = -0.07$; 95 % CI [−0.24, 0.11]; $p = .353$; $R^2 = 8.96$ %).

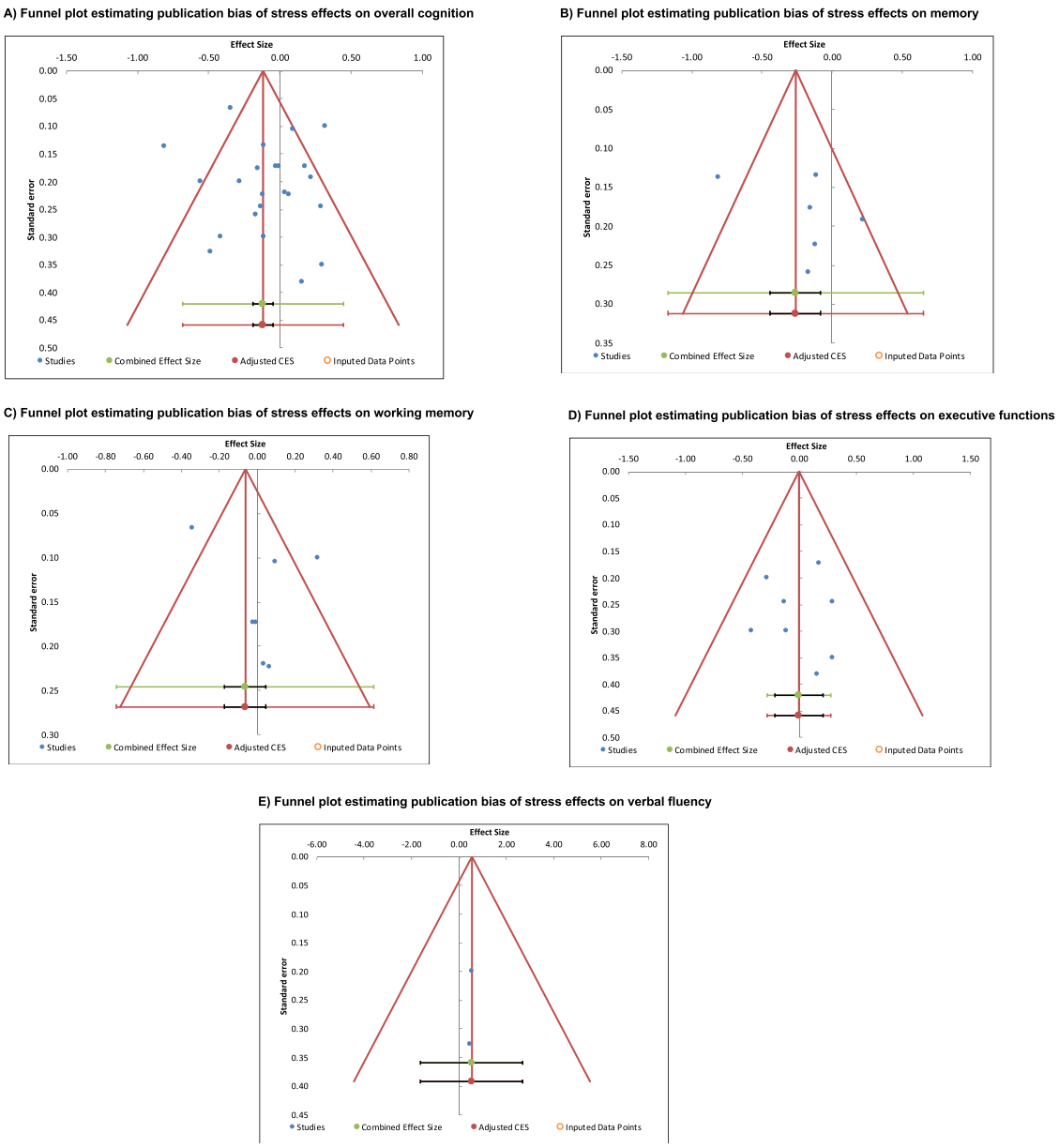


Fig. 2. Funnel plots estimating publication bias of stress effects on cognition in the overall study set (A), and on scores concerning memory (B), working memory (C), executive functions (D), and verbal fluency (E) in older adults. Asymmetry of points around the line by the standard error and presence of imputed data points (orange circles with no fill color) indicate evidence for publication bias. All related *p*s are > .05 indicating no funnel plot asymmetry. Together, these parameters are not suggestive of publication bias.

Fig. 4 represents the quantitative summary illustrating the combined effect sizes of stress effects on accuracy of episodic memory, working memory, executive functions, and verbal fluency in 12 selected studies on a total of 629 observations. For accuracy, a total of 45 effect sizes were aggregated into 17 synthetic effect sizes, while for reaction times 10 effect sizes were aggregated in six synthetic effect sizes (each study contributed on average 4.58 effect sizes).[5]

For overall accuracy of cognitive performance, we found a nonsignificant combined effect size of $g = 0.03$ (95 % CI [−0.14, 0.19]; $z = 0.32$; two-tailed $p = .746$), with a significant Cochrane's *Q*-test of Heterogeneity ($Q = 61.20$, $p_Q < .001$), $I^2 = 73.86$ % and $T^2 = 0.09$. This indicated that there was a high probability of heterogeneity between studies and that interpretation should not be based on the combined effect size but rather on the prediction interval (95 % PI [−0.62, 0.67]). The high I^2 value also suggested that this effect was likely to differ as a function of moderators and that a subgroup analysis might be worthwhile (Hak et al., 2016). Thus, we proceeded to investigate stress effects on memory, working memory, executive functions, and verbal fluency separately.

3.4. Memory

Ten studies (of which eight independent studies) investigated stress effects on memory in older adults (see Table 2). The qualitative results

[5] In addition, as robustness test, we also applied the approach of treating all 45 accuracy effect sizes as independent estimates in a random-effects model in *Meta-Essentials*. For overall cognitive performance we found a nonsignificant combined effect size of $g = -0.05$ (95 % CI [−0.16 0.07]; $z = -0.83$; two-tailed $p = .409$), with a significant Cochrane's *Q*-test of Heterogeneity ($Q = 158.55$, $p_Q < .001$), I^2 value of 72.25 % and T^2 of 0.11. Thus, this alternative approach provided a similar null combined effect size, similar 95 % CIs, higher Cochrane's *Q*, and similar I^2 and T^2 values.

were mixed: acute stress enhanced recall (Murphy et al., 2020) and spatial memory recall (Wolf et al., 1998), and in the rest of the reported outcomes it either impaired (30 %) or did not affect memory performance (54 %) in older adults. Impairing effects of stress have been found for word lists recall (Lupien et al., 1997), picture recall (Wolf et al., 1998) and recognition (Hidalgo et al., 2015), short story recall (Crosswell et al., 2021), and in the retroactive interference trial (Almela et al., 2011) of the Rey's Auditory Verbal Learning Test (RAVLT; Bean, 2011). The RAVLT consists of five repetitions of free-recall of a List A followed by one repetition of free-recall of a second "interference" list (List B). Subsequently, the participant is then immediately asked to recall the words from List A again, which is the retroactive interference trial (also called recall after interference). The remaining studies revealed that acute laboratory stress did not affect older people's memory performance. Lupien et al. (1997) was the only study to have examined non-declarative memory in older adults, finding no effects of stress. It is important to note, however, that few studies had properly separated between stress effects on retrieval (Pulopulos et al., 2013) and encoding (Smith et al., 2019), and no study has yet looked at stress effects on retention (i.e., consolidation) in isolation from other memory phases in older adults.

Regarding the cortisol-memory association, four studies reported a negative association where higher cortisol levels were related to a decrease in memory performance (Almela et al., 2011; Deal et al., 2018; Hidalgo et al., 2015; Lupien et al., 1997). Likewise, two other studies reported that cortisol "responders" tended to show poorer memory performance than "non responders" (Lupien et al., 1997; Wolf et al., 1998). However, this association is not robust across studies. For instance, Almela et al. (2011) found it to be the case only among older women, whereas Hidalgo et al. (2015) observed it only in young men and not in older adults. On the contrary, one study found a positive association between cortisol and immediate and delayed recall (Murphy et al., 2020). More specifically, cortisol reactivity to the TSST was associated with enhanced immediate recall after the TSST compared to a previous session without TSST in healthy older adults (Murphy et al., 2020). Moreover, three studies did not find any association between memory performance and cortisol (Crosswell et al., 2021; Pulopulos et al., 2013; Smith et al., 2019).

The estimated effect sizes for six of the studies on memory performance are illustrated in Fig. 4A and Hedges' g varied from −0.81(Deal et al., 2018)[6] to 0.22 (Murphy et al., 2020), reflecting the mixed pattern of results observed in the qualitative summary. We found a nonsignificant combined effect size of $g = -0.20$ (95 % CI [−0.57, 0.16]; $z = -1.41$; two-tailed $p = .158$; $g_{adj} = -0.26$ (95 % CI [-0.44, -0.08])), with a significant Cochrane's Q-test of Heterogeneity ($Q = 24.43$, $p_Q < .001$), $I^2 = 79.53$ % and $T^2 = 0.12$. This indicated that there was a high probability of heterogeneity between studies and that interpretation shouldn't be based on the combined effect size but rather on the prediction interval (95 % PI [−1.17, 0.76]).

3.5. Working memory

Five studies investigated stress effects on working memory in older adults (see Table 2). Acute stress enhanced working memory in two studies (Luers et al., 2020; Pulopulos et al., 2015, Experiment 1) but neither affected working memory nor spatial working memory in the remaining studies (Murphy et al., 2020; Oei et al., 2006; Pulopulos et al., 2015, Experiment 2). In particular, stress enhanced both accuracy and reaction time in a 2-back task (Luers et al., 2020) and enhanced performance in a Digit-Span Forward (Pulopulos et al., 2015, Experiment 1).

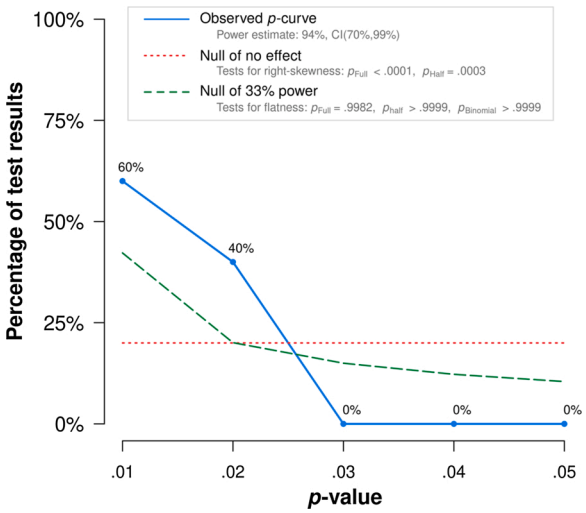


Fig. 3. P-curve of the studies included in the quantitative analyses.
Note: The observed p-curve includes 5 statistically significant ($p < .05$) results, of which 5 are $p < .025$. There were 7 additional results entered but excluded from p-curve because they were $p > .05$.

Moreover, both studies found significant positive cortisol-WM associations. Higher cortisol levels after the TSST were related to improved memory span (i.e., Digit-Span Forward) in older women, but not to the executive component of WM tasks (i.e., Digit-Span Backward and Letter Number Sequencing; Pulopulos et al., 2015). In addition, Luers et al. (2020) have showed stress-related working memory alterations in a sex-specific manner. More precisely, higher cortisol responses led to a decline in working memory performance in older men whereas the opposite was evident for older women, who appeared to benefit from higher stress responses. However, this relationship with cortisol was evident for accuracy scores only, and not for reaction times.

Finally, stress did not affect performance in a Digit Span Backward task (Pulopulos et al., 2015, Experiment 1), a Letter Number Sequencing task (Pulopulos et al., 2015, Experiment 2), an emotional distraction task (Oei et al., 2018), and a spatial working memory task (Murphy et al., 2020).

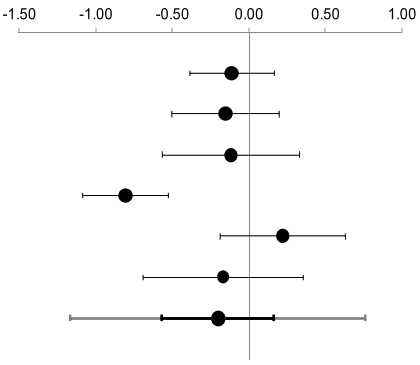
Regarding working memory's accuracy, the estimated effect sizes for these studies are illustrated in Fig. 4B and Hedges' g ranged from −0.01 (Oei et al., 2018) to 0.32 (Luers et al., 2020), reflecting a positive-to-null pattern of results. We found a significant combined effect size of $g = 0.16$ (95 % CI [−0.02, 0.34]; $z = 2.51$; two-tailed $p = .012$; $g_{adj} = 0.16$ (95 % CI [−0.01, 0.33])), with a nonsignificant Cochrane's Q-test of Heterogeneity ($Q = 4.25$, $p_Q = .373$), $I^2 = 5.92$ % and $T^2 < 0.01$. This indicated that there was low probability of heterogeneity between the studies and that interpretation can be based on the combined effect size and its CI.

Regarding reaction times for the emotional distraction task (Oei et al., 2018) and the 2-back task (Luers et al., 2020), we found a nonsignificant combined effect size $g = -0.22$ (95 % CI [−2.19, 1.75]; $z = -1.42$; two-tailed $p = .156$; $g_{adj} = -0.30$ (95 % CI [−1.09, 0.50])), with an approaching significance Cochrane's Q-test of Heterogeneity ($Q = 2.97$, $p_Q = .085$), $I^2 = 66.31$ % and $T^2 = 0.03$. This indicated that there was a relatively high probability of heterogeneity between the studies and that interpretation shouldn't be based on the combined effect size but rather on the prediction interval (95 % PI [−0.70, 0.39]). The high I^2 value also suggested that this effect was likely to differ as a function of moderators (Hak et al., 2016), however, more studies are needed to test this hypothesis.

[6] Of note, the combined effect size for stress effects on memory seemed to be driven by the study of Deal et al. (2018). Without this study, the combined effect size of stress on memory dropped to g = -0.07 (95 % CI [−0.26, −0.13]; z = −0.95; two-tailed p = .341), with a nonsignificant Cochrane's Q-test of Heterogeneity (Q = 2.80, $p_Q = .593$), $I^2 < 0.01$ % and $T^2 < 0.01$. Possible explanations are provided in the discussion.

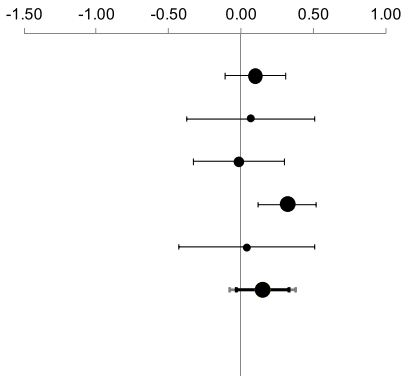
A) Effects of stress on memory

Study name	Hedges' *g*	CI Lower limit	CI Upper limit	Weight
Almela (2011)	-0.11	-0.39	0.17	18.72%
Pulopulos (2013)	-0.15	-0.50	0.20	17.11%
Smith (2018)	-0.12	-0.57	0.33	15.23%
Deal (2018a)	-0.81	-1.09	-0.53	18.65%
Murphy (2020a)	0.22	-0.19	0.63	16.49%
Crosswell (2021c)	-0.17	-0.69	0.36	13.81%
Combined	-0.20	-0.57	0.16	



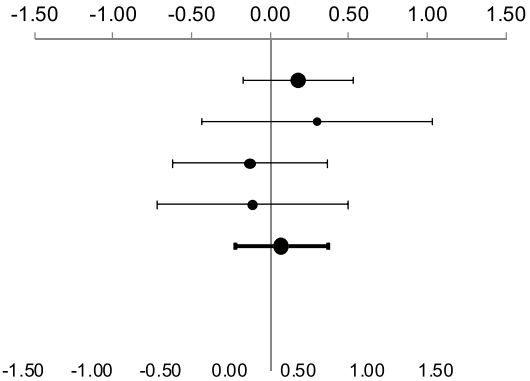
B) Effects of stress on working memory

Study name	Hedges' *g*	CI Lower limit	CI Upper limit	Weight
Pulopulos (2015a)	0.10	-0.11	0.31	32.17%
Pulopulos (2015b)	0.07	-0.38	0.52	8.40%
Oei (2018)	-0.01	-0.33	0.30	15.97%
Luers (2020)	0.32	0.12	0.52	34.78%
Murphy (2020b)	0.04	-0.43	0.51	8.68%
Combined	0.15	-0.03	0.33	



C) Effects of stress on executive functions

Study name	Hedges' *g*	CI Lower limit	CI Upper limit	Weight
Deal (2018b)	0.18	-0.17	0.53	48.16%
Dierolf (2018)	0.30	-0.44	1.04	11.71%
Crosswell (2021a)	-0.13	-0.62	0.37	24.08%
Crosswell (2021b)	-0.11	-0.71	0.49	16.05%
Combined	0.07	-0.23	0.37	



D) Effects of stress on verbal fluency

Study name	**Hedges'*g***	**CI Lower limit**	**CI Upper limit**	**Weight**
Schmank (2020a)	0.55	0.15	0.95	72.73%
Schmank (2020b)	0.48	-0.19	1.16	27.27%
Combined	0.53	0.14	0.93	

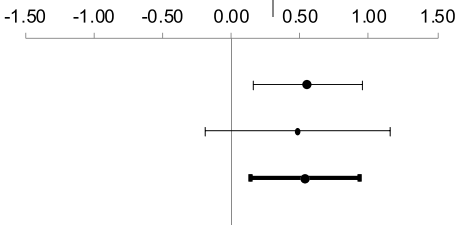


Fig. 4. Effects of stress on memory (A), working memory (B), executive functions (C), and verbal fluency (D) in older adults. Size of the circles indicates the relative weight assigned to that study in the analysis. Error bars represent the 95 % confidence interval of the effect size of each study and, below them, the combined effect size with its confidence interval (in black color) and its prediction interval (in gray color). Points to the left of zero indicate a study-average impairment, and points to the right of zero indicate a study-average enhancement. **A. Effect of stress on memory.** This meta-analysis indicated that stress did not significantly influence memory performance across studies**. B. Effect of stress on working memory.** This meta-analysis indicated that stress significantly enhanced working memory performance across studies. **C. Effect of stress on executive functions, namely (in order) cognitive control, response inhibition, cognitive flexibility, and problem-solving/planning.** This meta-analysis indicated that stress did not significantly influence executive functions performance across studies. **D. Effect of stress on verbal fluency.** This meta-analysis indicated that stress significantly enhanced tip-of-the-tongue states, indicating that it impaired verbal fluency.

3.6. Cognitive control, cognitive flexibility, problem solving and inhibition

Three studies investigated stress effects in older adults on other executive functions such as cognitive control (Deal et al., 2018), cognitive flexibility and problem-solving/planning (Crosswell et al., 2021), and response inhibition (Dierolf et al., 2018; see Table 2). Although the limited number of studies and the diversity of the tasks, the results showed rather consistently that acute stress did not impact performance in older adults on a consonant-vowel odd-even test (Deal et al., 2018), a card sorting task, and the Tower of London task (Crosswell et al., 2021). An exception is made for the only study that addressed stress effects on inhibition in older adults using a Go/No-Go task (Dierolf et al., 2018). Interestingly, it observed an enhancing effect on response accuracy in compatible trials in both young and older adults (although the study was conducted only on males). Only two studies assessed the cortisol-cognition association finding no significant link between cortisol and cognitive control (Deal et al., 2018), nor between cortisol and cognitive flexibility or problem solving (Crosswell et al., 2021)

Regarding performance accuracy, the estimated effect sizes for these studies are illustrated in Fig. 4C and Hedges' g ranged from −0.13 (Crosswell et al., 2021) to 0.30 (Dierolf et al., 2018), reflecting the positive-to-null pattern of results described in the qualitative part. We found a nonsignificant combined effect size of $g = 0.07$ (95 % CI [−0.23, 0.37]; $z = 0.78$; two-tailed $p = .433$; $g_{adj} = 0.07$ (95 % CI [−0.31, 0.46])), with a nonsignificant Cochrane's Q-test of Heterogeneity ($Q = 1.84$, $p_Q = .607$), $I^2 < 0.01$ % and $T^2 < 0.01$. This indicated that there was a low probability of heterogeneity between the studies and that interpretation can be based on the combined effect size and its CI.

Regarding reaction times for these studies, we found a nonsignificant combined effect size $g = -0.08$ (95 % CI [−0.62, 0.46]; $z = -0.46$; two-tailed $p = .644$; $g_{adj} = -0.09$ (95 % CI [−0.50, 0.32])), with a nonsignificant Cochrane's Q-test of Heterogeneity ($Q = 4.96$, $p_Q = .175$), $I^2 = 39.51$ % and $T^2 = 0.05$. The relatively high I^2 value was indicative of some sort of heterogeneity between studies and that this effect was likely to differ as a function of moderators (Hak et al., 2016).

3.7. Verbal fluency

Two studies investigated stress effects on verbal fluency in older adults (see Table 2). Stress showed a clear impairing effect in a word retrieval task in older adults (Schmank and James, 2020). More specifically, verbal fluency was measured by the percentage of trials that presented tip-of-the-tongue states (TOTs). Therefore, Hedges' g for these studies (Fig. 4D) are positive, reflecting a positive effect of stress on the production of TOTs. We found a significant combined effect size of $g = 0.53$ (95 % CI [0.14, 0.93]; $z = 17.14$; two-tailed $p < 0.001$; $g_{adj} = 0.53$ (95 % CI [1.63, −2.70,])), with a nonsignificant Cochrane's Q-test of Heterogeneity ($Q = 0.03$, $p_Q = .855$), $I^2 < 0.01$ % and $T^2 < 0.01$. This indicated that there was a low probability of heterogeneity between the studies and that interpretation can be based on the combined effect size and its CIs. Cortisol was not investigated in these studies.

3.8. Decision-making

Five studies investigated stress effects on decision-making under uncertainty in older adults (see Table 2), three of which were doctoral dissertations (Lighthall et al., 2013, Experiment 3; McMullin, 2020; Moreno, 2015, Experiment 1). Mather et al. (2009) examined risk-taking and found that older adults in the stress condition displayed a more cautious behavior than in the control condition. Using a computerized driving task, stressed older adults "risked" less driving time than their counterparts in the control condition. This study also reported robust age differences in the effects of stress, with older adults in the control condition only slightly differing from young adults in both stress and control conditions.

In another study, Moreno (2015, Experiment 1) also found that stress decreased risky choices in gain situations in older adults, which is in line with the results from Mather et al. (2009). Additionally, Moreno (2015, Experiment 1) reported that stress in older adults had no effects on decision-making under ambiguity and that it enhanced the phenomenon of temporal discounting, which is the tendency to discount rewards as they get farther in time (past or future). This study also found differential effects for cortisol responders vs. non-responders in both risk-taking and temporal discounting. Responders showed a decrease in risk-taking and an increase in temporal discounting in gains trials, whereas non-responders showed an increase in both risk-taking and temporal discounting in loss trials. However, and somehow surprisingly, 64 % of older adults were classified as non-responders to the TSST in this study, which is in contrast with the expected 20–30 % of individuals that would normally be classified as non-responders to the TSST (Miller et al., 2013).

Moreover, stress not affecting risky decision-making in older adults has also been reported in McMullin (2020) using an economic decision-making task. Finally, two studies were conducted in young and older adults using reinforcement learning paradigms and yielding opposing results (Lighthall et al., 2013, Experiment 3; Lighthall et al., 2013). In one study, Lighthall et al. (2013) observed that stress impaired sensitivity to recent feedback while enhancing learning of cues that were associated with positive outcomes in all age groups. Interestingly, only older adults' (but not young adults') performance was positively related to cortisol increases, thus older adults who experienced greater increases in cortisol learned better from positive reinforcement (Lighthall et al., 2013). However, the enhancing stress effect for positive cues was not replicated in a second sample of older adults, i.e., stress did not affect reinforcement learning in a separate study (Lighthall, 2012, Experiment 3).

4. Discussion

4.1. Stress and cognition in older adults

The present paper is a systematic review of the effects of acute stress on cognition in healthy older adults. To our knowledge, this is also the first attempt at quantifying the magnitude of stress effects on different types of cognition in older age through meta-analytical evidence. Our systematic search identified 22 studies that examined the effects of stress on cognitive performance in older adults, most of which assessed memory performance, followed by working memory, decision-making, executive functions, and verbal fluency. In line with what has been observed in young adults (for meta-analyses see Shields et al., 2016a, 2017; Starcke and Brand, 2016), one of the goals of this review was to examine whether stress exerts different effects on different cognitive processes.

Taken together, in the present review there is emerging meta-analytical evidence that, compared to a non-stressful condition, stress in older age impairs verbal fluency, and either impairs or does not affect episodic memory. On the contrary, stress has been found to enhance working memory performance and to have no effects on cognitive control, cognitive flexibility, and problem-solving/planning in older age. In addition, qualitative evidence suggests potential enhancing effects of stress on response inhibition as well as a role in shifting decision-making towards more careful strategies, in older people. Thus, our results challenge the assumption that exposure to acute stress in older adults would generally exacerbate age-related cognitive impairments and support the idea that acute stress on aging is specific for certain processes and brain regions (Wolf, 2015). On the one hand, older adults' cognition does not seem to particularly suffer from acute stress, at least not more to what is observed in young adults. On the other hand, however, old age cognition does seem, to some extent, *differently* affected compared to the current literature in young adults (see discussion below).

Furthermore, we were not able to replicate Shields et al. (2017)

moderating effect of age on stress-induced cortisol increases. Although old age is usually associated with greater cortisol reactivity (Otte et al., 2005), this seems to be still debated in the literature (Pulopulos et al., 2018; Zänkert et al., 2018). Indeed, four studies in our review who included young adults and cortisol assessments showed no age differences in stress-induced cortisol levels (Crosswell et al., 2021; Hidalgo et al., 2014; Lighthall et al., 2013; Mather et al., 2009), while one study showed decreased cortisol in older compared to young adults (Hidalgo et al., 2015). This between-study difference cannot be attributed to the stress induction methods given that Hidalgo et al. (2015) used the TSST just as Crosswell et al. (2021) and Hidalgo et al. (2014), while Lighthall et al. (2013), and Mather et al. (2009), used the CPT.

4.2. Stress effects on memory

Studies on memory assessed episodic memory using visual- and auditory-verbal stimuli (i.e., text, picture, or video recall; Table 2). On the first view, and in contrast to the literature in young adults, evidence in older adults suggests a null effect of stress on memory. The combined effect size of these studies was small and not significant while being subject to significant heterogeneity. Heterogeneity in memory studies can be explained by the fact that stress exerts differential effects on different memory phases (Shields et al., 2017). However, it appeared that the combined effect size for memory studies, as well as its heterogeneity, was driven by the study of Deal et al. (2018) which had a different design compared to the other studies (four laboratory sessions with the TSST being the last visit). Excluding this study from analysis reduced the combined effect size (from − 0.20 to 0.07) but did not change its significance (the combined effect stayed non-significant).

In sum, the currently most appropriate conclusion of the available literature suggests a null-to-negative pattern of stress effects on older adults' memory performance. This conclusion is supported by the fact that higher cortisol levels were related to a decrease in memory performance in some studies (Almela et al., 2011; Deal et al., 2018; Hidalgo et al., 2015; Lupien et al., 1997), but unrelated to cortisol in others (Crosswell et al., 2021; Pulopulos et al., 2013; Smith et al., 2019). This pattern of results is also in line with the previous review focusing on effects of acute stress on memory in young and older adults (Hidalgo et al., 2019), however, more research in older adults is needed to disentangle stress effects on different memory phases in this age group. Heterogeneity analyses indicated as well that the effect of stress on episodic memory was likely to differ as a function of moderators.

Interestingly, two studies found stress-induced enhancements in memory recall (Murphy et al., 2020; Wolf et al., 1998) which would be in line with results in young adults showing memory recall improvement during blockade of type II glucocorticoid receptors (GRs, Rimmele et al., 2013). This would support the idea that older adults might have reduced density and sensitivity of GRs receptors in the hippocampus (Heffelfinger and Newcomer, 2001). More specifically, cortisol binds with two types of receptors: the mineralocorticoid receptors (MRs, type I) and the glucocorticoid receptors (GRs, type II; de Kloet et al., 2011, 1999). In non-stressful conditions, cortisol occupies almost all the MRs, leaving the GRs relatively free. In stressful situations, however, GRs become increasingly occupied because of higher cortisol levels (de Kloet et al., 1999).

In line with the inverted U-shaped function, evidence coming from studies that administered receptor blockers suggests opposing roles of MRs and GRs in memory retrieval, with optimal retrieval when MRs are occupied and GRs are not (i.e., non-stressful conditions). In contrast, when MRs are less occupied, or when both receptors are occupied (i.e., stressful conditions), retrieval is impaired (Rimmele et al., 2013). However, this was observed only for episodic memory, and receptor blockades did not affect other functions such as attention and WM (Rimmele et al., 2013) which is in line with the present findings.

Although the effects of cortisol receptor blockades on cognition in older adults need to be studied more extensively, it appears that the direction of these effects depends on the cortisol history of older individuals (Lupien et al., 2002). It is possible that higher cortisol concentrations may be required for older adults to occupy their GR cortisol receptors and show stress-induced impairments on memory (Heffelfinger and Newcomer, 2001). Indeed, a study that increased cortisol pharmacologically did found that cortisol reduced recall from the word list learned before cortisol administration but did not influence recall of the list learned after cortisol administration in both young and older men.

The present review clearly reveals that more studies are needed to systematically compare stress effects on separate memory phases in different age groups to understand whether stress has different effects on memory depending on memory phase and age, and to understand underlying processes.

4.3. Stress effects on working memory

Regarding acute stress effects on working memory, a different pattern of findings emerged. The available evidence suggests a small *enhancing* effect of stress in older adults. The lack of heterogeneity in the analysis suggests that this effect is relatively consistent across studies. To be clear, it would be inadequate to claim that older adults benefit from acute stress. However, it is certainly an interesting result that needs to be further investigated, and replicated, given that in young adults WM performance is impaired by stress (Shields et al., 2016a).

Interestingly, pharmacologically increased cortisol has also been found to impair WM in young but not older participants (Wolf et al., 2001). The authors hypothesized that age-related alterations of the frontal cortex may account for this lack of responsivity in the sense that the dorsolateral prefrontal cortex may become less responsive to the effects of acute cortisol elevations (Wolf et al., 2001).

Indeed, the HPA axis, the prefrontal cortex, and WM abilities change throughout the lifespan (Bopp and Verhaeghen, 2020; Gaffey et al., 2016), which might alter the relationship between stress, cortisol, and cognitive performance. In addition, it has been suggested that PFC involvement in WM performance might decline with age (Yaple et al., 2019), which could explain why older adults do not show the impairing effects on WM observed in young adults.

Our review further shows consistent qualitative evidence suggesting an important moderating role of sex on the relation between stress and WM in older adults, which is in line with the moderation effect of sex detected in the meta-analysis on young adults (Shields et al., 2016a). For example, stress-induced enhancing effects of WM have been reported in young women but not men (Zandara et al., 2016). Thus, it is plausible to think that some moderating effects underlie the stress-induced WM enhancement in older adults as well, but unfortunately the low number of studies did not allow to formally test moderation effects on effect sizes.

In this regard, Luers et al. (2020) suggested that WM might be differently affected in men than women and in older as compared to younger adults being exposed to stressful situations. It is known that stress and estrogen (the female reproductive hormone) influence each other's function, and that estrogen can mitigate negative effects of glucocorticoids on the brain and cognition (Ycaza Herrera and Mather, 2015). It is also known that estradiol can facilitate working memory and executive function in peri- and post-menopausal women in the absence of hormone replacement therapy (Elsabagh et al., 2007).

In line with this, two studies in our review found specifically positive associations of cortisol levels with working memory performance in older women supposedly not taking hormone replacement (as part of the exclusion criteria for TSST; Luers et al., 2020; Pulopulos et al., 2015, Experiment 1). On a conceptual level, it is important to highlight the fact that the vast majority of behavioral neuroscience research was conducted in male animals until very recently, and thus our general understanding of stress effects in the PFC is within the context of the male brain (see Shansky and Lipps, 2013).

4.4. Executive functions

Regarding other executive functions namely cognitive control, cognitive flexibility, and problem-solving/planning, the present review reveals that acute stress did not impact performance in older adults (Crosswell et al., 2021; Deal et al., 2018). Although the number of studies is small, it is another instance of contrasting findings regarding young adults' literature. Similarly to WM, cognitive flexibility and cognitive control have been found to be mainly impaired by acute stress in young adults (Liston et al., 2009; Plessow et al., 2017; Sänger et al., 2014; Shields et al., 2016a, 2016b).

These findings have consistently been explained by acute stress impairing PFC-dependent cognition inducing a shift from top-down goal-directed behavior to bottom-up habitual control (Arnsten, 2009; Plessow et al., 2011, 2012a; Schwabe and Wolf, 2009; Shansky and Lipps, 2013; Smeets et al., 2019). Thus, the absence of stress effects on these tasks in older adults is surprising. One potential explanation is that older adults might make use of different cognitive strategies to solve PFC-dependent tasks, such as shown under normal non-stressful conditions (Amer et al., 2016; Braver et al., 2009; Paxton et al., 2008). In addition, there are reports of moderating sex effects where acute stress has been shown to attenuate cognitive flexibility in young men but not necessarily in women (Kalia et al., 2018; Shields et al., 2016b). In this sense, the null effect of stress on cognitive flexibility on older adults seem to be more in line with results reported on young women rather than men, which might underlie present results.

One study in our review assessed stress effects on inhibition, another PFC-dependent function (Aron et al., 2004; Cipolotti et al., 2016), and also found an enhancing effect of stress on inhibition's accuracy in young and older adults (Dierolf et al., 2018). However, this study included only male participants and did not examine the relationship between cortisol and inhibition, so it is not yet known whether sex or cortisol could moderate the relationship between acute stress and inhibition in older adults.

Based on young adults' literature, it seems, that acute stress might have opposing effects on inhibition based on the type of inhibition: enhancing response inhibition and impairing cognitive inhibition (Shields et al., 2016a). Response inhibition (e.g., Go/No-Go) refers to the motor suppression of a prepotent response; cognitive inhibition (e.g., Flanker task), sometimes called interference control, refers to selectively attending to or ignoring information. Dierolf et al. (2018) used a Go/No-Go task, thus, supporting Shields et al. (2016a) conclusions concerning stress effects on response inhibition. However, our results show that there is currently no study that has investigated stress effects on cognitive inhibition in older adults. In sum, our review reveals substantial gaps in our understanding of stress effects on executive functions in older adults.

4.5. Stress effects on verbal fluency

Considering verbal fluency, two studies found moderate negative effects of stress on verbal fluency (i.e., word retrieval) in older adults, and in a mixed sample of young, middle-aged, and older adults (Schmank and James, 2020), where no age differences were found. However, their TSST protocol was slightly modified and, instead of having experimenters, the participants were only led to believe that someone behind the mirror glass was observing them during the speech task. Since their cortisol levels weren't assessed, these results need to be interpreted carefully and data coming from other research groups assessing stress effects on verbal fluency in both young and older adults are necessary.

4.6. Stress effects on decision-making

Finally, although a quantitative analysis of stress effects on decision-making was not possible, a qualitative synthesis reveals that stress can impair older adults' ability to take risky decisions (Mather et al., 2009; Moreno, 2015, Experiment 1). These results suggest that after being stressed, older adults are risk avoidant, which can be interpreted as being more conservative and preferring a safer option as opposed to a larger gain which involves a gamble (Moreno, 2015, Experiment 1). In other words, in the available studies, older adults in the control condition made more unsafe decisions than the ones in the stress condition, which is coherent with the idea that the stress response is intended at preserving survival.

However, once more, these results contrast those obtained in young adults, where acute stress enhances risk-taking (Starcke and Brand, 2016). The results of the meta-analysis by Starcke and Brand (2016) showed that in situations in which reward-seeking and subsequent risk-taking were disadvantageous, participants under stress performed more poorly than unstressed participants. The authors proposed that both increased reward salience and risk-taking, as well as reduced executive control, might have caused the observed effects. This supports the idea that acute stress increases reliance on immediate and potentially high rewards via alterations in dopamine release at the cost of considering potential losses (Mather and Lighthall, 2012). Importantly, however, in the case of older adults, one must consider age-related changes in sensitivity to immediate reward that may result from transformations in dopaminergic neuromodulation with age (Eppinger et al., 2012; Garzón et al., 2021). Independently of stress, older adults have been found to make less impulsive decisions compared to young adults which might be due to a reduced sensitivity of striatal areas to reward (Eppinger et al., 2012).

5. General discussion

Currently the most common view in the literature is that stress biases cognition to process information that is most directly related to the current stressor (Plessow et al., 2012b). This is thought to induce a shift towards resource-saving behavior and a reallocation of executive resources in adaptive ways, which would explain why some cognitive functions seem to benefit from stress (e.g. risk-taking, memory retention, response inhibition), while others are impaired (e.g., memory recall, goal-directed behavior; Mather and Sutherland, 2011; Plessow et al., 2012a, 2011; Schwabe and Wolf, 2009; Shields, 2020; Vogel et al., 2016). Building onto this theoretical perspective, Shields et al. (2016a) proposed that stress produces a cognitive phenotype conducive to both approach and avoidance responses by impairing executive control over thoughts but improving executive control over motor actions, which would be ideal for fighting with or fleeing from a current stressor. This research group recently published further evidence, although, in young adults only, that acute stress can improve control over motor actions (Shields et al., 2019). However, at the current state of the art, it is an open question whether this holds true for older adults.

As a final point, we want to draw attention to the fact that the direction of the stress effect (enhancing vs. impairing) on cognition is not only influenced by hormone-neurotransmitter interactions, but also by several methodological factors. In this regard, Shields (2020) provides a complete summary of the necessary methodological factors to consider in stress and cognition research. In fact, in addition to sex, stress effects can further be modulated by how glucocorticoids are elevated (cortisol administration vs. stress induction,see discussion in Shields et al., 2016a), individual cognitive strategies (Scholz et al., 2009), task demands (Goldfarb et al., 2017; Oei et al., 2006), or type and valence of stimuli used (Luethi et al., 2009; Smeets et al., 2006).

More specifically, cortisol administration is not equivalent to a stress induction since it does not include the SNS activation (Schommer et al., 2003), catecholamines' and sex hormones' release (McGaugh and Roozendaal, 2002; Shansky and Lipps, 2013), nor the cognitive stress appraisal processes (Lazarus and Folkman, 1984). Furthermore, it has been shown that negative stress effects on an inhibition task can be countered in young adults using cognitive strategies such as

implementation intentions (Scholz et al., 2009). Moreover, it seems that stress can impair cognition at high cognitive loads, but not necessarily at low loads (Oei et al., 2006; Plieger et al., 2017) and that cortisol increases are associated with enhanced updating but impaired switching between trials with different task demands in a cognitive flexibility task (Goldfarb et al., 2017). Implementation intentions and cognitive load in the stress-cognition relation have not been investigated in older adults although it is possible that they could have an effect based on what is observed in young adults' literature.

Finally, based on animal's studies, it is usually expected that stress would affect emotional materials more than neutral materials (Roozendaal et al., 2006). In the human literature there is rather mixed findings regarding the effect of valence with some studies showing an enhancing effect of stress for emotional materials, others showing the opposite, and still others showing no difference (Shields et al., 2017). Most of the studies included in our review used neutral materials. Only one study on episodic memory reported that stress impaired recognition of positive pictures in both young and older adults (Hidalgo et al., 2015). Therefore, it might be the case that stress have stronger effects for emotional material in older adults.

5.1. Methodological recommendations

Although less research has been conducted on acute stress effects on cognition in older adults, the number of studies examining this relationship in young adults has grown substantially over the last two decades. Consequently, several methodological advances have been made (see Shields, 2020), and studies in older adults would benefit from taking these into account. For example, it is now established that stress exerts differential effects on specific memory processes such as retention and retrieval in young adults (Schwabe, 2017; Schwabe et al., 2012). Thus, it is surprising that only a handful of studies in older adults (Hidalgo et al., 2015; Pulopulos et al., 2013; Smith et al., 2019) actually assessed stress effects on separate memory phases. This lack of data in older adults renders it one of the most pressing issues for future research in this area.

In addition, echoing other reviews (Hidalgo et al., 2019; Liu et al., 2017; Pulopulos et al., 2018; Shields, 2020), our review further highlights the need for a systematic accounting for age, sex, and cortisol levels as moderating factors in the stress-cognition relationship. Ideally, the authors of the studies should report statistics regarding cortisol and cognitive performance for men and women separately, at least in their Supplementary Materials.

Of special relevance for the current review is also the necessity of having a validated stressor showing reliable cortisol increase. Finding unexpected effects in studies examining the impact of stress on cognition is common, and without stressor validation with a stress-specific biomarker one could never be sure whether it is indeed caused by stress (Shields, 2020). This is even more the case with studies conducted in older adults where age itself introduces an important source of alternative explanations to the stress effects.

As mentioned before, cognitive aging is itself extremely variable, leading to large interindividual differences in both brain changes (Raz et al., 2005) and cognitive performance (see Blazer et al., 2015; Salthouse, 2010). Thus, older adults cannot, and should not, be considered as a homogenous population. As a result, cognitive decline, stereotype threat, testing environment, age differences in stress appraisal and regulation are all potential confounders of stress effects on cognition in the absence of a validated stressor and if not properly controlled for (e.g., Sindi et al., 2013; Zandara et al., 2016; Zuber et al., 2019).

In this regard, we would like to underline the importance of having an age-adapted stressor. The TSST (Kirschbaum et al., 1993) is a widely used stressor and several variations of this protocol have been validated (Goodman et al., 2017), including an age-adapted version for children (see TSST-C and TSST-M, Allen et al., 2017; Buske-Kirschbaum et al., 1997). However, no validated age-related adaptation exists for older adults. This is all the more important when one considers that the TSST usually consists of a mock job interview, which might not be as relevant for retired older adults and, consequently, could contribute to the mixed findings regarding cortisol rises in response to a TSST in older adults when compared to young adults (for reviews see Kudielka et al., 2009; Pulopulos et al., 2018). A venue for future research would be to compare whether age-specific TSST adaptations (i.e., older age of TSST jury, adapted script for oral speech) might induce higher cortisol rises than the classic TSST, in older adults specifically.

Of notice, out of the 17 studies in this review that used the TSST, five reported having implemented different age-specific adaptations of the speech part of the TSST. The adaptations include a defense against an accusation of shoplifting (Moreno, 2015), an argumentation for being the best candidate for joining a particular club (e.g., choir, or private association; Oei et al., 2018), a debate on the topic of social security reform (McMullin, 2020), a speech on the topic of the effect of tuna fishing on the dolphins (Murphy et al., 2020), and having the option to choose between four different topics (social security reform, the cost of prescription drugs, education reform, and the rising cost of gasoline; Crosswell et al., 2021). There is also evidence that some of these TSST variations might be less effective than others (see 64 % of cortisol non-responders in Moreno, 2015).

Moreover, two other studies reported deviations from the classic TSST protocol that were not age-specific (shorter preparation phase for Smith et al., 2019; absence of a real TSST jury for Schmank and James, 2020). This does not necessarily mean that the remaining studies have not made adjustments to their protocol, as generally details pertaining to the TSST procedure are described briefly and vaguely (for reviews see Labuschagne et al., 2019; Narvaez Linares et al., 2020). In addition, SNS measures are rarely included in studies involving stress and cognition in older adults (Table 2) but could provide important complementary information regarding the stress induction, and its association with cognitive performance, especially when a high rate of cortisol non-responders is reported.

5.2. Future directions

With respect to the cognitive architecture, the present review delineates several additional blind spots regarding cognitive stress effects in older adults. Despite constituting key domains for cognitive aging (Cansino et al., 2020; Kliegel et al., 2016; Salthouse, 2005; Servant and Evans, 2020; Solesio-Jofre et al., 2012; Verhaeghen, 2013), processes such as memory retention, associative memory, prospective memory, spatial working memory, interference control (i.e., cognitive inhibition), reasoning, or cognitive flexibility, are mostly studied in young adults in relation to acute stress (Jiang et al., 2019; Kamp et al., 2019; Olver et al., 2015; Shields et al., 2019; Smith et al., 2021; Szőllősi et al., 2018), but are currently understudied in older adults.

Likewise, current research addressing stress effects on cognitive-affective processes such as fear conditioning, extinction, and reinstatement (Meir Drexler et al., 2019; Merz et al., 2020; Raio and Phelps, 2015), or introspective sensitivity (Barrientos et al., 2020), do not include predictions related to age differences or changes across the lifespan. Yet, recent evidence suggested that there may be age-related differences in fear conditioning via a decline in locus coeruleus functional connectivity (Lee et al., 2018). Moreover, extinction learning is also one of the most important underlying mechanisms of exposure therapy which is used for the treatment of, among others, anxiety disorders (Craske et al., 2018), commonly reported in older adults (Wolitzky-Taylor et al., 2010). Thus, elucidating how age affects the stress-cognition relationship is not solely needed to advance understanding in the field, but could also potentially improve the way psychological care is provided to older adults.

Overall, there is necessity in stress and cognition research to understand whether the underlying mechanisms differ with age by comparing young and older adults. From a life course perspective, it

would be interesting to also include middle-aged adults, to have an even more fine-grained knowledge on how these mechanisms evolve throughout the adult lifespan.

Moreover, future research addressing cognitive effects of acute stress should also take into consideration the differences in terms of subjective affect and emotion regulation reported in young and older adults. On the one hand, there is established literature indicating better emotion regulation and consequent higher emotional well-being in older adults compared to young adults (see e.g., Carstensen et al., 2011; Luong et al., 2018; Young et al., 2021). On the other hand, it is also true that cognitive evaluation may be perceived as threatening among older individuals (Schlemmer and Desrichard, 2018; Zuber et al., 2019), which could interfere with stress effects. The results of a recent study (Pearman et al., 2020), indicate that other covariates such as state anxiety or self-esteem might be of particular relevance when assessing stress (and cortisol) effects on cognition in older adults.

5.3. Limitations

Overall, interpretation of the literature with respect to cognitive stress effects in older adults is limited by the still relatively small number of existing studies. This neither allowed to quantitatively test moderating effects of sex on stress-induced cognition, nor of age on stress-induced cortisol. We also were not able to quantitatively integrate findings of some cognitive domains to draw more general conclusions (e.g., for decision-making), and the low number of studies limits conclusions on the effect sizes for some domains.

For instance, cognitive control, response inhibition, cognitive flexibility, and problem-solving/planning were combined together under the term executive functions which is a broad umbrella term that encompasses distinct but related cognitive processes (Diamond, 2013; Miyake et al., 2000). Although this definition might be useful in some contexts, when talking about stress effects on executive functions in the future, it would make sense to refer to these processes separately as stress and aging might have differential effects on them.

For example, stress effects on response inhibition did not appear to follow the same pattern as the remaining processes but a separate quantitative analysis for inhibition was not possible due to lack of studies in older adults. Nonetheless, when sufficient data were available, several significant and distinct trends emerged as in the case of working memory. On a similar note, most studies assessing stress effects on episodic memory did not isolate the different memory phases, thus limiting conclusions to a general null-to-negative effect of stress on episodic memory.

Another limitation of this review is that not enough studies had a sample of young adults within the same design to formally test whether the effects of stress on cognition differed in young and older adults leaving this question for future research.

Concerning assessment for risk of bias, we found no evidence of bias based on funnel plots asymmetry (Egger et al., 1997), trim and fill method (Duval and Tweedie, 2000), and p-curve analysis (Simonsohn et al., 2014). However, these methods come with their own limitations as none of them measure publication bias per se. For instance, funnel plots assume that the dispersion of effect sizes is caused by the studies' sampling error, but do not control for the fact that the studies may be estimators of different true effects (Harrer et al., 2021). This might be the case of different effects associated with different executive functions.

In addition, as a rule of thumb, tests for funnel plot asymmetry (such as Egger regression) should not be used when there are fewer than 10 studies in the meta-analysis because test power might be too low to distinguish chance from real asymmetry (Sterne et al., 2011). Thus, especially when considering the four cognitive domains separately, our Egger regressions might not have sufficient power to detect a real asymmetry due to the low number of available studies within each domain. However, there should be enough power to detect asymmetry on the overall study set, which was still non-significant.

In our case, p-curve analysis complements the absence of evidence for a publication bias with evidence for the existence of a true effect of stress underlying the overall study set, which is encouraging. However, by definition, the p-curve only focuses on significant findings and excludes by default all $ps > .05$, which has left only five studies in our p-curve analysis: three on memory, one on working memory and one on verbal fluency. Thus, the most appropriate conclusion is that there is evidence for a true effect of stress on at least some studies in these three domains, but one cannot conclude on evidential value for the other domains. In sum, methods for assessing risk of bias are useful tools that should be used to identify evidence of non-reporting biases, but when no evidence is detected, it is not evidence of an absence of bias.

Finally, we want to draw attention to the representation of the studies included in our review. All the studies were conducted in either the US or western European countries and most of the authors did not characterize their samples in terms of race and/or ethnicity, thus making it impossible to evaluate the representation of their results. When this information was provided (Deal et al., 2018; McMullin, 2020; Oei et al., 2018), it showed that the samples were mostly constituted by Caucasian healthy older adults, thus generalization of these results to older underrepresented minorities is questionable. This is a known phenomenon in psychology, and human research in general, where scientific conclusions are primarily based on western, educated, industrialized, rich and democratic (WEIRD) samples (Brady et al., 2018; Cheon et al., 2020).

This is all the more problematic in stress research where cortisol is known to be affected by culture and country of origin (de Souza-Talarico et al., 2014; Miller and Kirschbaum, 2019), socio-economic status (Cohen et al., 2006), but also by structural stigma (Hatzenbuehler and McLaughlin, 2014), and internalized racism (Tull et al., 2005). Miller and Kirschbaum (2019) demonstrated that around 25 % of cortisol response variability in the TSST is attributable to systematic differences between countries and suggested that the cortisol stress response may reflect the persistent threats to which an individual is used to in their sociocultural environment. Therefore, a major challenge for cognitive stress research is to understand to which extent factors moderating the stress response itself can in turn affect the stress and cognition relationship. Moreover, there is urgent need for future research to draw findings from more inclusive and diverse samples by implementing culture-conscious practices (Brady et al., 2018). Thus, this review also emphasizes the added value that future research would generate in this field and contributes to providing a conceptual and methodological starting point for studies in this field.

6. Conclusion

This literature review for the first time systematically synthesizes acute stress effects on cognition in a population of older adults. In summary, our review reveals some marked differences between stress effects on old versus younger adults. There is emerging evidence that stress has negative effects on verbal fluency and risk-taking, but null-to-negative effects on episodic memory, null effects on cognitive control, and, perhaps most surprisingly, enhancing effects on working memory and response inhibition in older adults.

This review also denotes that there are numerous blind spots in the literature that need to be addressed in future research by comparing effects of stress on young vs. older adults. Here we provide some specific recommendations for such studies. For instance, only one study each has investigated stress effects on nondeclarative memory (Lupien et al., 1997) and inhibition (Dierolf et al., 2018) in older adults. To our knowledge, no study has investigated acute stress effects on memory retention, interference control (i.e., cognitive inhibition), or fear conditioning in a population of older adults. These gaps need to be filled to better bridge the literature on stress and older age cognition.

To conclude, this systematic review provides first meta-analytical evidence that older adults' cognition does not seem to particularly

suffer from acute laboratory stress, in any case not to a greater degree than generally observed in young adults, and in some cases even to a lesser degree. However, it remains to be clarified whether stress affects cognition differently in young versus older adults. The relationship between stress, cortisol, age, and cognition needs to be further investigated in future research by directly comparing stress effects in young and older adults. Differences observed between age groups might yield some insight into differential neurobiological and psychological mechanisms at play.

Data availability

All data is within the manuscript and figure.

Declaration of Competing Interest

The authors report no declarations of interest.

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.neubiorev.2021.12.009.

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